Physiological Demands of Eventing and Performance Related Fitness in Female Horse Riders

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DECLARATION

I declare that this thesis is a presentation of my own original research work and all the written work and investigations are entirely my own. Wherever contributions of others are involved, this is clearly acknowledged and referenced.

I declare that no portion of the work referred to in this thesis has been submitted for another degree or qualification of any comparable award at this or any other university or other institution of learning.

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ABSTRACT

Introduction: Scientific investigations to determine physiological demands and performance characteristics in sports are integral and necessary to identify general fitness, to monitor training progress, and for the development, prescription and execution of successful training interventions. To date, there is minimal evidence based research considering the physiological demands and physical characteristics required for the equestrian sport of Eventing. Therefore, the overarching aim of this thesis was to investigate the physiological demands of Eventing and performance related fitness in female riders.

Method: The primary aim was achieved upon completion of three empirical studies. Chapter Three: Anthropometric and physical fitness characteristics and training and competition practices of Novice, Intermediate and Advanced level female Event riders were assessed in a laboratory based physical fitness test battery. Chapter Four: The physiological demands and physical characteristics of Novice level female event riders throughout the three phases of Novice level one-day Eventing (ODE) were assessed in a competitive Eventing environment. Chapter Five: The physiological demands and muscle activity of riders on live horses in a variety of equine gaits and rider positions utilised during a novice ODE, including jumping efforts, was assessed in a novel designed live horse exercise test.

Results: Chapter Three reported that aside from isometric endurance, riders anthropometric and physical fitness characteristics are not influenced by competitive level of Event riding. Asymmetrical development in isometric leg strength was reported with increased levels of performance; riders reported below average balance and hamstring flexibility responses indicating limited pelvic and ankle stability, and tightness in the hamstring and lower back. Chapter Four reports that physiological strain based upon heart rate during Eventing competition is considerable and close to maximal, however blood lactate data was not supportive of this supposition. Chapter Five reports that during horse riding, riders are exposed to intermittent and prolonged isometric muscle work. During horse-riding, riders have an elevated heart rate compared to the oxygen requirements for the activity, in addition to moderate blood lactate concentrations.

Conclusion: This thesis indicates that the most physiologically demanding aspect of Event riding is the light seat canter and where jumping efforts are introduced. During these positions and gait combinations, heart rate is elevated compared to oxygen uptake. Additionally, moderate blood lactate (BLa) concentrations are reported suggesting though cardiac strain is high, physical demands are moderate. The use of heart rate as a marker of exercise intensity during horse riding activities is not appropriate as it is not reflective of actual physiologic demand and BLa may be a more indicative marker of exercise intensity for equestrian investigations.

There are many factors that may affect heart rate as discussed throughout the thesis, such as cognitive anxiety, heat stress and isometric muscle work. The data from this thesis speculates that the elevated heart rate is in part affected by isometric muscle work; similar physiological profiles exist in sports such as Sailing and are attributed to the quasi isometric theory. Though this thesis is not able to comprehensively conclude that physiological responses are a direct result of quasi isometrics, the data set does infer this may be a potential contributor and as such is a recommended topic for future research. Regardless of the causal mechanism, riders should be conditioned to tolerate high heart rates to enable optimal physical preparation for competition; the physical characteristics and physiological demands placed upon Event riders reported throughout this thesis provides information for coaches and trainers to consider when designing such interventions.

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GLOSSARY, UNITS & ABBREVIATIONS

1RM = 1 repetition maximum

BE = British Eventing

BE100 = British Eventing 100

BE90 = British Eventing 90

BETA = British Equestrian Trade Association

BHIC = British Horse Industry Confederation

BLa = Blood Lactate Concentration

BMI = Body Mass Index

beats.min^{-1} = Beats Per Minute

cm = centimetre

DR = Dressage

EMG = Electromyography

Equestrian = a reference to horse riding

Equestrian Athlete = Pertains to the rider (also termed horse-rider)

Equitation = the practise of horse riding

f = critical f statistic

FAPT = Front Abdominal Power Test

FEI = Fédération Equestre Internationale

GS = Grip Strength

H = Live Horse Exercise Test

HR = Heart Rate

kg = Kilgogram

l = Litre

LT = Lactate Threshold

LTPD = Long Term Participant Development

m = meters

MAV = Mean Absolute Value

MH = Mechanical Horse Simulator

mmol = Millimole

MUAPs = Motor Unit Action Potentials

mV = Millivolts

MVC = Maximal Voluntary Contraction

N = Newton

Nm = Newton Metre

ODE = One Day Event

p = probability value

r = correlation coefficient

r^2 = co-efficient of determination

RPE = Rating of Perceived Exertion

RPEo = Overall Rating of Perceived Exertion

RPEp = Peripheral Rating of Perceived Exertion

RT = Rising Trot

s = Second

sEMG = Surface Electromyography

SJ = Show Jumping

t = critical t-statistic

V = Volt

VE = Ventilation

$\dot{V}O_2$ = Oxygen Uptake

$\dot{V}O_{2max}$ = Maximal Oxygen Uptake

$\dot{V}O_{2peak}$ = Peak Oxygen Uptake

W = Watts

µm = Micrometre

µV = Microvolts

XC= Cross Country

THESIS RESEARCH DISSEMINATION

Douglas, J., Price, M., Peters, D.M. (2012) A systematic review of physiological fitness and biomechanical performance in equestrian athletes. *Comparative Exercise Physiology,* 8 (3), 53-62.

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Johnson, J., Price, M., Peters, D.M. (2011) Maximal aerobic power and lactate threshold in Novice female Event riders is affected by additional un-mounted training. *The 16th Annual Congress of the European Congress of Sports Sciences*, *6-9th July 2011,* Liverpool, UK.

CHAPTER ONE: INTRODUCTION

Eventing is an equestrian discipline comprising of three phases: Dressage (DR), Show Jumping (SJ) and Cross Country (XC), the difficulty of each phase is progressive with competitive level. The demands are increased by including more complex gymnastic movements in the DR phase, increasing height and complexity of jump combinations in the SJ phase and increases in length, height and complexity of jumps for the XC phase, there is also manipulation of phase ordering and number of competition days (e.g. One, Two or Three Day Eventing) at the advanced levels. Dressage is an event in which the rider and horse perform a series of exact movements in a semi enclosed arena over a period of between approximately 5-8 minutes with a percentage of scores attributable to rider posture/position. This phase assesses the harmony between horse and rider and anecdotally requires postural control and core stability to produce what is termed an 'independent seat' that permits the rider to direct and aid the horse without overt body movement (von Dietze 1999). Show Jumping, requires the rider and horse to navigate a course of between 8-20 jumps at a pre-determined height, lasting for approximately 5 minutes and has been suggested to require agility, speed, strength, technique and precision of the rider and horse (Houghton Brown 1997). The XC phase requires the rider and horse to navigate an undulating course of between 1,500-4000m comprising of 12-40 natural solid obstacles at a gallop (British Eventing 2009).

Equestrian Team GB have proven successful at the elite level over the 2000-2016 Olympic Games with all five podium representations between 2000-2008 occurring as a result of the success of the British Eventing teams. The London 2012 Olympics was the most successful games to date with Equestrian Team GB being awarded five Olympic medals including two gold, Rio 2016 saw Equestrian Team GB being awarded 3 medals, two gold and a silver. British Eventing (the national governing body for Eventing in the UK) holds over 180 events annually during the competitive season (March – October) and manages over 94,000 competition entries for over 15,000 members (British Eventing 2017) and is a popular sport for both spectators and competitors. As a successful sport, GB Equestrian receive priority funding to ensure continued success at the elite level, as such there is support available for both horses and their riders to ensure each athlete is in optimal physical condition for competition.

The research problem here exists, there is a dearth of research investigating the physiological demands of event riding (Roberts et al. 2010) on which trainers and coaches can base physical preparation strategies. It is well documented that a thorough understanding of the specific physiological requirements and performance related fitness variables in a particular sport is necessary for an athlete's strength and additionally conditioning of energy demands to be specifically prepared, thus ensuring an effective transfer of physical improvements from the gym to the specific sport setting (Cunniffe et al. 2009; Gonzales-Millian et al. 2016; Highnam et al. 2016).

Literature to date indicates that as the horse and rider progress through the equine gaits (walk, trot, canter), the riders heart rate and oxygen consumption increase and within the DR phase, aerobic metabolism dominates. It is generally the faster gaits, and jumping such as in SJ and XC that require the rider to adopt a 'forward' position where the riders are then un-seated in an isometric semi-squat position, causing weight bearing to be through the rider's legs (Roberts et al. 2010). It is apparent that positional differences required for fast cantering and jumping increase anaerobic metabolic system requirements with reported increases in cardiovascular load and associated increased blood lactate values (Guitérrez Rincón 1992; Trowbridge et al. 1995; Roberts et al. 2010; Perciavalle et al. 2014) and therefore greater physiological strain in these phases of Eventing can be assumed. More recent work in horse-riders is suggestive that heart rate is elevated when compared to other cardio-metabolic parameters (Sainas et al. 2016), and that the use of heart rate as a measure of physical effort is not accurate during riding activities and is an important consideration when interpreting available data.

Elevations in heart rate can be influenced by many variables including cognitive anxiety; the nature of riding an unpredictable animal is a risk and thus some elevations in heart rate in response to competitive and situational anxiety seem reasonable. The causal mechanism for elevation in a rider's heart rate and not other physiological variables during equestrian activities has yet to be investigated but is an important consideration for the interpretation of physiological demand and the use of heart rate monitoring during an equestrians training programme.

Sports where isometric muscle actions predominate, such as Sailing, Windsurfing and Motorcorss have reported a high heart rates compared with other physiological markers of exercise intensity, such as oxygen consumption and blood lactate (Cunningham and Hale 2007; Konittinen et al. 2002; Konittinen et al. 2008; Sheel et al. 2004; Vogiatziz et al. 2002). Researchers have identified that physiological data were not matched i.e. heart rate was higher than necessary for recorded oxygen uptake with moderate blood lactate concentrations. Such isometric muscle activity is considered to simulate chemical afferents via the muscle metaborereflex which to date has explained a dissociation between heart rate and oxygen uptake (Konittinen et al. 2002; Konittinen et al. 2008). These physiological responses are not apparent in dynamic sports where a rise in heart rate is linear to oxygen consumption and where a more marked blood lactate concentration is apparent. Though yet to be investigated in Event riders, earlier investigations using electromyography (EMG) of the riders' muscles during walk and trot gaits indicate isometric muscle activity predominates (Terada et al. 2004) and therefore may be a contributing factor for heart rate responses reported to date in riders during equestrian activities.

1.1 Purpose of the Research

There is a limited amount of information concerning the physiological demands of Event riding or of horse riding in general on which trainers and coaches can base physical preparation strategies specific for riders. Event riding consists of three phases which include the equestrian Olympic disciplines of DR and SJ and was therefore the selected discipline to examine within this thesis, the detailed investigation of Event riding will also assist in the knowledge of physiological demand during DR and SJ riding that can be transferred to these equestrian sports. Eventing has many performance categories; Novice level Event riding is the level that riders' headway towards more focused competition. This competitive level is popular and therefore deemed an appropriate level to initiate academic investigations to explore the physiological demands during competition; as such the following research aims have been developed.

1.2 Research Aims and Objectives

The overarching aim of this thesis was to investigate the physiological demands of Eventing and performance related fitness in female riders.

To meet this aim, the specific research objectives are outlined as follows:

1. To identify anthropometric and physical fitness characteristics and to document training and competition practices in Novice, Intermediate and Advanced level female Event riders.
2. To characterise the physiological demands and physical characteristics of Novice level female event riders throughout the three phases of Novice level one-day Eventing (ODE).
3. To determine the physiological demands and muscle activity of riders on live horses in a variety of equine gaits and rider positions utilised during a novice ODE, including jumping efforts.

1.3 Delimitations

In such a newly and underdeveloped research area, certain characteristics were made to set boundaries for this research as the potential for research expansion is vast. All studies were restricted to female participants to avoid heterogeneous exercise and training differences. In addition to gender restrictions, the study within Chapter 5 used horse-riders as opposed to Event riders, the justification was that the aim of the study was to analyse the response to certain conditions that exist during Event riding rather than explore responses in an Event riding population.

The study within Chapter Four (Objective Two) focusses on the physiological demands of Novice level Event riding (as opposed to Intermediate and Advanced) and is justified throughout the body of this thesis.

The research within this thesis to meet objective Three and Four, concentrated on measuring the physiological responses to exercise including heart rate, blood lactate concentration and oxygen uptake. There are factors that may influence physiological responses during exercise, that are presented within the literature review for consideration and interpretation of data. The aims of the research studies were to investigate the physiological responses of Event riding, and though additional factors are likely to influence data, they have not been considered as a measure within this thesis but are discussed as limitations within the relevant chapters.

THESIS OVERVIEW

Chapter Two: The Literature Review, introduces the context and complexities of the equestrian sport of Eventing including detailed consideration of the current national governing body rider fitness recommendations and guidance. This chapter also introduces and critically evaluates equestrian specific research literature that has examined the physiological demands of horse-riding. Following the equestrian literature, this chapter explores factors that may affect physiological mechanisms and additionally sports specific testing considerations in a laboratory and competitive sporting setting.

The study in Chapter Three aimed to identify if performance tests discriminated between levels of performer in Novice, Intermediate and Advanced level female Event riders. Research within this chapter was conducted between September 2011 to January 2012 and includes a fitness test battery on n=27 Novice, Intermediate and Advanced Event riders incorporating assessments for aerobic power, balance, hand-eye co-ordination, hamstring flexibility, core stability and muscular endurance. This study is the first to investigate the physical fitness characteristics within an Event rider population and reports differences in fitness tests based on the performance level of the Event athlete.

The study in Chapter Four aimed to characterise the physiological demands placed upon Novice Female Event riders throughout the three phases of Novice Level ODE. Data was collected during the 2009-2010 Eventing season (March-October 2010). Twenty-seven female Novice Event riders had their heart rate sampled throughout the three stages of competition continuously. In addition to heart rate data, post warm up and post competition blood lactate samples and grip strength measurements were recorded. Seventeen riders returned to the laboratory to complete a reference maximal exercise test to ensure all field data could be reported at relative intensities. This study was the first to investigate the physiological demands of Eventing during affiliated competitions and thus is reflective of a true competitive response.

The final empirical study in Chapter Five was conducted between January and April 2014 and aimed to determine the physiological demands and muscle activity of riders on live horses in a variety of equine gaits and rider positions, including jumping efforts. The aim was achieved by sampling heart rate, oxygen uptake, and blood lactate throughout the horses' gaits (walk, trot, canter) and also in response to jumping fences in n=13 female riders. This study is the first to investigate the physiological responses across all equine gaits and rider positions, including jumping efforts. Additionally, this study is the first to document muscle activation in the lower body and upper body of riders during canter and jumping.

The findings from the studies are then discussed and synergised with incorporation of the most recent literature in Chapter Six, Discussion. The chapter therefore critically evaluates the overall outcomes of the studies in relation to the thesis aims and highlights the original contributions to knowledge. Chapter Seven provides conclusions against the thesis aims and through appreciation of, and synergy with, current knowledge, provides recommendations for future research direction.

CHAPTER TWO: LITERATURE REVIEW

2.1 The Equestrian Sport Context

The equestrian industry within the UK is valuable contributing ~£7bn per annum to the economy (BHIC, 2014). The equine sector has a large economic gross output which the British Equestrian Trade Association (BETA) optimistically have reported as being on the rise post a successful 2012 London Olympics. In 2015, BETA reported an estimated turnover of £4.3 billion compared to £3.8 billion in 2011, which is a lower economic value than previous years (BETA 2015). Participation in equestrian sports within the UK overall is high but varies with time, during 2010-2011 an overall estimation of people who had ridden was 3.5m with 1.6 m riding regularly within the UK (BETA, 2015). There was a decrease in participation between 2011 to 2015 with a drop in overall riding to 2.7m and a decrease in regular riding activity to 1.3m riders (BETA, 2015). The UK Sport active start 2015-2016 survey reported weekly participation rates in > 16 year olds as 289, 900 people (Sport England 2016) and although participation rates have decreased, they are still high compared to other sporting activities within the UK. Sports generating higher participation rates than equestrian sports within this 2015-2016 survey include Swimming, Athletics, Cycling, Football (all generate over >2 million participants weekly), Golf, Dance and Tennis (400-450,000 weekly participation). Equestrian has higher weekly participation rates than sports such as Rugby Union (196,900), Netball (164,100), Gymnastics (44,800) and Judo (16,700) to name a few (Sport England 2016) and as such holds an important position with regards to the sporting success of Great Britain at international events, such as the Olympic Games. The BETA reported participation in horse-riding related activities to includes ~2.7 million overall riders in 2015, 96% of these riders are participating for pleasure and 59% in non-affiliated equestrian competitions (BETA 2015). Despite large participation rates in equestrian sports, only a small percentage of riders are affiliated via a governing body (6.4%) (Sport England 2016). The small amount of riders competing under a national governing body within the UK does not appear to affect success at the elite level in equestrian sports. The London 2012 Olympics was the most successful games to date with Equestrian Team GB being awarded five Olympic medals including two gold, Rio 2016 saw Equestrian Team GB being awarded 3 medals, two gold and a silver.

Based on high participation and success at the elite level, the national governing body for equestrian sport, The BEF, were granted a £6 million investment from Sport UK for the 2013-2017 funding period, a 46% increase from the previous Olympiad. Historical funding from UK Sport to The BEF has included £3 million at Sydney, £4.4 million for Athens, and £11.4 million for Beijing. The further £6 million totals a UK Sport investment of £17,929,600 to The BEF for the Rio Olympics (and a further £3.7 million for Paralympic Equestrian sport) which meant that equestrian was a priority funded sport for Rio 2016 alongside Cycling (£30,267,816), Sailing (£25,504,055), Rowing (£32,622,862), Gymnastics (£14,615,428) and Athletics (£26,824,206).

There have been governing body attempts to further increase participation in equestrian sports within the UK; the benefits of increasing and creating a large base of mass participation in sports is that a positive breeding ground for elite sport develops and in turn elite athletes are believed to attract young athletes to particular sports (Weed 2009). Post the 2012 London Olympics, an equestrian specific participation strategy, 'Hoofride' was introduced. Hoofride is an initiative funded by Sport England which aims to encourage more people to enjoy horse-riding and become interested in equestrian sports. Despite this strategy being in place, as previously indicated a general decrease in participation in equestrian sports has occurred within the UK between 2011-2015. There has however, been an increase in the number of youth participants which is suggested to be beneficial to the future of the sport (ages 16-24) from 368,000 to 403,000 per annum, and equestrian sport as a whole is on the rise, with an 83% increase in international competition since 2007 (FEI 2016).

There is a strong gender bias in equestrian sports with females representing 74% of the total riding population with 962,000 female compared to 348,000 males participating in equestrian related activities in 2015 (BETA 2015). At the elite level the gender bias is less evident, in the 21st century 47% of Olympic Equestrian athletes were female and 55% male (BETA 2015).

Despite sporting success and the recognition of Equestrianism by UK Sport, there are many websites, media and press releases that express strong negative opinions about whether equestrian sports should belong in the Olympics. Equestrian sports have a long-standing history at the Olympic Games and have proliferated from the Ancient Olympics (de Haan 2015), this historical importance of equestrian sport has allowed it to remain on the Modern Olympic programme from 1900.

The Federation Equestrian International (FEI) was founded in 1921 and is the international body governing equestrian sport recognised by the International Olympic Committee (IOC). The FEI governs eight equestrian disciplines including the three Olympic disciplines (Dressage, Eventing, Show Jumping) and the Para-Olympic discipline of Para-Equestrian Dressage. The largest equestrian competition is the World Equestrian Games (WEG) held every four years. The inaugural WEG was established by the FEI in 1990 where 37 countries competed against one another over six equestrian disciplines. In addition to the Olympics and WEG, the FEI hosts European Championships in Eventing, Showjumping, Dressage and Para-Equestrian Dressage every two years in between Olympic cycles.

The national governing body for equestrian sport in Great Britain is the BEF which works alongside the FEI in managing equestrian sport. The BEF also distributes government funding from UK Sport, Sport England and Sport Scotland to support riders from grassroots to elite level. The BEF has a strategic focus for the development of its athletes; within equestrian sports the athletes are considered to be both the horse and the rider. The BEF have developed a World Class Programme designed to support success for human and equine athletes in Eventing, Show Jumping, Dressage and Para-Equestrian Dressage designed to identify talented riders and also horses and working with them to reach maximum potential at the world levels. Unique to equestrian sports there is a need for both world class athletic horses and riders, as such an Equine Pathway was introduced in 2006-2007 parallel to the human development pathway.

To develop elite athletes, world class programmes are designed to identify and develop talent and produce performance on the world stage. The Equestrian World Class Programme has this in place for both the horse and rider and is catergorised into three areas: The Equine Pathway, The Development Programme and the Performance

Programme. Alongside the performance programmes, the British Equestrian Federation launched a Long Term Athlete Development Model unique to equestrian sports (BEF 2010), which was re-titled to the 'Equestrian Specific Long Term Participant Development Programme' (LTPD) in 2013 for riders that encompasses all equestrian disciplines (BEF 2013). Equestrianism does not fit the classic 'early specialisation' or 'late specialisation' models apparent in many other sports and instead experts adapted the LTPD for a unique model as riders are typically 'early start-late specialisation'. Riders usually learn to ride at the age of three but do not generally compete or specialise in a discipline until the age of sixteen. With the potential of career longevity, the LTPD focusses on the components of physical literacy that will maintain and develop elite performance for an extended period of time. The LTPD is a model that defines the most appropriate environment and activities for a given athlete as they develop and applies to recreational and competitive riders alike. The LTPD considers each individual athlete throughout their equestrian career and offers an insight into optimal training and recovery programmes to ensure athletes reach their potential.

The LTPD indicates that equestrian sports should carefully consider the core components of athleticism off of the horse alongside the demands of horse riding. It outlines the key components of physical literacy that should be expected at each training level. Table 2.1 shows that the BEF considers off horse training for riders to be important with a clear focus on functional stability and mobility training and well as training for symmetry and balance. As the stages advanced towards training to perform and training for excellence, structured annual and four yearly periodised off-horse training cycles are suggested as the optimal for elite athlete development. There is also the explicit mention of discipline specific strength and stamina indicting riders should be concentrating on their equitation skills and their off horse physical literacy.

Table 2.1: The components of off-horse physical literacy riders should aim to achieve at each stage of the LTPD model.

Leaning to Take Part	Improve dynamic balance, spatial awareness, co-ordination, flexibility and basic stamina. • Functional stability and mobility • Specific flexibility • Testing for sidedness, handedness, eye testing and tilt • Training aimed at symmetry and balance
Training to Improve	Understand concepts of warming up/down, basics of nutrition and hydration. • Frequent musculoskeletal evaluations • Functional stability and mobility • Stamina and strength • Suppleness for mobility
Training to Perform	• Year round structured training • Event specific strength and stamina • Improvement of stability/mobility • Strength and condition to increase career longevity • The ability to make high volume attempts in technical training without physical fatigue becoming a limiting factor. • Regular body alignment monitoring and correction of postural imbalance
Training for Excellence	• Four yearly physical performance plan aimed at maintaining key physical condition factors due to long working and competition periods. • Regular testing of body alignment and functional stability • Maintain/enhance event specific strength and stamina • Ability to peak physically for a major competitive event • Includes prehabilitative training • Balance training • Fluctuation in physical training cycles and cyclical modulation of training loads • Maintenance of physical fitness specific to the discipline • Optimal diet

The LTAD model is the most prominent ideology to enhance long term athletic performance (Bayli and Hamilton 2004) and offers a coaching framework using credible principles. The LTAD and the associated physical developmental process that occurs during childhood and adolescence with respect to short and long term athletic performance has been investigated in detail (Viru et al. 1999; Boisseau & Delamarche 2000; Baquet et al. 2003). When considering individual sports models however, there is minimal, if any evidence to support the suggestions detailed for the components of physical literacy to support the LTAD claims, due to the wide variation of physiological factors that influence performance. To support the LTPD framework specific knowledge of the physiological demands and performance related fitness in equestrian sports is necessary.

2.2 Intricacies of the Equestrian Sport of Eventing

The equestrian sport of Eventing (also often referred to as horse-trials) is a three-phased equestrian discipline. Eventing has an Olympic presence and is a sub-discipline of the broader categorisation of 'Equestrian Sports'. Eventing is considered by the FEI as a sport that demands the competitor has considerable experience in all branches of equitation and a precise knowledge of the horse's ability, and of the horse, a degree of competence resulting from intelligent and rational training.

Eventing covers every aspect of horsemanship: the harmony between horse and rider that characterise DR; the contact with nature, stamina and extensive experience essential for the XC phase; the precision, agility and technique involved in SJ, these phases run concurrently at a single event (Whitaker and Hill 2005a). Penalties are awarded within each of the phases of competition, which are carried forward. The lowest combination of penalty points over the three phases is declared the winner (British Eventing 2009). Depending on the level of performance and number of competitors, points are awarded for finishing position in that competition. These points amass to a lifetime performance score for the horse, where a pre-determined level of points accrued limits entering lower levels of competition (Whitaker and Hill 2005a). Within the UK, Eventing is governed by British Eventing (BE), a member of the BEF.

The structure of levels within Eventing is progressive with horse and rider combinations (the same horse and rider must compete at all three phases) advancing through increasingly more complex levels of competition. Eventing within the UK is broadly divided into three levels: Novice, Intermediate and Advanced. Within these levels there are also further incremental divisions such as, Novice being split into classes BE90, BE100 (formerly known as pre-novice) novice and open novice (British Eventing 2009). There are no subdivisions in the Intermediate and Advanced levels. There are, however, Intermediate phases, for example, 'Intermediate Novice' and 'Advanced Intermediate'. At the national level, all three phases of competition are on a single day and thus termed a ODE.

There are three common formats for Eventing. These are:

- *One-day event*, in which all three phases take place on the same day (ODE);
- *Two-day event*, in which the phases are intended to introduce competitors to the additional and technical skills required in Three Day Events. DR and SJ take place on day one, with an extended XC test on the second day;
- *Three-day event*, the three tests take place on three separate days in the order, DR, XC and SJ. The object of the last day is to test the horses' ability to remain supple with the fitness stamina and obedience to compete (British Eventing 2009).

The ordering of the phases within Eventing are; DR takes place first with XC last, unless otherwise authorised by the Sport Director or FEI rules. British Eventing (2009) state that each horse is required to have an interval of at least 30 minutes finishing between one phase and starting the next. When SJ is the final phase, the interval should be at least 60 minutes.

The progressive star system used by the FEI indicates that the difficulty of competition increases and thus is more physically demanding for the horse, particularly for the XC phase (Schroter and Marlin 2002). For the horse, the DR test for a ODE appears to be of similar demand in terms of heart rate compared to an Elementary level Dressage test (Marlin et al. 1995) and heart rates of horses have been reported to range from 90-120bpm during this phase. The cardiovascular demands placed upon the horse increase during the SJ phase, for a three-day event, equine heart rates have been reported as ~148bpm. Considerably more information exists concerning the XC phase and heart rates are reported to range from 155-195bpm (Khon and Hinchcliff 1985; Khon et al. 1995; Marlin et al. 1995). The direct effects or implications of these increased demands on the horse and the subsequent physiological demands that are placed on the rider are not researched.

It is known that horses do not tolerate heat well, and as such there is a plethora of research investigating heat stress and acclimating the performance horse to tolerate heat. The main mechanism for horses to exchange heat with the environment is by sweating, the horse has a disadvantage to heat exchange because of their high body mass to surface area ratio and their reliance on sweating as a heat dissipation method; horses can sweat ~15l of fluid per hour during exercise in hot conditions (Marlin et al. 1995). The direct affect this has upon the rider is not documented, but presumable heat exchange between the horse and rider would account for some increases in physiological responses of the rider and should be a factored consideration when interpreting results.

The physical difficulty of competition and thus the physiological demand increasing with competitive level is not documented with respect to the rider, as such it is necessary to define physiological demand with respect to level of competition. Novice level Event riding is described as a considerable step up from the pre novice divisions of BE80, BE90 and BE100 and is the level that riders progress to should they wish to take their Event riding seriously, amateur or otherwise (Horse and Hound 2017). As such, it is a very large and competitive division and therefore deemed an appropriate starting point to explore the physiological demands placed upon riders within this sport. There is a limited amount of information that exists concerning the physiological demands of Novice ODE and therefore it is necessary to provide equestrian governing bodies and equestrian coaches with evidence based information to physically develop riders to achieve optimal performance at competition.

2.3 Equestrian Specific Research Literature

There has been limited published research investigating the physical characteristics and physiological demands placed on the rider during riding and specifically the three phases of Eventing. The following section therefore discusses literature considering body composition, physiological demands and physical characteristics in an equestrian demographic. This section also reviews the positional demands of horse riding and the use of mechanical horse simulators.

Firstly, before specific equestrian literature is considered, it is important to define the 'rider', within the available research. To date, riders have typically been defined by the level at which they are competing (Devienne and Guzennec 2000; Roberts et al. 2010; Cullen et al. 2015) or by the experience they have to riding activities (Westerling et al. 1983; Meyers and Sterling 2000; Lovett et al. 2005; Beale et al. 2015; Williams and Tabor 2017). To assist with categorisation, Williams and Tabor (2017) propose a clear taxonomy to profile riders which they suggest will assist future research investigations by applying clear definitions of rider status (Table 2.2). The taxonomy proposed by Williams and Tabor (2017) was developed based on the work of Swann et al. (2015) who originally suggested a two system approach to defining an athlete's status within research. This two system approach advocates an absolute status for exceptional athletes where performance defines expertise, and a relative approach to asses expert status defined using level of experience. This is a useful tool, and will allow categories of riders to be more directly compared between the literature if it is an adopted future method. The term 'Novice' within Event riding may lend the reader to assume that the riders are 'Novice' or as indicated in the following taxonomy, inexperienced. This is not the case however, a Novice level Event rider has progressed through the earlier stages of competition and is thus more accurately defined as an experienced or amateur rider.

Table 2.2: Taxonomy of rider status categories in equestrian sports (Williams and Tabor, 2017).

Category	Description
Leisure rider	Engage in hacking and unaffiliated equestrian activities
Novice rider	Rider is inexperienced and who has less than 3000 h riding
Experienced rider	Over 3000 h riding experience and has an independent seat and competent riding ability on the flat[a] (up to and including lateral work) and over jumps[a] (≥1.00 m), with some competition experience in affiliated equestrian disciplines
Amateur Rider	Experienced riders who regularly compete in affiliated equestrian activities but for whom equestrianism is not their main source of income
Professional Rider	Experienced riders who work and/ride horses or coach as their main form of employment.
Elite Rider	Experienced riders who have competed at National and/or International level in a named equestrian discipline
Expert Rider	Elite rider who has represented their country at the Olympic games in equestrian sport (or at the highest level of equestrian discipline-specific competition for non-Olympic sports)
Para- Rider	Rider (can be inexperienced or experienced) who engages in para-equestrian activities as defined by the International Equestrian Federation (FEI).

2.3.1 Body Composition

In accordance with presenting participant demographics, many studies report data including height and mass of participants to allow for data to be expressed in relative form, a review of body composition data (height, mass, body mass index and percentage body fat) reported in the available equestrian literature is detailed in Table 2.3.

In addition to height and mass, Meyers and Sterling (2000), Roberts et al. (2010), Hobbs et al. (2014) and Beale et al. (2015) reported body mass index (BMI) in female equestrians, with findings of 24.8±1.7; 21.7±1.9, 24.4±4.1 and 24.7±5.4 respectively (BMI=weight/height^2) (Table 2.3). A BMI score of between 18-24.9 is considered a normal and healthy weight range; equestrian participants appear to have average values across the literature to be at the upper limit of a normal weight range or within the overweight category. Body Mass Index in horse-riders is greater compared to active women who run ~15km weekly, where mean BMI is reported as 22.7±3.5 (Williams and Satariano 2005). The use of BMI has gained acceptance in epidemiological studies based upon reports of correlations with per cent body fat. The use of BMI however, does come under strong criticism in muscular and athletic participants where lean mass is not accounted for (Eston 2002). Caution should be applied when using BMI in athletic populations, when BMI is compared to body fat percentages in athletic and non-athletic populations, acceptable BMI is elevated based on measured body fat (Ode et al. 2007) and there is increasing evidence to suggest that there is a need for different BMI classifications in muscular and athletic populations. Body Mass Index may be suitable for giving an indication of fatness within a population, and is a standard descriptor in many research trials in addition to height and body mass and results should be interpreted with respect to the population demographics utilised. With respect to the horse riders, it appears that Event riders have lower BMI than DR and Collegiate riders which is also supported by reported body fat percentage (Table 2.3). With such limited data to compare, it is inappropriate to conclude that the physiological demands of Eventing are responsible for a leaner body composition, but warrants future investigations.

Table 2.3: Body composition data reported for equestrian athletes.

Research	Study Population	Mean Age	Mean Height (cm)	Mean Mass (Kg)	BMI	Mean % Body Fat
Westerling (1983)	n=13 female experienced riders	21	--	61.5	--	--
Alfredson (1993)	n=20 female collegiate riders	18	165.1±4.5	61.8±7.0	--	28.6±6.5
Meyers and Sterling(2000)	n=24 female collegiate riders	24	161.8±5	64.9±9.3	24.8±1.7	24.5±6.0
Devienne and Guzennec (2000)	n= 5 (3female, 2 male) Show Jump riders	26	172±1	54.2±11.1	--	--
Roberts et al. (2010)	n=16 female novice event riders	25	166±3.8	60.3±5.8	21.7±19	23.4±5.3
Hobbs et al. (2014)	n=134 (132 female; 2 male) Dressage riders	39	166±12.8	67.1±12.8	24.4±4.1	--
Beale et al. (2015)	n=16 recreational female riders	25	163±0.05	66.2±17.1	24.7±5.4	30.6±6.4
Sainas et al. (2016)	n=19 (9 male, 10 female)	30	166.7±8.1	59.3±11	--	--

Body fat in riders is documented to be between 24.5-30.6% (Table 2.3). Novice ODE riders reported a lower body fat percentage compared with collegiate and recreational riders (Table 2.3), supported by a lower BMI. Roberts et al. (2010) noted that the high body fat percentages reported in equestrian athletes reflect a lack of physical conditioning when compared to other groups of athletes, suggestive that body composition is not a primary indicator of performance in horse riders. Body composition in equestrians has been investigated using a range of techniques including Dual X-Ray Absorbtiometry (Alfredson et al. 1998), Hydrodensitometry (Meyers and Sterling 2000) and using skinfold techniques (Roberts et al. 2010). Hydrodensitometry and Dual X-Ray Absorbitometry are considered the most valid measures for measuring body composition (Khort 1998; Eston and Reilly 2009a) as used by Alfredson et al. (1998) and Meyers and Sterling (2000). Skinfold measures as used by Roberts et al. (2010), Beale et al. (2015) and Cullen et al. (2015) are widely incorporated in the field and in practice by fitness professionals as skinfold measures provides an inexpensive, quick tool to estimate body fat percentage. To improve accuracy of estimated body composition skinfold measures using an empirically derived mathematical relationship with methods such as Dual-energy X-ray Absorptiometry (DXA) or hydrodensitometry are of best value to researchers (Eston and Reilly 2009a). The work of Roberts et al. (2010) is limited because the skinfold method used was not described nor did the research provide a regression equation used to calculate body fat percentage from skinfold. As with BMI, body fat percentage reported for equestrians are considered average (25-31%) according to the American Council on Exercise for female populations (ACE 2017).

An equestrian sport that has not been considered thus far, where body composition becomes more specific, includes race jockeys, where mass of the jockey is manipulated to increase athletic performance of the equine (Cullen et al. 2015). This specific population of equestrian athletes report much lower body composition variables for height (165.1±4.5cm) mass (54.9±2.9 kg) and thus BMI (19.2±1) and percentage body fat (7.4±1.3%) compared with literature concerning recreational, collegiate, DR and Event riders, and for this population of riders, body composition is directly related to performance outcome.

2.3.2 Postural Symmetry

In addition to mounted investigations, un-mounted trials are emerging concerning riders posture, mostly relating to asymmetry. Functional asymmetry is a concern because both the horse and the rider can be affected (Hobbs et al. 2014). Hobbs et al. (2014) investigated posture in n=134 (2 male, 132 female) DR riders to determine anatomical asymmetry in a population of riders. Overall posture type was classified using pre validated methods and conducted by a chartered physiotherapist, and functional and dynamic seated and standing postures were assessed using an infra-red motion capture system. Results indicated that riders had an increase in asymmetry of mean iliac crest height, authors reported that years of riding affects pelvic alignment. There was also an interaction between functional range of motion with relation to lateral bending (limited lateral bending to the left side). Decreased lateral bending increased with prevalence of pain in higher levels of riding and so lateral asymmetry indicates clinical relevance here. A greater acromion height to the right in experienced riders was linked by Hobbs et al. (2014) to lateral asymmetries, and asymmetries in shoulder height. It was discussed that increased muscular stiffness and development on the right would lead to limitations in movement to the left, which could be additionally attributed to a predominantly right handed population and as a result lead to pain.

Increased iliac crest height to the right has been reported with time spent riding in previous literature (Hobbs et al. 2014) and authors had suggested that the causal factor may be greater muscle stiffness and development on the right side would limit lateral bending to the left. This right hip limitation and blocking of movement to the left is also reported during actual riding by Symes and Ellis (2009). It appears this right side asymmetry may be attributed to hand dominance, grip strength (as indicted by Hobbs et al. 2014) used during daily activities and potentially exacerbated in this horse riding population due to the daily physical tasks associated with owning and riding horses such as stable work. Asymmetry during riding is not just related to posture, differences in rein tension between left and right hands have also been reported (Khunke et al. 2010) further suggesting this differential left-right muscle recruitment pattern that is being adopted is a precursor for asymmetrical shoulder height (Hobbs et al. 2014). Hobbs et al. (2014) concluded that axial rotation to the left and asymmetric shoulder height were attributed to muscle development and stiffening on the right side of a rider's body. This asymmetry has clinical relevance, as increased prevalence of pain has been reported in riders with asymmetrical postural development, years riding and competitive level (Hobbs et al. 2014).

2.3.3 Maximal Oxygen Consumption.

The importance of a high $\dot{V}O_{2max}$ for equestrian athletes is uncertain, although heart rate data throughout Eventing (Roberts et al. 2010), SJ (Guitérrez Rincón et al. 1992), Racing (Trowbridge et al. 1995) and Polo (Wright & Peters 2008) suggest that the aerobic demands of equestrian disciplines requiring galloping and jumping efforts are high.

Westerling (1983), Devienne and Guzennec (2000), Beale et al. (2015), Cullen et al. (2015) and Sainas et al. (2016) used cycle ergometer protocols to induce fatigue in riders and reported wide ranges in maximal oxygen uptake with 43.8±4.0 $ml.kg.min^{-1}$, 54.9 $ml.kg.min^{-1}$ (converted from $l.min^{-1}$), 37.2±7.4 $ml.kg.min^{-1}$, 54±3.3 $ml.kg.min^{-1}$ and 34.73±7.1 $ml.kg.min^{-1}$ respectively. When considering the range of protocols participant populations should be considered, a higher $\dot{V}O_{2max}$ was reported by Cullen et al. (2015) in male race jockeys, a greater value would be expected in a male sample due to heterogeneous exercise and training responses. Treadmill protocols were used by Meyers and Sterling (2000) and was justified due to equestrians riding the stirrup irons and exhibiting high degrees of upper body and total body work than can be derived from a cycle ergometer which again limit comparability between data.

A high heart rate, indicates a requirement for high maximal oxygen consumption and this would presumably transfer into greater aerobic fitness in equestrians (based on the linear relationship between heart rate and oxygen uptake during exercise). This supposition is not supported by Meyers and Sterling (2000) who observed mean $\dot{V}O_{2max}$ values of female equestrians (age range 18-24 years) to be 33.4±1.2 ml.kg.min^{-1}. Unlike other equestrian literature, Meyers and Sterling (2000) used a treadmill protocol; the maximal oxygen uptake reported in this study were lower mean values than data reported in equestrians when using a cycle ergometer (CE). Given the known under-reporting of maximal oxygen consumption on a CE compared to treadmill modes (Abrantes et al. 2012) the values would have been expected to be lower when using a CE. Direct comparisons between sample populations cannot be made, there may be multiple factors that affect the differences; the population in Meyers and Sterling (2000) for example may be less aerobically conditioned than other investigations. There are also aforementioned considerations that can affect physiological data including such as the sample population used, mode of exercise and test design.

The reporting of $\dot{V}O_{2max}$ values in the research by Devienne and Guzennec (2000), Meyers and Sterling (2000) and Westerling (1983) included the participants subjective exhaustion and heart rate being at or above predicted maximal values. This suggests research in an equestrian population have reported $\dot{V}O_{2peak}$ as opposed to $\dot{V}O_{2max}$ as the research did not state the plateau criterion for maximal oxygen consumption had been met, $\dot{V}O_{2peak}$ was also reported for Meyers and Sterling (2000). The establishment of the plateau criterion for maximal oxygen consumption is not always achievable during exercise tests and other criterion such as respiratory exchange ratio, heart rate, and blood lactate are used to demonstrate exercise intensity. It is possible that the participants within this research did not achieve values close to their maximum based on the criterion.

2.3.4 Muscular Strength

Electromyographical (EMG) studies in horse-riders indicate that riders require muscular endurance due to long periods spent with muscles in tonic contraction to maintain posture (Terada et al. 2004). The approach to measuring strength in an equestrian population has varied from laboratory based methods such as isokinetic dynamometry (Westerling 1983; Alfredson 1998), and field based exercise tests, such as push ups and sit ups (Meyers and Sterling 2000).

Westerling (1983) reported physical strain during riding and in addition to on horse measures also evaluated static muscular strength in equestrians. Strength was reported as the mean of three maximal voluntary isometric contractions during knee extension (147Nm), hip adduction (140Nm), elbow flexion (52Nm) and hand grip (403N). Normative data was not available and so a control sample was used to allow for direct comparisons. The control group showed no significant strength differences compared to a rider population. Westerling (1983) concluded that in trot sitting, static muscle contraction is more important than in other gaits. This was determined based on the high maximal aerobic power of the riders (43.8 $ml.kg.min^{-1}$) and that static muscle strength was not different between the rider and the control group. Westerling (1983) included isometric strength measures within the research but did not use them to further understand the physical strain of riding. Mean isometric strength values were compared to a non riding sample, but the level of activity and type of training of the control group was not described. The conclusions made by Westerling (1983) regarding static strength requirements of riders are based on laboratory measures only, and so may describe the strength of this population but does not really allow the data to be used to describe physical strain of horse riding as the research intended. Documenting muscle activity and oxygen uptake during riding activities would be a more accurate way of concluding the muscle work necessary and its relationship with physiological parameters.

Alfredson et al. (1998) investigated bone mass and isokinetic concentric and eccentric thigh strength in equestrians to identify skeletal and muscular adaptations to horse-riding and additionally if bone mass and muscle strength were related in horse-riders. Alfredson et al. (1998) used an isokinetic dynamometer at two speed settings and muscle actions in adolescent females who were non-active other than their equestrian pursuits. During the concentric tests five maximal repetitions were made at 90°.second^{-1} and ten at 225°.second^{-1}. During the eccentric tests three maximal repetitions were made at 90°.second^{-1} and the highest peak torque for each test was recorded. Unlike the research of Westerling et al. (1983), Alfredson et al. (1998) reported strength differences between riders and their control counterparts.

Alfredson et al. (1998) reported concentric strength in riders for quadriceps at 90°.second^{-1} as 137.7±18.2 Nm and 225°.second^{-1} as 56.0±9.5 Nm. Hamstring concentric strength was reported for 90°.second^{-1} as 56.0±19.5 Nm and 225°.second^{-1} as 61.2±10.3 Nm. Eccentric strength was reported for the quadriceps as 206.3±42.5 Nm and hamstrings as 98.5±16.0 Nm. Horse-riders had significantly greater concentric hamstring strength at low and high speeds (16.2 and 25.4% respectively) compared to the control group. The horse-riders also had greater eccentric quadriceps (18.1%) and hamstring strength (20.9%) than non-actives. Unlike research of Westerling (1983) the control group sample in the work by Alfredson et al. (1998) was detailed as non-active females (<2 hours activity per week) and were matched to the sample group in terms of age, height, weight and race. A specific control group allows the reader to interpret that differences in muscle strength were as a result of riding specific adaptation.

Laboratory based testing is not always applicable and thus field tests can provide a useful tool for field based analysis of an athlete. Meyers and Sterling (2000) investigated physiological and exercise responses of female collegiate athletes to provide a greater insight into the health fitness of this unique competitor, and to compare results to other better studied sport athletes. In terms of assessing muscle strength Meyers and Sterling (2000) used a curl up test, reverse sit ups, push ups and handgrip strength performed as the number of repetitions per minute to assess muscular strength of the abdominals, back and arms. The authors reported mean values for the curl up of 57±16 #/min^{-1} (range 23-88 #/min^{-1}), reverse sit up, 37±13#/min^{-1} (range 8-58 #/min^{-1}), push up 32±11 #/min^{-1} (range 12-50 #/min^{-1}) and hand grip right 29±7kg (range17-44.5 kg) and hand grip left, 27±6kg (range 18-42.5kg). Meyers and Sterling (2000) concluded that mean values for equestrians curl up, reverse sit-up and push up responses to be average to above average for the participant age group. Handgrip strength was lower than established normative values for young females (Meyers and Sterling 2000). Like the work of Alfredson et al.

(1998) a demographic matched sample control group of non-actives would be a useful and direct comparison however, Meyers and Sterling (2000) compared their results with normative values established previously in academic research trials.

2.3.5 Heart Rate Analysis

The gait of the horse or the position of the rider has been reported to affect the heart rate response of horse-riders. Westerling (1983) reported an increase in mean heart rate to increase from 108±13 beats.min^{-1} during walk, 163±19 beats.min^{-1} for trot rising, 170±15 beats.min^{-1} for trot sitting and 172±18 beats.min^{-1} for canter in thirteen experienced females who spent 3-14 hours per week in SJ and DR disciplines. This research additionally reported individual mean heart rates in small sample (n=3) elite riders that participated in this trial (n=2 female, 1 male). In addition to ground work, Westerling (1983) investigated physiological responses of two of the experienced female riders throughout an advanced jumping test (10 obstacles at 1.10m) that lasted less than one minute in duration. The heart rate was reported to rise almost immediately and reached the maximal value attained during the maximal cycle ergometer test (values not reported).

Of the three elite riders investigated, two (1 female, 1 male) participants had significantly lower heart rate responses compared to the experienced riders, one of the elite riders heart rate responses were comparable to the experienced rider group. Individual mean values for the three elite riders were not reported, however the elite samples mean heart rates were 88 beats.min^{-1} for walk, and 135 beats.min^{-1} for sitting trot, rising trot and canter combined. The data may initially suggest that elite riders with increased exposure to riding horses may have developed a cardiovascular training effect. The data from the elite riders is not a large enough sample nor standardised enough to consider the data a true reflection of the differences between riders and riders of higher competitive level. For example, one of the male riders did not conduct the same test as the other participants and instead his heart rate was extracted during a high level (Prix St. George) Dressage test.

There are many variables that may have affected heart rate (further outlined in section 2.6) during the research of Westerling (1983) that can be considered a methodological limitation. The order of the test was not described in detail by Westerling (1983), presumably data was collected in walk, followed by trot and then canter. The order of the test not being stated is a limitation in the dissemination of this research because intensity, duration and rest periods between the riding would affect heart rate responses. The DR test would not have followed the same pattern as the standardised test the other riders were exposed to. Details on data collection throughout the riding test were also not described, how long each rider had to complete each gait for would affect the mean data, for example whether the data was collected over the last minute of each gait or for the entire duration. The competitive discipline of the elite riders was also not considered and could have had an effect on heart rate responses.

Westerling (1983) declares that heart rate recording was the most problematic measure throughout the study. Electrocardiograph (ECG) heart rate recording methods via portable tape recordings were used to measure heart rate. This required many test repeats to gather acceptable data; the repeats may cause additional accumulative physiological responses in this sample population, the duration of rest (if any) was not stated in the methods section of this research write up. Westerling (1983) was one of the first to investigate the physiological demands of horse riding and documents heart rate increases with the gait and position of the rider and provides valuable information on heart rate responses to different gaits and positions of the rider.

A SJ specific investigation was conducted by Guitérrez Rincón et al. (1992). Heart rate was analysed in a small sample (n=3) of riders during a course consisting of 13 jumping efforts of 1.20m high. Although specific heart rate values were not reported, the study detailed that show jumping riders used >90% of their maximum heart rate over the duration of the course which is in agreement with Westerling (1983) that jumping considerably increases heart rate compared to riding on the flat. Guitérrez Rincón et al. (1992) included a heart rate trace for two of the riders before, during and post competition but it did not specify on the figure where the competition took place. The write up of this research is brief and many specifics have been omitted. As a new area of research (at the time) the data that Guitérrez Rincón et al. (1992) provided is useful to the body of literature but the research would have been more impactful and useful if specific details such as mean heart rates during competition were included. A participant group of only three is also very small and questions the relevance of the data to the entire equestrian population. The write up makes generalised conclusions or statements that are not supported by the data collected. For example, it was discussed that heart rate may have been high due to nervous tension, and within the introduction the authors state that physical effort is related to technical riding ability, neither of which were investigated within this research or supported by prior research citations.

Competitive National Hunt racing has been reported with peak values ranging from 162-198 beats.min^{-1} and mean values of 136-178 beats.min^{-1} in seven male jockeys (Trowbridge et al. 1995). The seven jockeys competed in multiple races and therefore some jockeys heart rates were collected and analysed multiple times. Heart rate was collected using a Polar heart rate monitor and monitored continuously throughout the race. Average heart rate throughout the race was reported, and a range of mean heart rates were given where a participant had raced more than once. Additionally, peak heart rate was reported, and again given as a range in peak heart rates where more than one race for each jockey was collected.

During a National Hunt race, the jockey will be required to adopt an out of the seat semi-squat position while the horse is galloping and will have to maintain this position at fast speeds over multiple jumping efforts. The data reported by Trowbridge et al. (1995) suggests that National Hunt jockeys are exposed to a task that invokes a higher than average cardiovascular load during a race, which was always above 80% heart rate maximum for the duration of the competition (between 4 and 7 minutes) (Trowbridge et al. 1995). These heart rates are comparable to what had been previously collected during jumping by Westerling (1983) and Guitérrez Rincón et al. (1992) where the horse will be in a canter or a gallop and the rider will adopt an out of seat position in preparation for jumping efforts and indicates out of the saddle positions and jumping increase heart rate demands significantly when compared to data collected in walk trot and seated canter.

The work of Trowbridge et al. (1995) reports typical heart rate traces for jockeys in contention for winning a race, to those out of contention. In those jockeys that were more successful, the heart rate increased towards the finish line, compared to a declining heart rate in those not as successful. The authors conclude that muscle activity is a contributing factor to increased cardiovascular load during National Hunt racing. Trowbridge et al. (1995) note that although lower limbs appear to be isometric there are dynamic contractions which guide and control the horse. When riding to a finish, the action of the legs become more dynamic in an effort to drive the horse which is matched by the jockeys' upper body driving the horse forwards towards the end of the race. Trowbridge et al. (1995) concludes that this 'driving' muscular activity of the upper and lower body requires a high cardiovascular response.

Trowbridge et al. (1995) additionally report heart rate responses in National Hunt jockeys that are competing multiple times in one day. Typical duration of rest between races for jockeys is 30-35 minutes, and the jockeys heart rate remains elevated throughout this rest period and does not return to baseline. As a result, the following races report higher mean and peak heart rate compared to the initial race of the day. There are clear comparisons yet distinct differences that should be considered between race riding and Event riding during the XC phase that allow the work of Trowbridge to be included within this review for comparability in data. The similarities include elevated velocity of the horse (although more so for race riding), the inclusion of regular jumps (for National Hunt riding) and an unseated posture adopted by the rider. To date, literature has indicated it is these factors that elevate physiological demand in horse riders and the review of literature related to national hunt racing may prove useful in the transfer for discussion points to Event riding. It is important to note however, that the position adopted by a race jockey and an event rider are different and will likely recruit different types and amplitudes of muscular activity, the jump and speed profile will also make direct comparisons impossible.

Compared to Westerling (1983) and Guitérrez Rincón et al. (1992) the work of Trowbridge et al. (1995) is detailed and provides evidence that supports previous data that indicates horse riding does provoke a significant cardiovascular load, and that un-seated and jumping efforts are more demanding from a cardiovascular perspective than riding in walk trot and seated canter. In addition to a more detailed methodology, the participants used in Trowbridge et al. (1995) is exclusive to a sports specific population of riders and thus the data is more applicable to that sport. There are many equestrian sporting disciplines and each requires different skill sets; targeting a specific discipline and understanding the precise physiological requirements of that sport appears to be a more accurate way to understand physiological responses as opposed to catergorising equestrians as a whole participant group.

Devienne and Guzennec (2000) recognised that previous research had investigated the heart rate responses of riding where the rider only rode one horse (Westerling et al. 1993; Trowbridge et al. 1995). At this point in the progression of equestrian research (up to the year 2000) the effect of riding different horses of the energetic cost to the rider had not been investigated. Deviennce and Guzennec (2000) aimed to investigate how the energetic cost of riding varied depending on the horse being ridden where participants (female n=3 and male n=2 participants), who were considered experienced and rode for an average of 7 hours per week were used within this research. The riding test was more explicitly outlined than has been reported in prior research, and riders completed four minutes in walk, trot and canter progressively. Heart rate was monitored continuously and reported as a mean over the four-minute duration in each gait. Reported findings for walk, trot and canter were; 106±15 beats.min^{-1}, 131±20 beats.min^{-1}, 159±26 beats.min^{-1} respectively. Devienne and Guzennec (2000) show similar trends to Westerling (1983) where mean heart rate increased with the horse's gait. Additionally, Devienne and Guzennec (2000) monitored heart rate during jumping as a separate test. Riders completed the show jump test on one horse, the test warm up included four minutes riding in unseated canter, followed by a three-minute rest. Riders then jumped five small obstacles in trot for a further five minutes which followed by a repeated three-minute rest. A further five minutes of jumping five small obstacles at canter was preceded by the final three-minute rest period at walk. The final jumping test included 12 obstacles between 1-1.10m in canter. These authors reported mean heart rate over one minute for jumping a Show Jumping course as 176±24 beats.min^{-1}, which is comparable to Trowbridge et al. (1995) and this data further supports equestrian jumping inducing a significant cardiovascular load on riders.

Wright and Peters (2008) accepted the limitations of a single method approach to determine physiological demands and used heart rate to describe cardiovascular responses of riders to a Polo match. Polo is an equestrian team sport that is intermittent in nature requiring the rider and horse to go from walk to gallop instantly. The rider adopts both seated and unseated positions, with large proportions of play time in faster gaits and hence the rider out of the saddle. Polo riders have been reported to spend 67% of total match play in the 'hard' heart rate zones with mean overall heart rate of 149 beats.min^{-1}, with heart rate ranging from 99-182 beats.min^{-1} (Wright and Peters 2008). Polo is an intermittent mounted team sport and as riders would adopt both a mounted and a seated riding position throughout the match, variability in heart rate recorded is expected. The elevated heart rates during Polo match play are likely as a result of fast cantering efforts. Heart rate data describes the heart rate demands of the sport but the study is limited regarding paralleled time motion analysis to investigate the causal mechanism for elevated heart rate.

Roberts et al. (2010) reported heart rate values throughout a simulated competition in novice female one-day event riders. It is unknown how Roberts et al. (2010) simulated the competition environment, minimal detail is given in the research article in relation to even design specifics. There is a reference within the paper that suggests the methodological design followed BE rules, however detail as to how they made this a competition as opposed to an event simulation is not specified. As such, when interpreting the results caution must be given to the additional factors that may affect physiological variables during competitive compared to simulation based research trials. The XC phase produced the highest mean heart rate (184±11 beats.min^{-1}) followed by SJ (180±11 beats.min^{-1}) and then DR (172±15 beats.min^{-1}) phase. This research organised the simulated competition according to the governing body rule book, however the methods section did not detail specific durations between phases which would have an affect on heart rate as a lack of recovery between phases could cause an increased cardiovascular shift (Crisafulli et al. 2006a; Tocco et al. 2015). Heart rate was reported by Roberts et al. (2010) as a mean over the phase as opposed to gait of the horse which is beneficial for understanding the cardiovascular demands of Eventing, although does mean data is not comparable to previous research that investigated heart rate by gait of the horse or position of the rider. This research does support work of Westerling (1983), Guitérrez Rincón (1992) and Devienne and Guzennec (2000) that it is equestrian disciplines that involve jumping that significantly increase heart rate.

More recently, Sainas et al. (2016) investigated the cardio-metabolic responses to horse riding in n=19 (9 male, 10 female) horse riders during a live horse test comprising of 10 minutes walking and 10 minutes trotting followed by five minutes in canter. A consistent elevation in heart rate during the trial was observed (~100beats.min^{-1} during walk, 120beats.min^{-1} during trot) peaking during canter (~140beats.min^{-1}) which is comparable to previous literature. It was noted by the authors that heart rate was significantly elevated compared to other cardio-metabolic variables such as oxygen consumption, blood lactate and ventilation and thus using heart rate as a method for determining physiological load is misleading as it was out of proportion in comparison to other physiological variables. This is an important discussion point for consideration when investigating or interpreting data regarding the physiological demands of equestrian sports; a dissociation between heart rate and oxygen uptake and has been highlighted in sports where static muscle activity predominates (motor sports, sailing and kitesurfing (Konittinen et al. 2002; Cunningham and Hale 2007; Vogiatziz et al. 2007; Callewart et al. 2013). These research investigations report that physiological data that is not consistent with findings for dynamic sports (Cunningham and Hale 2007; Vogiatziz et al. 2007; Callewart et al. 2013) where physiological data were non linear with intensity, heart rate was higher than was needed for oxygen supply. Section 2.6 explores factors that may affect heart rate within an equestrian population in more detail.

In addition to these factors that may influence heart rate, it is important to note the protocol design when considering heart rate responses to the trial. The protocol was designed in a consecutive order i.e. walk, trot, canter as opposed to a randomised order which the authors note may induce cardiac drift. Cardiac drift is whereby there is a gradual increase in heart rate unrelated to energy expenditure caused by dehydration, hyperthermia and cardiac pre load (Crisafulli et al. 2006a; Tocco et al. 2015). Sainias et al. (2016) concluded that the short duration (20 mins) and moderate intensity was an unlikely contributing factor during this protocol.

2.3.6 Blood Lactate Concentration

Blood lactate concentration has been investigated in equestrian sports that require jumping efforts including SJ (Guitérrez Rincón et al. 1992), National Hunt racing (Trowbridge et al. 1995) and simulated Novice Level ODE (Roberts et al. 2010).

Guitérrez Rincón et al. (1992) reported that during a 1.20m SJ round, mean blood lactate concentration ranged from 4.0-6.3 $mmol.l^{-1}$ in equestrians. This range of blood lactate concentration demonstrates that a significant involvement of anaerobic energy systems are utilised during jumping. The utilisation of the anaerobic pathways during jumping are supported by work in National Hunt jockeys (Trowbridge et al. 1995) where observed mean blood lactate values were 7.1 mmol.l^{-1}. Roberts et al. (2010) investigated blood lactate responses during a simulated Novice ODE and observed lactate concentration to increase progressively during the three phases (DR, SJ, XC) reaching an overall mean of 9.5 mmol.l^{-1}.

Guitérrez Rincón et al. (1992) sampled blood from the earlobe of riders (n=3) using an Analox system at 1,3,5 and 7 minutes post completion of a show jumping round, however, only reported data for 1 and 3 minutes in 3 riders. Blood lactate concentration was always higher at 3 minutes post than those at 1minute post (rider 1, 1 minute = 2.8 mmol.l^{-1}, 3 minutes = 5 mmol.l^{-1}; rider 2, 1 minute = 5.7 mmol.l^{-1}, 3 minutes = 6.3 mmol.l^{-1}; rider 3, 1 minute = 4.1 mmol.l^{-1}, 3 minutes = 6 mmol.l^{-1}). Roberts et al. (2010) analysed blood lactate only 1 minute post completion of each phase of a simulated ODE, using a Lactate 'Analox' system sampled at the riders fingertip. This immediate sampling technique used by Roberts et al. (2010) may not have been adequate to achieve a true maximal blood lactate recording, as optimal blood lactate dissipation time is between 3 and 6 minutes post completion of exercise (Beaulieau et al. 1995) and like Guiterrez-Rincon (1992) and Trowbridge et al. (1995) choosing a single later duration or multiple collections times would have provided a more accurate representation of blood lactate for this population of riders.

Roberts et al. (2010) have reported highest blood lactate levels of 9.5 mmol.l^{-1}, post the XC phase in a ODE despite using an immediate sampling technique indicating that XC is anaerobically demanding for the rider. The dissemination of the methods section in this research does not make it clear how long the riders were able to rest between phases of their simulated competition. The high blood lactate post the XC phase may be a reflection of a higher metabolic load in the XC phase, than other disciplines reported. It may also be an accumulative effect of fatigue; it is unknown if the riders went from phase to phase with limited rest or whether there was long durations of rest between phases. Knowing the duration of rest and working period would help interpret the data set reported by Roberts et al. (2010).

Trowbridge et al. (1995) like Roberts et al. (2010) also used fingertip as the sample site. In addition to reporting mean blood lactate (7.1mmol.$^{-1}$) this research also reported a wide range (3.5 – 15mmol.$^{-1}$). It was reported that riders in contention of winning reported higher blood lactate profiles compared with those riders not in contention. The increased blood lactate values were accompanied by a higher cardiovascular load and Trowbridge et al. (1995) concluded that the increased muscular drive of the riders in contention for winning at the finish of the race increased the anaerobic requirements of the rider.

Perciavalle et al. (2014) disseminated research concerning blood lactate and attention in Show Jumpers to examine whether a typical course is capable of influencing intensity and selectivity of attention. Twelve participants (n = 6 male, n=6 female) completed an eight obstacle 1.15m show jumping course and fingertip blood lactate samples were taken immediately, 5 and 10 minutes post completion of the course. Three rounds were completed and the best and worst round was used, it is not clear from the research how much rest was given between rounds. An attention and concentration task test was completed 10 minutes prior, immediately upon completion and 10 minutes post the round. Blood lactate concentration was reported as 3.8 mmol.l^{-1} for the riders' best performance and 4.2 mmol.l^{-1} or their worst performance, regardless of performance the blood lactate concentrations post a SJ round are comparable to previous research (Guitérrez Rincón et al. 1992; Trowbridge et al. 1995; Roberts et al. 2010). Perciavalle et al. (2014) concluded that although the concentrations of blood lactate were moderate, they were great enough to worsen reaction time in riders and provides further justification for riders to condition themselves to off-set the early onset of blood lactate concentration.

Sainas et al. (2016) investigated anaerobic glycolytic energy contributions using $CO_{2excess}$ in n=19 riders. The authors accepted that direct measurements of BLa is a more common approach to assessing anaerobic glycolysis involvement but justified their method since riders must stop for several seconds to allow blood collection. Using $CO_{2excess}$ allowed continued information on the contribution of the anaerobic glycolytic energy pathway during the entire riding duration, providing a comprehensive picture of the metabolic requirements.

Sainas et al. (2016) reported that anaerobic glycolytic energy sources were indeed recruited and significantly increased during cantering, however this parameter remained below the anaerobic threshold suggestive that anaerobic energy sources were not required to a large extent and were only moderately activated during riding which is in agreement with Guitérrez Rincón et al. (1992), Trowbridge et al. (1995) Roberts et al. (2010) and Perciavalle et al. (2014).

Interestingly, Sainas et al. (2016) speculated that the main sources of BLa during horse riding can be attributed to bouts of isometric strain as a requirement to maintain balance whilst on the horse. The authors continue to discuss forearm activity in riders suggesting that fast twitch fibers utilised within the forearm produce more lactate than slow twitch (Saltin 1985) and that is was reasonable to assume that arm muscles contribute to lactate production during riding, an area considered important for future research investigations. Though the method used by Sainas et al. (2016) may allow for a complete assessment during riding activities without the requirements to stall for blood collection purposes, direct comparison of results to previous literature should be done so with caution; correlations have been reported between $CO_{2excess}$ and BLa accumulation previously (Angius et al. 2013), however it is not possible to directly calculate BLa using this method.

The research conducted on blood lactate during equestrian activities indicates that jumping horses requires anaerobic metabolism of the rider and as the duration and number of jumps increase (e.g. during a national hunt race or during the Cross Country phase in Eventing) the reliance on the anaerobic pathways increases as a higher blood lactate concentration is reported.

2.3.7 Oxygen Consumption and Pulmonary Ventilation

Westerling (1983) measured oxygen consumption and pulmonary ventilation during riding in walk, trot rising and sitting, and canter (Table 2.4). Data were collected and mean values reported over 5 minutes at each gait, similar to Devienne and Guzennec (2000) who analysed mean oxygen uptake over four minutes at each gait. Data in table 2.4 show that as the horse and rider progress through the horse's gaits (walk, trot, canter) the metabolic cost of horse riding increases. Devienne and Guzennec (2000) also reported that metabolic cost differed depending on the type of horse being ridden (e.g. lazy or forward going). This presents greater variability when attempting to compare data sets and standardise protocol. This is an interesting extraneous variable to attempt to standardise when investigating physiological responses to horse riding. An individual rider's responses will be dependent on the reaction of the horse to the rider's aids. When using different horses to investigate an individual rider's responses, a general subjective behaviour score may need to be noted for comparison in data sets presented. The safety aspects to riding unknown horses and practicality of using one horse for trials is often a motivation for each rider to ride their own horse.

Table 2.4: Comparison of oxygen consumption (ml.min.kg^{-1})* and pulmonary ventilation (l.min^{-1}) between Westerling (1983) and Devienne and Guzennec (2000).

	Measurement	Walk	Trot (Rising)	Trot (Sitting)	Canter	Jumping
Westerling (1983)	Oxygen Consumption (ml.min.kg^{-11})	9.59	27.3	27.6	30.24	---
	Pulmonary Ventilation (l.min^{-1})	21.2	44.3	49.4	55.4	---
Devienne and Guzennec (2000)	Oxygen Consumption (ml.min.kg^{-1})	12.0	---	25.3	37.3	38.7
	Pulmonary Ventilation (l.min^{-1})	19.39	29.57	---	47.45	59.11

* Data was converted to ml.min.kg^{-1} based on the mean mass of the participants from each study to allow direct comparison of data between research.

Roberts et al. (2010) measured oxygen uptake in female Novice ODE riders at a simulated competition event using a portable Metamax system, which indicated that mean oxygen consumption increased progressively with each phase; DR (20.4 ml.kg.min^{-1}), SJ (28.1 ml.kg.min^{-1}) and XC (31.2 ml.kg.min^{-1}). The data for the simulated competition phases are lower than reported by Westerling (1983) and Devienne and Guzennec (2000) but can be explained by the competition requirements. During a DR test a horse and rider would be expected to complete approximately 5 minutes of various gaits including walk trot and canter, not 4-5 minutes solely in one gait. If the mean data for walk, trot and canter in Westerling (1983) are averaged the mean value is ~23.7ml.kg.min^{-1} which is more comparable to what is reported during DR by Roberts et al. (2010). The data reported for jumping by Devienne and Guzennec (2000) is greater than what Roberts et al. (2010) reported throughout the SJ and XC phases. This is also explained by competition requirements. A SJ phase lasts for less than half the duration of data collection used by Westerling (1983) and Devienne and Guzennec (2000), also during the XC phase there will be periods of canter interspersed with jumping efforts, rather than a continuous 5 minutes in one gait.

Westerling (1983) and Devienne and Guzennec (2000) presented absolute values for oxygen consumption data instead of relatively which is a more common presentation method. As such data has been converted to ml.l.kg^{-1} by dividing l.min^{-1} by mean body mass multiplied by 1000 to allow direct comparison to data by Roberts et al. (2010).

Westerling (1983) used a portable meter by carrying Douglas bags on the back of the rider, the practicality and weight of this method is unknown. The research by Westerling (1983) was conducted over thirty years ago, and newer technologies are more advanced in terms of validity and reliability though data is comparable to progressive research. The Cosmed-K2 system used by Devienne and Guzennec (2000) and the Metamax system used by Roberts et al. (2010) have both been validated in academic literature (Larsson et al. 2004).

A plausible cause for the demonstrated increases in heart rate and oxygen consumption as a rider progresses through the horse's gaits (Westerling 1983; Devienne and Guzennec 2000; Roberts et al. 2010), and jumping (Trowbridge et al. 1995; Roberts et al. 2010), is that faster gaits and those that require adopting a forward seat, may recruit greater use of leg musculature, and necessitate greater trunk control. Though Trowbridge et al. (1995) did not measure muscle activity of jockeys, they did make reference that the isometric lower body activation combined with a dynamic upper body was a causal factor for a greater cardiovascular drive and reliance on anaerobic metabolism since blood lactate concentration was also elevated.

Later work by Beale et al. (2015) investigated oxygen cost of recreational riding in n=16 recreation female horse riders. Within this experiment, oxygen cost was analysed by a mixture of gaits within an epoch rather then individual equine gaits or rider positions as per previous literature. For example, post a walking warm up, 10 minutes of the lesson comprised of walk and trot (17.4±5.1 ml.kg.min^{-1}), the second 10 minute epoch consisted of trot and canter (18.4±3.9 ml.kg.min^{-1}), followed by 10 minutes work without stirrups (14.5±3.9 ml.kg.min^{-1}). The benefits of this study was that it mirrored a typical British Horse Society (BHS) lesson, and is thus reflective of typical oxygen requirements. The data indicates that typical equitation lessons are less demanding with regards to oxygen requirements, in comparison to sports specific training (Westerling 1983) jumping (Devienne and Guzennec, 2000) or competing (Roberts et al. 2010). Critiques of this study include the categorisation of averaging oxygen uptake during multiple gaits and positions only as it is less comparable to the work of Westerling et al. (1983), Devienne and Guzennec (2000) and Sainas et al. (2016).

2.3.8 Positional Demands and Muscular Activity During Horse-Riding

Literature investigating the physiological responses of riders to horse-riding indicate that the position of the rider in addition to the gait (and thus speed) of the horse and thus muscular activation impact the relative intensity and metabolic pathway contribution (Trowbridge et al. 1995; Roberts et al. 2010).

Schils et al. (1993) investigated positional differences in novice, intermediate and advanced equestrians throughout stride cycles in walk, sitting and rising trot. It was distinguished that riders of different levels could be classified according to the angles of their shoulder, hip, knee, thigh, lower leg, upper arm and trunk. Position of advanced riders resembled a seat described by many riding theories; the riders' upper body was upright with arms carried in front of the trunk. In contrast, novice riders leaned forwards with their upper body, and carried their arms closer to the vertical.

Lovett et al. (2005) investigated the angles of the riders trunk, thigh and lower leg in walk, trot and canter in five female riders. During the rising trot it was found that upper body position was tilted further forwards than in walking, in agreement with Schils et al. (1993). In the rising trot the rider is required to rise and sit from the saddle, which may induce more movement from the thigh, and coordinating the centre of balance with that of the horse. The range of movement seen at the trunk in canter was comparable to the walk. Since ground reaction forces are greater in canter than they are walk (Back and Clayton 2001) and the change of orientation of the trunk is also greater, a comparable trunk movement suggests that the rider uses a greater degree of muscle activity to maintain the position of their trunk during canter. This may be an explanation for aforementioned results that suggest that heart rate, oxygen consumption and thus metabolic cost is higher in canter, than in walk and trot (Westerling 1983; Devienne and

Guzennec 2000). Lovett et al. (2005) is an influential paper and as of 2017 has been cited in over thirty-five publications despite limited methodological analysis. Lovett et al. (2005) used a digital camera at a 25Hz sampling rate, which is particularly low for movement analysis where 50Hz is usually considered more appropriate yet still considered less accurate in comparison to camera with a sampling rate of 100-200Hz. Additionally, this research manually analysed angles from a photograph still instead of using digital analysis software. The accuracy of analysis and the likelihood of human error can thus be questioned. Despite the approaches to analysing data, Lovett et al. (2005) has been used as a motive for many research trials, it still to date remains one of the few biomechanical studies that explores rider position, and though may not utilise the most accurate analysis methods, does provide a simple and useful representation of rider position between horses' gaits.

Muscular activity of horse-riders to various gaits, positions and disciplines has received minimal research attention. Terada et al. (2000) investigated whether advanced riders had more skillful co-ordination patterns without using unnecessary strength. Three novice and three experienced riders completed a live-horse exercise test in walk, sitting trot and canter. Bilateral muscle activity was recorded for the *rectus abdominis*, the *erector spinae* and the *adductor magnus*. Data for EMG was analysed by frequency bands (Hz), the frequency bands were catergorised as: low frequency 5-45Hz, intermediate frequency 46-80Hz, high frequency >81Hz. The walk reported novice riders to have a greater rate of activity in the intermediate activity band, particularly for the *erector spinae*. The experienced riders had a similar muscle activity profile over all three muscles analysed. During sitting trot, advanced riders had limited activity of the *adductor magnus*, this muscle reported a greater activation rate during sitting trot in novice riders indicating they were using this muscle to 'sit' to the sitting trot.

Terada (2004) compared timings of EMG activity in the rider with the temporal variables of the horse at a trot. Electromyographic activity of twelve muscles (*rectus abdominis*; upper, mid and lower *trapezius*; *serratus anterior*; *teres major*; *flexor carpi radialis*, *extensor carpi ulnaris*; *biceps brachii*; *triceps brachii*; mid *deltoid* and *pectoralis major*) was analysed in six experienced riders. Unlike Terada's earlier work, EMG activity was normalised to each rider's percentage of maximum muscle activity allowing activity to be relatively expressed. The data was also expressed in amplitude (mV) as opposed to frequency bands. The stance phase is the aspect of the phase where the horse's hoof is in contact with the ground and within itself is split into two aspects. During early stance phase the riders' *trapezius* muscles, *flexor carpi radialis* and *biceps brachii* were activated, during late stance the *pectoralis major, triceps brachii* and *rectus abdominis* became activated. The authors concluded that the predominant role of muscle action during trot was for co-ordination and postural stabilisation, rather than for the production of power. Unfortunately, it is not clear whether the trot was performed at the 'sitting' trot or the 'rising' trot, since Westerling (1983) and Devienne and Guzennec (2000) report elevated physiological responses to sitting trot, and the obvious biomechanical differences between the positions of the rider in this equine gait, it would have been a useful detail to include for interpretation of the results.

It is clear that the horses gait pattern affects general motion patterns of the rider and, due to muscular control, expert riders appear less shifted in their mounted positions using synchronization of the *rectus abdominis* and *erector spinae* muscles to move with the horse and are less reliant on the *adductor magnus* muscles which are used to support novice riders by gripping with the leg during sitting trot. It appears a common trend is that the trunk orientation of riders is more vertical in advanced riders, most likely due to trunk control exhibited by abdominal musculature. An increased muscular drive in unseated canter and jumping efforts has been purported by Trowbridge et al. (1995) to increase metabolic effort of riders and evoke a significant cardiorespiratory demand. Electromyographic analysis in horse-riders as is isolated to the gaits of walk, trot and canter and mostly focused on the analysis of upper body muscular activation patterns. Though minimal evidenced based information exists, Trowbridge et al. (2005) and Sainas et al. (2016) speculate isometric muscle activity affects physiological intensity of riding reflected in an elevated BLa.

Unlike many other sports, riding a horse limits the accessibility to potentially analyse important and active muscles due a large surface area of the lower body (*gluteus maximums, adductor magnus, hamstrings and gastrocnemius*) being in contact with the horse during ridden activities and is a limitation to investigations concerning muscle activity within this population.

2.3.9 The Use of Mechanical Horse Riding Simulators

The use of horse riding simulators (often referred to as mechanical horse simulators (MH)) range from the assessment of biomechanical profiles of riding activities (Longhurst and Lesniak 2013), the assessment or comparison of physiological variables to live horse situations (Walker et al. 2015; Ille et al. 2014; Cullen et al. 2015), and for their use in the rehabilitation and treatment in specific populations such as those with diabetes (Hosaka et al. 2010), the elderly and in patients with motor neuron defects such as cerebral palsy (Quint and Toomey 1998; Borges et al. 2011; Kim and Lee 2015; Park et al. 2015; Kim et al. 2013).

The physical benefits of hippotherapy include enhanced balance, muscle strength and co-ordination (Hosaka et al. 2010), however the risks of riding negate the use of live horses in specific populations, as such the use of a horse simulator has become an area of interest in special populations to investigate the efficacy compared to actual riding. The use of a horse simulator for the use of treatment and rehabilitations for medical concerns are not wholly relevant to this thesis and as such studies are not reviewed in detail. It is however important to note that research does indicate the horse simulators when used regularly can improve insulin sensitivity (Hokasa et al. 2010) and improve trunk flexor and extensor strength improving lower back pain and reduce fat mass in young males (Yoo et al. 2014). Additionally, the use of horse simulators have been reported to improve balance in chronic stroke patients (Park et al. 2015), improve postural control in children with cerebral palsy (Borges et al. 2011; Lee et al. 2014) and promote reductions in the risk of falling in elderly populations (Kim and Lee 2015).

The use of mechanical horse simulators in special populations have clear clinical advantages, however the efficacy of horse simulators in replicating actual riding is not as persuasive. It is important to note the range of models available regarding horse simulators, and more concernedly, the lack of reliability or repeatability trials ensuring standardisation within the methods of experiments of studies using horse simulators. As such, comparisons between research trials cannot be done with confidence and each study should be considered relative to the model used, as opposed to generalisations regarding horse simulators overall.

Ille et al. (2014) investigated the physical effort of riding compared to a live horse by analyzing the heart rate response to riding in riders jumping a course of obstacles on a show jump simulator (thirteen jumps 90-110cm) and during a show jump round (eight jumps 80-90cm) on a live horse. Ille et al. (2014) reported a lower maximal heart rate (123 beats.min^{-1}) on the mechanical horse compared to live horse testing (175 beats.min^{-1}) and concluded that the physical effort of riding a live horse was thus more pronounced than on a simulator. Although simulators were useful to identify and address the riders position, a show jump simulator was not beneficial in terms of physical fitness training.

The biomechanical similarities between a general model of riding simulator compared to live horse motion has not been investigated. Racing simulator models are commonly used to facilitate race jockey training (Walker et al. 2016) as benefits include economically intensive training sessions, reduced risk of injury to the horse or rider falls and if representative of actual riding, a greater scope to physically correct technique while improving muscle and movement-specific fitness (Bailey et al. 1997; Kang.et al. 2010; Hitchens et al. 2012).

Walker et al. (2016) investigated the kinematics and kinetics of jockeys galloping on a MK9 racehorse simulator and a live horse in n=6 male jockeys. Inertial Measurement Unit's (IMU's) were used to analyse jockey kinematics to measure displacement at the feet, sternum and pelvis of jockeys. Walker et al. (2016) concluded that a racehorse simulator did not mimic the movement trajectory of actual riding, the simulator has a more consistent pattern with less dorso-ventral and medio-lateral but greater cranio-caudal displacement. Walker et al. (2016) noted that race riding jockeys have reported that the movement of the simulator is different to that of real horses and concluded that simulator training should be used with caution since there is potential for adaption to incorrect movement patterns. Waker et al. (2016) concluded that the cranio-caudal stability of jockeys may benefit when training on a horse simulator but that lateral stability and fitness will not reap the same benefits, which is considered important for overall jockey conditioning. There were reports of smaller dorso-ventral displacements and thus associated stirrup forces on the simulator. This would limit opportunity for the jockeys to develop the ability to modulate the perturbations found in real horse. Walker et al. (2016) concluded that race riding simulators may be beneficial in developing basic technique in a safe and controlled environment, yet they are limited in their ability to develop the technical skills required.

The lack of comparability in the movement patterns between the mechanical horse simulator and to riding a live horse presumably require different amplitudes of muscular activity, and possibly different muscle recruitment. To date, research indicates that general riding, show jump and racehorse simulators have their merits in training riders but do not replicate the physiological nor the biomechanical demands of actual horse riding.

2.3.10 Strength Training Interventions

As previously intimated, an understanding of the physiological demands of a sport should be critically evaluated to ensure that strength and conditioning interventions are targeted to improve specific physical requirements. Recent research however has considered the effect of training interventions within equestrian populations regardless of this lack of evidenced based information.

Lee et al. (2015) sought to investigate the feasibility of an eight-week isometric based programme on strength increases and a standardised riding test score. This study recruited riders >40years of age, justified because of the lack of information to assist older riders with their fitness. The intervention consisted of a three day per week programme that was progressively designed over eight weeks. The programme consisted of six exercises targeting *rectus abdominis, erector spinae* and hip adductors and was implemented using body weight and TheraBands®. The intervention was designed to improve muscular fitness through moderate-resistance, high repetition movements and/or timed isometric holds (depending on the exercise). Participants logged adherence, compliance, and recorded hours per week spent riding. Although training sessions were completed at home, a familiarisation and correct form training session was conducted prior to intervention.

The strength intervention provoked significant changes in the riders muscular strength and muscular endurance, authors concluded an isometric off-horse strength based programme is more effective than an equitation based training programme for the purpose of increasing muscular strength and endurance (Meyers 2006). Lee et al. (2015) reported no correlation with the muscular endurance score to total riding test performance score and ultimately concluded that an isometric based strength intervention was effective at improving muscular strength and endurance in an older population but did not confirm any positive benefit on ridden performance. The ridden performance test had no reliability or validity trials, before an intervention can be concluded to improve performance a reliable and repeatable measure to determine equestrian performance is necessary.

Hampson and Randle (2015) considered the effects of a strength and conditioning intervention from an equine welfare rather than rider performance perspective. Their research aimed to investigate the influence of an eight-week rider core fitness programme on the pressure distribution under saddle to the equine back. Ten medium level DR riders (8 female, 2 male; mean age 41.5±14.83 years; rider body mass= 69.28±14.04kg) participated in this study; riders completed a 20 minute video designed by the author. The programme was body weight based including core strengthening, hip stability exercises and stretches and was implemented for eight weeks. The paper lacks clarity in terms of how many times per week riders were expected to complete the video, and how participant adherence was monitored which would affect results. The efficacy in improving core strength was also not corroborated by any field based tests to compliment the live horse testing. Interestingly, this study demonstrated that an 8-week core fitness programme had a significant effect on the evenness of the left-right dynamic pressure distribution on the equine back. In terms of equine back health this study has important implications and further suggests that riders should complete off-horse strength training interventions, not only to improve their own health, but that of their horses too.

Ultimately, the research to date considering off horse strength training interventions are limited by factors such as small sample sizes, lack of control groups and limited measures to assure validity and reliability and relevance to on horse performance.

2.4 Performance Related Fitness

Physical fitness test batteries are a series of tests grouped into one testing session to quantify performance related fitness in a specific group of athletes. Tests should have relevance to supposed sport specific physiological attributes and should be able to predict performance since the purpose of fitness test batteries is to determine if specific variables can be attributed to enhanced performance levels (Platzer et al. 2009). The design of a fitness test battery is generally supported by investigations into the physiological demands of that sport.

The comparability in research design approaches that include fitness test batteries, is that all tests commence in a short frame of time, usually a single day but occasionally over two (Zabulovek and Tiidus 1995; Roetert et al. 2006; Duncan et al. 2006; Tan et al. 2009; Enemark Miller 2009). Some research groups leave more time in between testing (90 minutes per test over a 9 hour testing day) (Zabulovek and Tiidus 1995); whereas others complete testing over a period of hours with only five minutes between tests (Duncan et al. 2006), usually leaving a longer duration between anthropometric and strength testing and the final maximal exercise test. Some research groups choose to test anthropometric and strength measures on one day and follow on a separate day with the maximal exercise test (Tan et al. 2009; Platzer et al. 2009). With regards to test order, the tests that require the least physiologically demanding are placed first (e.g. anthropometrics) followed by tests for flexibility, strength, reaction time and agility and finally where applicable, the exercise test to determine maximal aerobic capacity (ACSM 2009).

There are two common approaches to data analysis, these being averaging three trials for each test (Enemark Miller 2009) or selecting the best result from three trials (Duncan et al. 2006). The reliability and validity of test selection is important, and where applicable pre validated tests are chosen for inclusion in a fitness test battery. Some studies also included test re-test reliability analysis within their methods (Tan et al. 2009), particularly where novel tests were selected.

The implementation of a fitness test battery can be used to describe fitness characteristics in a population of athletes and also to determine fitness characteristics that are discriminators between level of performer. Platzer et al. (2009) noted that when training elite athletes, testing is imperative and the testing battery should correlate to performance. Assessing fitness test performance to competitive performance is done using two common approaches, by selecting different levels of performer based on competitive level and grouping them accordingly within the research design (Roetert et al. 1996) or by correlating test battery component performance to official competitive rankings (Enemark Miller 2009). Given the complexities of a rider being able to compete with different horses at different levels in equestrian sports, selecting the highest competitive level of a rider for grouping purposes is considered appropriate.

2.4.1 Physical Test Selection for the Event Rider

Test selection in a physical fitness test battery is individual to the requirements of the sport, and thus there is less comparison in terms of research design between fitness test batteries and differing sports. Many test batteries include anthropometric measures of height and body mass and usually include body composition assessed using skinfold methods (Duncan et al. 2006). The majority of fitness test batteries include a test to determine maximal aerobic power since aerobic fitness is a component required in many athletic activities (Duncan et al. 2006; Platzer et al. 2009). The remaining tests are usually considered sport specific where traits that are transferred from a test environment to an athletic setting are included, for example testing for maximal explosive power is perhaps not an appropriate measure for an equestrian and more suited to sports such as sprinting. Performance tests are often novel, and reflect the physiological demands of a particular sport. For example, in Water Polo participants completed an in water vertical jump test, a 10m maximal swim sprint and a multistage shuttle swim test (Tan et al. 2009) and in a population of snowboarders, a snowboard start simulator test has been used (Platzer et al. 2009).

As highlighted in the prior section detailing equestrian specific literature, there is limited evidence based information that currently describes the physical characteristics and performance traits necessary for success for an Event rider. Though not validated by academic investigations, it has been suggested that equestrian sports (Houghton Brown 1997; Von Dietze 1999; Bompa and Haff 2009) require strength of the core and lower body musculature, balance, quick hand eye co-ordination and flexibility and are deemed appropriate physical fitness traits suitable for further preliminary explorations in a physical fitness test battery. Since there is minimal information to base the design of a fitness test battery, it seems practical to explore tests that investigate suggested components necessary for riding success to determine if competitive level discriminates between test outcome and success.

As detailed within section 2.3, equestrian literature has so far considered anthropometric measures such as stature and mass in addition to measures such as of BMI (Meyers and Sterling 2000; Roberts et al. 2010; Hobbs et al. 2014; Beale et al. 2015), percentage body fat (Alfredson et al. 1995; Meyers and Sterling 2000; Roberts et al. 2010, Cullen et al. 2015) and additionally posture (Hobbs et al. 2014). The BMI of horse riders is reported at the upper limit of a normal weight range or within the overweight category. Unlike other athletes, the body composition of horse riders does not appear to be as impactful to successful performance (Garlinghouse and Burrell 1999); that stated, increased bodyweight of a rider has been evidenced to increase physiological responses of the horse (Stenfansdottir et al. 2017). From the available literature, it has been recommended that horse riders require a good aerobic fitness foundation (Westerling 1983; Meyers and Sterling 2000; Devienne and Guzennec 2000; Roberts et al. 2010; Beale et al. 2015; Sainas et al. 2016) and as such aerobic fitness in horse riders has been assessed by maximal oxygen uptake (Westerling 1983; Devienne and Guzennec 2000; Meyers and Sterling 2000; Beale et al. 2015; Cullen et al. 2015; Sainas et al. 2016).

It appears from the current literature (Meyers and Sterling 2000) that increases in strength (assessed via press ups, curl ups and grip strength) are observed with exposure to riding activities, which is suggestive that strength may increase with level of ridden performance, but to date this has not been supported within the literature. High degrees of absolute muscular strength have not been considered an attribute for successful performance in horse riders (Alfredson 1998; Meyers and Sterling, 2000), though increased strength of the quadriceps and hamstrings measured using isokinetic dynamometry has been reported in riders compared with control groups (Alfredson et al. 1993). Interestingly, isometric measures (other than grip strength) have yet to be investigated within an equestrian population and considering there is an isometric component required during riding (Terada et al. 2004; Trowbridge et al. 2005; Sainas et al. 2016), it seems pertinent to identify whether enhanced isometric strength discriminates between performance in Event riders.

Flexibility, balance and hand eye co-ordination are less investigated variables within current equestrian literature, and where they have been included, some measures are not entirely appropriate for a test battery mostly due to not being able to be measured within quick succession of other tests which is usually a design consideration when choosing appropriate tests. Hobbs et al. (2014) investigated flexibility in DR riders using trunk ranges of movement and an infra red three dimensional biomechanical data capture set-up to measure lateral bending and rotation in a seated position on a horse model. Though this is a sport specific investigation, it is not a measure that can be easily conducted, for example by coaches and trainers to asses performance or adaptation to training. As such, flexibility measures that are more practicable to conduct such as sit and reach test protocols are frequently used within the literature (Hoeger and Hopkins 1992) particularly where trunk and hip flexibility are suggested as a required fitness component within equestrian sports.

Despite assumptions that physical fitness characteristics may affect a rider's performance, there has been limited investigations regarding the association of such traits between Event riders competitive level. Chapter Three reviews literature regarding test selection and presents justification for test selection and design for a fitness test battery suitable for an Event rider sample population.

2.5 Sports Specific Physiological Testing

It is well established that a thorough understanding of the physiological demands of a sport should be critically evaluated to ensure that sport specific training programmes are targeted to improve specific physical requirements (Deutsch et al. 1998; Cunniffe et al. 2009; Platzer et al. 2009). Maximum benefits are obtained when the training stimulus mimics or overloads the physiological performance conditions (Deutsch et al. 1998). Many authors have recognised and made specific references that scientific investigations to determine physiological demands are integral and necessary to identify general fitness, to monitor training progress, and for the development, prescription and execution of successful training interventions (Deutsch et al. 1998; Bangsbo et al. 2006; Platzer et al. 2009).

The common methodological approach to determining physiological demands of sports is a two stranded research design, whereby participants complete a specific sporting activity for the assessment of physiological demand and also a laboratory exercise test (Voigiatzis et al. 2002; Draper et al. 2008; Draper et al. 2010) or laboratory validated field test (Montgomery et al. 2009) to provide a relative to maximum expression in the field. There are some restrictions to in field testing, such as use of equipment or access to the athlete during competition, and as such research design is adapted and often data collection methods may not be the most desirable from a standardisation perspective but are the most applicable and practicable to the situation (Montgomery et al. 2009). The laboratory test usually consists of a maximal exercise test to attain $\dot{V}O2_{max}$ (Florida-James and Reilly 1995) on TM (Draper et al. 2008; Draper et al. 2010) or CE (Voigiatzis et al. 2002; Spiering et al. 2003; Kottinen et al. 2007) modes, however some literature has used tests such as the YoYo intermittent recovery test (Montgomery et al. 2009) to establish heart rate maximum and to estimate peak oxygen uptake.

The physiological measures that will be able to be explored will depend on the experimental design, a non competition environment will allow for increased standardisation and control for test variables with the potential for a data set that is more reliable. In a non-competitive environment, there is an opportunity for more detailed variables to be measured such as oxygen uptake which is complementary to measures that are more applicable during competition environments, such as blood lactate and heart rate. That said, a true understanding of the physiological demands a rider is subjected to during competition requires the psychological element actual competition allows, which is not necessarily replicated by a simulated competition set-up. The balance between standardising variables and validity and reliability of the data set and collecting responses to competitive situations is complex. Limitations in standardisation of experimental variables exposes the research for a plethora of factors that may affect the interpretation of the data, yet data is reflective of the competition scenario. As such, a combination of testing to include physical and physiological testing within a laboratory setting, complemented with a research investigation during actual competition in addition to trial and live/mechanical horse test protocols was considered an appropriate approach to establish the physiological demands of Event riding. Common measures used to investigate the physiological demands of sporting activities include measurements of heart rate, blood lactate accumulation and oxygen uptake and as as these measures are utilised multiple times throughout this thesis, their use within research are reviewed within this section.

2.5.1 Measurement of Heart Rate

In the field, physiological testing is commonly assessed by monitoring heart rate based upon its relationship with oxygen uptake at submaximal workloads (McArdle et al. 2001). Intensity of exercise is commonly assessed as a percentage of heart rate maximum (Florida-James and Reilly 1995; Capranica et al. 2001; Spiering et al. 2003; Krustrup et al. 2005; Tessitore et al. 2006; Draper et al. 2008; Veale and Pearce 2009; Montgomery et al. 2009; Draper et al. 2010) or catergorised into heart rate zones to establish exercise intensity (Deutsch et al. 1998; Spiering et al. 2003; ACSM 2009).

The use of heart rate to investigate physiological demand in sporting activities is often selected based upon the ease of measurement, the ability for modern systems to measure values over extended durations and the indication that heart rate has of the relative stress on the cardiopulmonary system during physical activity. The use of heart rate as a measure is often selected based upon the relationship between heart rate and oxygen consumption (Arts & Kuipers 1994). It is important to consider when selecting to use heart rate that it is affected by the amount of active muscle mass and the type of activity (continuous or intermittent). An athlete's heart rate can also be affected by factors including; overtraining syndrome (Jeukendrup and Van Diemen 1998), exercise mode and position (Jeukendrup and Van Dieman 1998) and adrenaline (Ensigner et al. 1993) which should be accounted for in the design or interpretation of the results. As such, it is common to asses physiological demand using heart rate in addition to other markers of exercise intensity, such as blood lactate concentration and rating of perceived exertion.

When varying conditions are expected during exercise a high frequency of sampling to capture regular changes of intensity are necessary. Heart rate averaged over a 5 second interval or less avoids spectral distortion and diminishes the frequency content of heart rate signal and excludes the indications representing rapid changes in heart rate (McCarthy and Ringwood 2006) and a 5 second sampling rate or less is considered appropriate for recording heart rate at all exercise intensities. The use of a 5 second heart rate sample is consistent across the literature in soccer (Capranica et al. 2001; Krustrup et al. 2005; Tessitore et al. 2006), hockey (Boyle et al. 1994; Johnston et al. 2004) basketball (Rodriguez-Alonso et al. 2003; Abdelkrim et al. 2007) and rugby (Deutsch et al. 1998) and as such sampling frequency of 5s or less is appropriate during research investigations.

2.5.2 Measurement of Blood Lactate

Blood lactate concentration is another physiological variable regularly assessed in field to determine the anaerobic glycolytic energy contributions of a particular exercise (Guitérrez Rincón 1992; Deutsch et al. 1998; Jemni et al. 2000; Matthew and Delextrat 2009). In competition, data collection is manipulated to fit with the competition structure e.g. assessed at baseline, quarters or half times (where applicable) and post competition using portable blood lactate analysers (Florida-James and Reilly 1995; Deutsch et al. 1998; Spiering et al. 2003; Veale and Pearce 2009). Documented times to sample blood post competition are varied throughout the literature; some experiments have reported measurements to be immediately upon completion of exercise (Voigiatzis et al. 2002), others three minutes post competition (Florida-James and Reilly 1995; Voigiatzis et al. 2002) and in some occurrences durations of fifteen minutes post competition (Draper et al. 2008; Draper et al. 2010), the post competition sampling duration and frequency must be considered in the design and discussed in the interpretation of the findings.

Portable blood lactate analysers permit blood lactate concentration to be sampled in the field and during competition. There are many brands available on the market (Medbo et al. 2000), with high correlation to laboratory methods (McNaughton et al. 2002) and is a suitable choice during field and lab based protocols to ensure consistent protocols in both the test situations.

Blood lactate can be sampled in a number of locations of competitive athletes, commonly the fingertip or earlobes. Dassonville et al. (1998) conclude that lactate values may differ depending on the sampling site and the type of exercise mode and as such for all studies a single location was necessary. Earlobe sampling sites are commonly selected in sports where the hands are frequently used, such as ball sports (Deutsch et al. 1998; Jemni et al. 2000; Matthew and Delextrat 2009). An ear capillary sample is considered appropriate in an equestrian sample as riders are often wearing gloves and will need to immediately post sampling use their hands on their reins to obtain control of the horse.

2.5.3 Measurement of Peak Oxygen Uptake

The upper limit of oxygen consumption is defined as the maximal oxygen uptake ($\dot{V}O_{2max}$) (Astrand et al. 2003), habitually it is regarded as a gold standard method for assessing cardiovascular function and cardio-respiratory fitness, and best defines the functional capacity of both the cardiovascular and pulmonary systems (Eston and Reilly 2009b). Measures of maximal oxygen uptake are important in understanding differences between fitness levels of groups of athletes and requirements of sporting activities and was a justification for its selection in assessing physiological performance within this thesis. Maximal oxygen consumption ($\dot{V}O_{2max}$) has been determined using numerous exercise modes that activate large groups of muscle mass, provided the intensity of effort and protocol duration are sufficient to maximise aerobic energy transfer (McCardle et al. 2001). The terms peak oxygen consumption and maximal oxygen consumption are often used interchangeably, yet it is important to note the clear distinctions between them. It is easier to define and determine $\dot{V}O_{2peak}$, but its relevance to physiological functioning is less reliable. Simply put, $\dot{V}O_{2peak}$ is the highest value of $\dot{V}O_2$ attained during a particular test to bring a participant to volitional exhaustion, without considering the frame of reference chosen for the determination. Essentially, it does define the highest value for that participant during a particular effort but it does not necessarily define the highest value attainable by them (Day et al. 2003). In an attempt to quantify effort, other criterions have been introduced such as a maximum heart rate more than 90% of maximum, a respiratory exchange ratio greater than 1.15 and a peak post-exercise lactate of greater than 8mmol.l^{-1}. Although these assure intensity, there is no guarantee that maximal oxygen consumption has been attained, though it can lend to a greater understanding of a persons physiological functioning. Unless there is demonstrable evidence that the plateau criterion for maximal oxygen consumption has been met then the value maximally attained should be reported as peak oxygen consumption.

2.6 Factors Affecting Physiological Mechanisms

When investigating the physiological demands of a particular sport, due attention must be given to associated factors that affect physiological mechanisms that are being assessed, in addition to physical exertion. This is particularly so when the environment has less ability for variable control and standardisation, such as within competition. The delimitations section set the boundaries and the context for this research outlining the parameters that were to be investigated. Within this thesis, common measures include heart rate, blood lactate concentration and peak oxygen uptake and thus reviewing factors that may affect these variables aside from physical exertion itself are important to the interpretation of the data collected. As such, this section reviews factors that may influence physiological data, such factors undoubtedly include the competition environment itself and associated competition anxiety. Additionally in an equestrian specific content, there are potential heat stress contributors that might affect physiological responses and thus interpretation of demands of the sport. Potential heat contributors include variables such as protective clothing and notably the horse itself, and whilst there is limited available research to critique in this specific population, this section aims to review potential contributors to increased physiological variables in addition to physical exertion itself.

2.6.1 Competition and Hormonal Considerations

A competition environment increases an athlete's arousal levels and associated competitive anxiety and as such is a strong motivator for increased performance. There have been several theories to describe the intricate inter-relations between cognitive anxiety, physiological arousal and athletic performance (Hardy et al. 2007). During research explorations, considering the autonomic reactions (involuntary and unconscious responses of the internal organs) is a favored approach when investigating the physiological response to psychologically stressful situations as they are mediated by the peripheral aspect of the nervous systems. Stressors in humans evoke autonomic reactions and should be considered when investigating and interpreting results during competitive environments.

The stress response to competition has received research attention since the psychological stress an athlete is exposed to affects the physiological response (including elevated rating of perceived exertion (RPE), heart rate, and cortisol responses) and thus the interpretation of the physiological demands of competitions (Fernandez-Fernandez et al. 2014). During exercise, the body is subjected to physical stress, during a competition environment there is the additional introduction of emotional factors, which can additionally affect the physiological response of an athlete. It is well known that competition environments can induce anxiety and anticipatory changes in many of the cardiovascular and respiratory parameters in athletes. In certain situations, hormonal and metabolic responses can be altered from those usually seen during exercise of a non-competitive nature (Viru et al. 2010). Having a thorough understanding of the physiological demands is important for the specificity of science application and thus exercise and training prescription, yet the effects of competitive situation affecting physiological demands and thus interpretation is not as well documented.

Eventing, as a mixed species sport is undeniably dangerous and is classified as a high risk sport (Thompson and Nesci 2016) and is therefore associated with high levels of competitive anxiety, as assessed using survey approaches to quantification (Wolframm and Micklewright 2010). Anxiety can be considered a biological warning system, and according to neuropsychological theories, when a situation is considered threatening, to prepare the body for reaction a cascade of autonomic responses occur, such as elevated physiological mechanisms including increased heart rate, blood pressure and sweat gland activity to prepare the body for action.

Circulating catecholamines have been a biomarker for anxiety during training and competition environments in sporting activities (Williams et al. 1978); the stress hormones, adrenaline (epinephrine) and noradrenaline (norepinephrine) are responsible for many adaptations at rest and also during exercise. Adrenaline and noradrenaline are involved within the processes of cardiovascular and respiratory adjustments during exercise and as such it is important to consider the effects of stress and the effects this may have on the physiological responses to exercise. Catecholamines influence the cardiovascular system and metabolism enabling the body to function during stressful situations, catecholamine release is also anticipatory and can influence pre competition elevation in heart rates (Zohaul et al. 2008)

Circulating catecholamines indicate psychic stress during competition as they are reported to be elevated in comparison to other markers of physical stress such as blood lactate. In badminton players, during competition, players showed similar adrenaline and noradrenaline affects to an intensive training session, whereas lactate levels were ~ three times lower (Weiler et al. 1994). It is well established that circulating catecholamines are elevated in response to the psychic stress that occurs during competition (Baumingather et al. 1988; Dimsdale et al. 1980) and under normal conditions, stress is considered a primary factor in catecholamine secretion (Zohaul et al. 2008). Cathecholamines have been reported to stimulate respiratory, cardiovascular, metabolic and thermoregulatory function, they act to permit prolongation of physical exercise and play an important role in the oxygen and energetic substrate transportation to working muscles. When beta-blockers are used to inhibit catecholamine secretion in athletes, reduced maximal oxygen uptake and resultantly endurance performance is affected. There have also been reports of lower blood pressure and additionally lower heart rates at rest and during exercise when catecholamine secretion is blocked (Zohaul et al. 2008). This information supports that secretion of chatecholamines during competition are of benefit to the athlete physiologically.

The sympathadrenal response to exercise varies depending on the characteristics of physical exertion that occurs, for example, the position of an athlete or the muscular requirements can directly affect catecholamine secretion. The increase in adrenaline and noradrenaline related to oxygen uptake and heart rate are particularly important during isometric exercise; during static exercise there is additional physical stress in the form of hypoxic stress where intra-muscular blood vessels are constricted. During dynamic exercise it is well reported that circulating cathecholamines increase, and this is also the case for static exercise (Vecht et al. 1978). During dynamic exercise catecholamines do not increase significantly if heart rate does not increase over ~30 beats.min^{-1} or approximately 30% of $\dot{V}O_{2max}$. Where heart rate strongly increases during exercise irrelevant of other physiological measures, marked increases in adrenaline and noradrenaline have been reported (Banister et al. 1972), and elevated heart rates in relation to other physiological variables of oxygen uptake and blood lactate concentration are reported during isometric exercise (Sheel et al. 2003).

Any stressing situation can have the potential to elevate circulating catecholamines, an experimental situation as well as competition environments will likely affect the secretion of adrenaline and noradrenaline based upon unfamiliar surroundings, new test equipment and exercising in front of a research group (Zohaul et al. 2008). To account for stress responses upon physiological variables, the adrenaline and noradrenaline basal concentrations should be measured pre and post exercise to determine stress affects on the physiological responses. Where this is not appropriate nor possible, the potential affects of circulating catecholamines should be considered when interpreting physiological data. Habituation in the realisation to a test environment has been reported to reduce adrenaline concentration (Sheurink et al. 1989), familiariation of a test situation can directly influence circulating catecholamine responses to exercise (Zohaul et al. 2008) and is a standardisation measure that should be considered when designing experimental trials.

In addition to catecholamines, the investigation of cortisol in sporting situations is popular since cortisol plays an important role in the physiological and behavioral response to both physical challenges and psychological stressors. Mild increases in cortisol prepare an athlete for action and lower cortisol responses can indicate resilience to stress responses (Levine 2000). The hormone is considered important in the preparation for physical and mental demands and ultimately concluded to affect physical performance (Salvador et al. 2003), yet too high a concentration can lead to poor performance and interference with cognitive processes (Erickson et al. 2003). Cortisol once released is taken up by a variety of tissues and its presence is used to mediate exercise capacity. In situations where high levels of cortisol exist, gluconeogenesis can occur providing additional carbohydrate for energy production (Viru et al. 2004).

There is much controversy surrounding optimal cortisol production in relation to performance, female rugby players for example have reported lower cortisol in the winning teams compares to higher cortisol in the losing teams (Bateup et al. 2002); the general consensus amongst the literature is that with competition there are elevations in salivary cortisol levels (Edwards et al. 2006). Generally, increases in salivary cortisol are thought important for preparing for physiological and mental demands, however extreme elevations can lead to poor performance.

The investigation of circulating catechomalines during equestrian sports are absent, however, preliminary investigations in equestrian samples using cortisol as a marker for stress in the rider indicate mixed cortisol responses. Lewisnski et al. (2013) did not report any significances in horse-riders between salivary cortisol in a public or private test rehearsal. Salivary cortisol can be affected by factors such as age, oral contraceptives, gender and medical conditions and the correlation with cortisol and stress requires careful experimental standardisation. The strict standardisation process was not detailed within the work of Liewinski and those mentioned variables may well influence the data set reported. The authors also discussed the public rehearsal though being in front of an audience was a simulation environment and not competition which may have affected the cortisol response reported. Salivary cortisol in riders was also investigated by Peeters et al. (2013) during a 'home environment' SJ competition. Results indicate that riders with a greater increase in salivary cortisol level received more penalties in competition indicating that increased stress had a negative effect on performance in riders. Initial investigations concerning riders salivary cortisol in response to competition environments are in the preliminary stages and in both articles the simulation environment as a potential factor that may affect the stress response is detailed and indicates the need to actual competition based data to further understand the stress response in training versus competition.

Lewinski et al. (2013) investigated the physiological stress parameters (heart rate, heart rate variability and cortisol) of training and competition environments in horses and their riders. The increases in heart rate and heart rate variability was interestingly more pronounced in riders during the public performance compared to elevation in the horse's physiological parameters. The results of this study indicate that heart rate increases are as a result of increased physical activity, yet during public performance a decrease in heart rate variability, specifically a more pronounced sympathetic and or decreased parasympathetic activity in riders and indicated a stress response of the riders as a result of spectators.

2.6.2 Psychological Factors

The psychological factors that can affect physiological mechanisms is complex, research suggests that personality traits (particularly extroversion and neuroticism) are additionally a contributing factor to the stress and thus physiological response to certain situations. The study of personality aims to elucidate how semi-permanent traits or dispositions effect peoples lives and in the context of sport their performance. The Five Factor model of personality encompasses broad considerations of personality including neuroticism, extroversion, agreeableness, conscientiousness and openness to experiences (Wolframm et al. 2015). Agreeableness is considered a personality trait that has the potential to regulate neuroticism related distress and is be a trait associated with lower pre-competition arousal. There is also evidence suggesting a negative association between pre competition physiological arousal and the personality trait of conscientiousness. This trait has been found to be associated with lower daily cortisol concentration (Nater et al. 2010) and thus the personality of participants during research investigations may well affect the physiological responses to competitively stressful situations.

Personality of equestrians is a newly explored area and attempts to quantity the role of personality in equestrians sports was conducted by Wolframm et al. (2015). Within this study competitive riders were considered more conscientious and extroverted compared to non competitive counterparts which is congruent to literature across other sports (Wolframm et al. 2015). It was also noted that riders involved in high risk disciplines (such as Event riding) perceived themselves as less conscientious and were less agreeable than risk-aversive individuals. Later work of Hart and Furnham (2016) investigated personality and performance in Event riders and their work is agreeable with the findings of Wolframm et al. (2015) as they too reported that Core Self Evaluations (CSE), conscientiousness and extraversion were predictors of performance. Essentially, riders that are negative and inconsistent with their self views will generalise negative implications of failure and are thus resultant in lower performance. During the XC phase in particular there is usually a large audience and can affect competitors with low CSE scores. Competitive Event riders score low for agreeability and are less conscientious individuals; though there is not enough evidence to make a conclusive assumption it appears that the personality of competitive event riders would be more susceptible to enhanced physiological responses to stressful situations and is a factor for consideration when interpreting physiological data.

2.6.3 Muscular and Positional Demands

There is evidence to suggest that heart rate is affected by the muscular recruitment and thus position of the athlete, for example cyclists report higher heart rate when they adopt an aerodynamic position on the bike and when static load of the upper body is increased, in fact a dissociation of heart rate from oxygen consumption has been reported in this position and attributed to the isometric activity of the upper body (Jeukendrup and Van

Damien 1998). This attribution of isometric exercise as a causal factor for elevated heart rate is well documented (Sheel et al. 2003). This disproportionate rise in HR to $\dot{V}O_2$ is considered to be as a result of isometric muscle contraction hindering local blood flow whereas in contrast, dynamic exercise facilitates local blood circulation. The heart rate response to isometric exercise is also dependent on the size of the contracting muscles or the magnitude of muscle activation. Muscle receptors are sensitive to metabolic changes related to muscle activity, during isometric contractions of increased intensity there is increased muscle mass and individual muscle activation. As a result, the metabolite production is greater which may as a consequence increase activation of the muscle metaboreflex (Lellamo et al. 1992; Fisher and White 2004).

A disproportionate rise in HR compared with $\dot{V}O_2$ has been observed in sports where stabilisation predominates such as motor sports and water sports. The repetitive isometric contractions in these sports are thought to stimulate chemical afferents via the muscle metaboreflex, which has explained the reported heart rate-$\dot{V}O_2$ dissociation (Konittinen et al. 2002). In addition to work in motor sports there has been research in other travel sports (sailing and kitesurfing) that also report physiological data that is not consistent with findings for dynamic sports (Cunningham and Hale 2007; Vogiatziz et al. 2007; Callewart et al. 2013). These researchers identified that in sailing and kitesurfing physiological data were non linear with intensity, heart rate was higher than was needed for oxygen supply, heightened blood pressure was evidenced, along with high respiratory rates.

During an isometric contraction sustained at more than 15-20%MVC, muscle blood flow increases several times above its resting levels (Sheel et al. 2003); this increase in blood flow however, is not sufficient to meet the metabolic requirement. As as a result, there is a deficit of oxygenated blood and in turn leads to production of blood lactate. This provides some explanation to interpret an ample concentration of blood lactate during riding considering a low oxygen consumption presented. Though there are no investigations that specifically investigate total body muscle activity in riders, early work of Terada et al. (2004) does suggest isometric reliance during riding activities. Trowbridge et al. (2005) and Sainas et al. (2016) also make reference to isometric muscle work contributing to elevated physiological responses during horse riding. In accordance with the suggestion by Lind (1983) where there is prolonged isometric muscle work, higher blood lactates than what are currently reported within the equestrian literature compared with such high heart rates should be expected. Vogiatziz (2008) attributed moderate blood lactate responses and elevated heart rates in sailing to the quasi-isometric concept; this concept was first introduced by Spurway (2007) where lower blood lactates than may be expected were reported and were a result of dis-continuous isometric muscle work. In sailors specifically, the discontinuous action is as a result of muscle relaxation as a result of changing position to re-direct the boat. Spurway (2007) concluded that these periods of rest intervals would allow partial restoration of the muscles oxygen accessibility, promoting a more oxidative degradation of glycogen and low lactate concentration.

At present, it is problematic to interpret physiological data across available equestrian research studies due to methodological and sample population differences. It would be beneficial to investigate the responses of Event riding in a competition setting and a controlled setting; these two environmental situations would document the competitive demand (with limited variables to analyse) complemented by a controlled trial where more detailed measures such as oxygen uptake and muscle activity can be obtained.

2.6.4 Heat Stress

It is well documented that heat stress affects physiological mechanisms and depending on the situation can elevate metabolic rate and anaerobic contributions during exercise (Sawka et al. 1993). Heart rate is affected by thermal stressors; cardiac output must increase during exposure to heat stress to perfuse the cutaneous vasculature for heat dissipation purposes. As stroke volume is only elevated slightly, the increased cardiac output comes mostly from elevation of heart rate, this may be as a result of direct effects of temperature on the sinoatrial node or sympathetic and parasympathetic effects on the heart due to baro-reflexes or a hyperadrenergic state (Wilson and Crandall 2011). In addition to heart rate elevations, there is also evidence that supports elevations in blood lactate accumulation where athletes are exposed to thermally stressful environments (Young et al. 1985; Parkin et al. 1999). It is suggested that elevated blood lactate concentration during thermally stressful conditions are due to decreases in blood flow to active muscles because of the blood flow relocated to the skin for evaporative cooling (Ciba et al. 2011).

The higher the ambient temperature, the greater the dependence upon evaporative cooling (Sawka et al. 1993); when considering heat stress, it is important to consider the affect equestrian attire may have as a potential contributor for enhanced physiological demands placed on an equestrian athlete. The attire for Event riders will typically differ between phases; for all phases riders will be required to wear protective headwear, full length jodhpurs and full length riding boots and will generally wear riding gloves. During the DR and SJ phases a shirt and riding jacket is customary and for the XC phase the riders are additionally required to wear a body protector. As a result, nearly the entire body of the rider is covered and acts as a potential attributer for increased thermal stress throughout competition. A helmet alone can reduce evaporative cooling by 20-40% (Liu and Holmer 1995) and research has evidenced that physiological strain including heart rate and blood lactate that can be elevated in fully clothed individuals (Fogarty et al. 2005). Though there is no specific information relative to the physiological strain as a result of equestrian attire it can be assumed based on research regarding protective clothing that total body protective gear and the additional heat stress as a result of transfer between horse and rider will be a variable to consider when interpreting these physiological responses to horse riding. The use of clothing provides an insulated layer and protective clothing severely impedes heat transfer the ability to cool using evaporative mechanisms effectively (Holmer 1995; Gavin et al. 2003). The protective clothing worn during American Football covers the total body including a helmet, and although the demands of the sports cannot be compared, the literature regarding whole body protective equipment on physiological responses allows for some consideration to the equestrian context. Armstrong et al. (2010) suggest that full body protective equipment causes a microclimate above the skin, that reduces heat dissipation to the surface environment that can cause thermally related exercise exhaustion (Armstrong et al. 2010). These results are not exclusive to football, exertional heat stress and exhaustion have been reported in military personnel, and those required to wear occupational protective clothing (Armstrong et al. 2010).

Heat exposure in equestrians of course will be relative to the environment and protective clothing requirements as discussed, but additionally a unique situation for the potential of heat absorption emitted from the heat of the horse underneath the rider that must be considered when interpreting physiological responses. As previously mentioned within this review, horses principally exchange heat with their environment via sweating; the direct result of this transfer of heat energy on the physiological responses of the rider are unknown and has not been investigated. Seeing that the horse and rider are in such close contact it seems sensible to assume that demands of the rider may increase as a result of additional heat stress as a result of riding a horse that is emitting thermal energy and like protective clothing a potential opportunity for a microclimate between the horse and rider which may limit the ability for a rider to dissipate heat. Since the demand on the horse and thus heat stress increases with each phase of Eventing, the potential for heat transfer to affect the physiological demand on the rider is more likely to occur during the SJ and XC phases as opposed to the DR phase. As mentioned, the investigations of thermal stress on the rider as a result of the horse has not been investigated but is an important consideration when investigating physiological responses to horse-riding.

2.7 Summary

This review details the popularity of equestrian sports and the success of Eventing at grassroots and elite level. The national governing body for equestrian sports places an emphasis on riders committing to off-horse training to prepare for competition demands and increase athletic longevity since age is not a determining factor for reduced performance in equestrian sports. It is well recognised and highlighted within this review that critical evaluation of performance related fitness tests in addition to the development of the physiological demands in Event riders is instrumental to planning sports specific training programmes.

Literature to date indicates that as the horse and rider progress through the equine gaits (walk, trot, canter), the riders heart rate and oxygen consumption increase and within the DR phase, aerobic metabolism dominates. It is generally the faster gaits, and jumping such as in SJ and XC that require the rider to adopt a 'forward' position where the riders are then un-seated in an isometric semi-squat position, causing weight bearing to be through the rider's legs (Roberts et al. 2010). It is apparent that positional differences required for fast cantering and jumping significantly increase anaerobic metabolic system requirements with reported increases in cardiovascular load and associated increased blood lactate values (Guitérrez Rincón 1992; Trowbridge et al. 1995; Roberts et al. 2010; Perciavalle et al. 2014) and therefore greater physiological strain in these phases of Eventing can be assumed. More recent work in horse-riders is suggestive that heart rate is considerably high when compared to other cardio-metabolic parameters (Sainas et al. 2016). In addition, isometric muscle activity in non-dynamic sporting activities have too reported a high heart rate compared with other physiological markers of exercise intensity and as such heart rate does not reflect the physiological demands of those sports as a single measure. Since the equestrian research is agreeable that heart rate demands are high, and initial investigations suggest isometric muscle activity predominates it is necessary to further explore the physiological demands and muscular activity within this population. In this context, this thesis explores the physical characteristics of event riders and the physiological demands of event riding in both a competitive and simulated environment. This thesis comprises of three main research investigations which are presented as individual studies outlined in detail in the following chapters.

CHAPTER THREE: ANTHROPOMETRIC, PHYSICAL FITNESS CHARACTERISTICS AND THE TRAINING AND COMPETITION PRACTICES OF NOVICE, INTERMEDIATE AND ADVANCED EVENT RIDERS

3.1 Introduction

There is limited evidence based information pertaining to the physical characteristics of horse riders on which to establish selection of performance based tests to discriminate between level of performance, even less concerning Event riders specifically. It has been suggested that equestrian (Houghton Brown 1997; Von Dietze 1999) and other travel based sports (e.g. sailing, surfing, motor sports including horse-riding) (Bompa and Haff 2009) require strength of the core and lower body musculature, balance, quick hand eye co-ordination and flexibility and are deemed appropriate physical fitness traits suitable for further preliminary explorations.

Body composition in horse riders, with regards to BMI have been reported across the literature to be at the upper limit of a normal weight range or within the overweight category. It appears that Event Riders have lower BMI and thus lower body fat (Roberts et al. 2010) than Dressage and Collegiate riders (Devienne and Guzennec 2000; Meyers and Sterling 2000) which is also supported by reported body fat percentage, yet it would be unwise to base this assumption from one paper alone and thus warrants further investigations. Unlike other athletes, the body composition of horse riders does not appear to be as impactful to successful performance (Garlinghouse and Burrell 1999). It is important to differentiate race jockeys from this broad categorisation of horse riders however, as body composition has clear evidence to impact successful race performance (Pfau et al. 2009; Cullen et al. 2014). It would seem a sensible concept that a horse of any discipline would be able to perform better with a lower mass of rider to carry and that a reduced bodyweight would be advantageous to successful equestrian performance. Indeed, increased bodyweight of a rider has been evidenced to increase physiological responses in Icelandic horses (Stenfansdottir et al. 2017). An assessment of body composition with respect to competitive level within Event riders has yet to be determined.

From the available literature, it has been recommended that horse riders require a good aerobic fitness foundation (Westerling 1983; Meyers and Sterling 2000; Devienne and Guzennec 2000; Roberts et al. 2010; Beale et al. 2015; Sainas et al. 2016) with suggestions that riders would benefit from anaerobic training (Guiterrez Rincon et al. 1992; Trowbridge et al. 1995; Perciavalle et al. 2014; Sainas et al. 2016) to offset lactate production during equestrian activities that incorporate prolonged out of saddle situations or include jumping efforts. High degrees of absolute muscular strength have not been considered an attribute for successful performance in horse riders (Alfredson 1998; Meyers and Sterling, 2000), though increased strength of the quadriceps and hamstrings measured using isokinetic dynamometry has been reported in riders compared with control groups (Alfredson et al. 1998).

Meyers and Sterling (2000) concluded that mean values for curl up, reverse sit-up and push ups to be average to above average compared to normative values for young females for the participant age group. Handgrip strength was lower than established normative values for young females (Meyers and Sterling 2000). It appears that increases in strength are observed with exposure to riding activities, which is suggestive that strength may increase with level of ridden performance, but to date this has not been supported within the literature. Research does however indicate that isometric muscular endurance may play a role during horse riding (Terada et al. 2004; Trowbridge et al. 1995; Sainas et al. 2016) and warrants further investigation.

Horse riders have been reported to develop asymmetric postural alignment (Symes and Ellis 2009; Hobbs et al. 2014) which may be a precursor to injury but the assessment of this and the relationship to functional performance tests are yet to be established. Pelvic asymmetry develops with increased years of riding; limited lateral bending to the left has been considered to increase muscular stiffness of riders to the right. The causal factors of this limitation in left lateral range of motion, in addition to increased years of riding is attributed to a largely right handed population. This asymmetry has clinical relevance, as increased prevalence of pain has been reported in those riders that present with asymmetrical postural development, years spent riding and competitive level (Hobbs et al. 2014). Despite assumptions that physical fitness characteristics may affect a rider's performance, there has been limited investigations regarding the association of physical fitness traits between Event riders competitive level.

In addition to limited sport specific information detailing the physiological demand and physical characteristics of Event riding, there is also an absence of information pertaining to the physical activity, training and lifestyle practices of Event riders. The training and competition practices in Event riders remains to be determined, which limits the information available with regards to appropriateness of physical preparation of Event riders. Although not an Event rider specific population, the average amount of on-horse training in apprentice jockeys has been reported by Greene et al. (2013) as 24.6 ± 6.9 $hrs.wk^{-1}$ which is greater than reported for a control group, unfortunately exact activities were not specified, however it is reported that jockeys main training practices include riding horses for many hours each day (Labadarios et al. 1993, Leydon and Wall 2002) which is also documented in DR riders (Walters et al. 2008). For race jockeys, there are low reported levels of alternative physical activity in addition to riding, with only 22% of jockeys participating in other forms of exercise (Leydon and Wall 2002). Low levels of alternative physical activity was not corroborated by Moore et al. (2002) where jockeys participated in additional physical activity as a means to control body composition. Race jockeys, with body composition requirements are not directly comparable to an Event rider population, but the limited preliminary explorations regarding physical activity in horse riders is suggestive that reliance on mounted training for physical preparation in the primary mode. Seeing that literature suggests increased time on the horse as a precursor for asymmetry and injury, further research detailing the training and competition practice of Event riders is warranted to further evaluate physical fitness characteristics and physiological demand within this equestrian sport.

Due to the apparent lack of research examining anthropometric and physical fitness traits in addition to a absence of information regarding training and competition practices in Event riders the following research aims were developed.

3.1.2 Aim:

The overall aim of this study was to identify anthropometric and physical fitness characteristics and to document training and competition practices in Novice, Intermediate and Advanced level female Event riders

This study aim translates into the hypotheses as follows:

1. Event riders competing at higher levels will perform better in physical fitness test variables compared to competitors at lower performance levels.
2. Training and competition practices will differ between competitive level of Event rider.

3.2 Methods

3.2.1 Participants

Twenty-seven female Event riders, n= 11 novice, n=9 intermediate, n=7 advanced (group mean±SD age 32.3±9.9years; height 167±6.6cm; mass 65.16±8.9kg; BMI 23.2±2.6; body fat 28.8±5.42%) competing at affiliated British Eventing competitions participated in this trial, Table 3.1 details participant data by competitive level.

3.2.2 Study Design

There were two aspects to data collection required to investigate the anthropometric and fitness characteristics of Novice, Intermediate and Advanced Event riders. The first was laboratory based performance testing at the University of Worcester. The second, a questionnaire to quantify training and competition load. Specific details of the questionnaire are detailed within section 3.2.15.

3.2.3 Laboratory Measurements

The experimental protocols received Institutional Ethics Committee Approval (Appendix 3a). Prior to testing, written consent was obtained and a pre-exercise health screening questionnaire completed for all participants (Appendix 3e). Each participant wore light athletic clothing.

3.2.4 Fitness Test Battery

All participants were advised to report to the laboratory rested, euhydrated and at least 3 hours following the consumption of a light carbohydrate based meal and to avoid smoking and drinking both caffeine and alcohol. They were also asked to continue with their normal diet (Winter et al. 2007). The order of tests were as follows: Standard anthropometry, balance test, hand eye co-ordination, handheld dynamometry, wall sit, press ups, plank, sit and reach test, isokinetic dynamometry. One-hour post testing on the isokinetic dynamometer a final test was a combined test to determine lactate threshold and peak oxygen consumption on a cycle ergometer. The order or tests were designed to place the most physiologically demanding last as outlined in the ACSM Manual (ACSM 2009).

3.2.5 Anthropometric Measurements

Hydrodensitometry is considered the gold standard measure of assessing body composition in a laboratory environment (Eston and Reilly 2009a), and excellent reliability patterns have been reported using air displacement plethysmography (Noreen and Lemon 2006). In addition to hydrodensitometry and air displacement plethysmography, dual x-ray absorbitometry (DXA) has also been considered as a valid tool for analysis of body composition (Khort 1998). It is apparent that densitometry, air plesmography and DXA methods of measuring body composition have their limitations, but are considered amongst the best methods for estimation of body fatness. There is accessibility logistics to consider when considering use of these methods, as many laboratories may not have access to such advanced equipment. The importance body composition has to the research aim should be considered when selecting the method to report body composition. Often when body composition is being reported to asses sporting performance rather than clinical studies, more practical methods may be utilised. These methods use equations that represent empirically derived mathematical relationships between measured parameters and per cent fat outlined by more advanced methods (such as DXA and underwater weighing). Derived by regression analysis, these measures are more vulnerable to errors and assumptions, however these methods are quick, have low expense, can often be field based, and easy to replicate with an athlete population and was a justification for the use of skinfold to assess body fat percentage in this thesis. Skinfold measures as used by Roberts et al. (2010), Beale et al. (2015) and Cullen et al. (2015) are widely incorporated in both research and practice environments as skinfold measures provides an inexpensive, quick tool to estimate body fat percentage.

In view of complexities surrounding per cent fat prediction from skinfold thickness, guidelines have been formulated to estimate per cent fat in particular populations, derived from sample characteristics. It can be considered better to use equations with skinfold sites that include arm, leg and trunk measures. The value of adding lower limb to the sum of upper body skinfolds have been confirmed using DXA (Eston et al. 2005)

Three widely used skinfold prediction equations were developed by Durnin and Womersley (1974), Jackson and Pollock (1978) and Jackson et al. (1980), validated by hydrodensitometry. As these equations are based on assumptions it is important to note that there are significant variations in hydration levels and mineral content between participants age, gender, ethnicity and training status. There have therefore been new equations using a four compartmental model as the criterion, compared to the previous literature (Peterson et al. 2003) and have been reported as more accurate that the three previous studies (Eston and Reilly 2009a) and as such was selected as the chosen estimation equation for body composition for this thesis as it was able to accurately predict body fat percentage when compared with the same population sample for hydrodensitometry results (Peterson et al. 2003).

Body composition using surface anthropometry was used in this study. Percentage of body fat was calculated using the sum of four skinfold measurements (SUM4SF). Skinfold measures from the triceps, subscapular, iliac crest and front thigh using a Harpenden Skinfold Calipers (British Indicators, Hertfordshire, UK) were taken using previously established guidelines (Olds et al. 2006). Three measures from each site were sampled and averaged. To estimate percentage body fat, the equation as described and validated in female populations by Peterson et al. (2003) was used where;

$$\%Fat = 22.18945 + (age \times 0.06368) + (BMI \times 0.60404) - (Ht \times 0.14520) + (\Sigma 4 \times 0.30919) - (\Sigma 4^2 \times 0.00099562)$$

Where Ht, is height in centimeters and Σ4 = SUM4SF. BMI was calculated using the following equation: $BMI = weight/height^2$.

A stadiometer was used for the assessment of stature (SECA 217, UK). The participant was asked to remove their shoes and stand erect with heels together and arms hanging naturally. Heels, buttocks and scapulae were aligned with the vertical wall. The participant was positioned with their back against the stadiometer, heels together on the stadiometer foot board, looking straight ahead and measurement was taken at the point of maximal inhalation. Stature was measured to the nearest 0.1cm (Winter et al. 2007). Three measurements were taken and an average was calculated.

Body mass was measured to the nearest 0.1 kg, wearing light exercise clothing and no footwear on a calibrated scale (SECA 877, UK). Participants were asked to stand evenly on the scale until instructed to step off the scale. Three measures were taken and an average was calculated.

3.2.6 Single-Legged Blind Balance

The single leg balance test is popular in physical test batteries due to the nature of unilateral support required in many daily activities and sports and are often implemented as an assessment within training programmes with the aim to optimise performance, prevent injury and provide rehabilitation. The single leg stance requires activation of the hip abductors, which provides stability to the pelvis. The pelvis is balanced by co-contraction of the ipsilateral and contralateral adductor and abductors (Riemann 1999). Considering the suggested requirement of pelvic stability and independent lower limb movement required during equestrian activities, a method to measure single leg balance in this population of athletes was justified.

The Balance Error Scoring System (BESS) is a clinical field test which was originally developed to provide an objective and inexpensive way to assess postural stability outside the laboratory in a field based setting (Bell et al. 2011). It is based on descriptive parameters that allow the participant to collect a score or time to error that can be recorded using the balance error scores and termination of testing. Errors include: lifting hands off the iliac crests, opening of eyes, stepping, stumbling or falling, lifting the foot or heel (Riemann et al. 1999; 2000) Reimann et al. (2000) reported the BESS as a valid and reliable tool for interpreting postural stability when correlated to analysis using a force plate and as such was selected to measure single leg balance. Typically, the test includes, double and single leg balance tests on both hard and dynamic surfaces in a randomised order. When incorporating tests within a test battery situation, the length of time must be considered and evaluated against the importance of the test in question (Bell et al. 2011). Therefore, within this chapter, only the single leg, hard surface test was considered, the BESS criteria was used to define test termination as opposed to accumulating a test score.

Single leg balance was measured by time to task failure on the blind single leg task. Participants were instructed to stand as motionless as possible with their shoes on, on a firm un-carpeted surface whilst maintaining their hands on the iliac crests and their non-dominant limb in 30° of hip and knee flexion and closed eyes as outlined by Reiman and Schmitz (2012). Participants were instructed to perform one short (seven second) practice trial. Thirty-second rest periods were allotted between trials by allowing the subject to touch down their contralateral limb. Participants were allowed three timed trials on each leg, interchanging dominant with non-dominant limb. Leg dominance was defined as the preferred leg to use while kicking a ball (Riemann and Guskiewicz 2000; Bell et al. 2011). Three measures from each limb were sampled and averaged.

Task start was considered when the participant had the contralateral limb in 30° of hip and knee flexion, eyes were closed and hands were on the iliac crests. Termination was considered when compensatory events occurred included lifting the hands off the iliac crests, opening the eyes during eyes closed trials, stepping or stumbling, moving hip into more than 30° of flexion or abduction, and lifting forefoot or heel (Reimann and Schmitz 2012).

3.2.7 Hand Eye Co-Ordination

Sport vision trainers have received minimal attention in academic press, however, the specificity of their use in sporting populations, and the ease of test administration makes this type of testing a favorable choice when considering test of choice within a large physical test battery. Specific diagnostic tests of psychomotor abilities and visuo-motor skills, such as sport vision trainers are useful in identifying individual differences in human behavioural performance and general hand eye co-ordination abilities (Vesia, Esposito et al. 2008). Studies in other fields have identified incremental predictive validity of psychomotor tests for rapidity of skill acquisition and reported such tests to improve predictions of training performance based solely on cognitive abilities (Johnston and Catano 2002). Practical applications may therefore be prevalent if performance on visuo-motor tasks can be predicted, as individuals who possess the ability to process and respond to visual information quickly may be able to gain an advantage (Akarsu et al. 2009). Equipment has been developed to measure and enhance hand eye co-ordination such as the Batak wall. Ellison (2015) documented that a Batak Wall sport vision trainer correlated to task performance (wall catch, grooved peg board, SVT sport vision trainer and visual search performance tests) in n=85 sports participants (male n=57; female n=28). The research of Ellison (2015) concluded that Batak Wall apparatus may contribute to psychomotor assessment and be useful for effective selection and identification of individual differences in general hand eye co-ordination abilities. There are known limitations regarding the use of such sport vision trainers, such as the lack of reliability and validity trials concerning the Batak wall and other sport vision assessment modes, but the relationship of this method with the ability to identify general hand eye co-ordination abilities justified the use of this method within this physical test battery.

Participants stood relaxed approximately one meter in front of the Batak™ board. Twelve polycarbonate high impact resistant and high intensity LED cluster targets were attached to a strong tubular frame (2.08 m (width) x 0.95 m (depth) x 1.95 m (height) (see Figure 3.1) A sixty second protocol was initiated in which LED`s were lit in a random sequence. The participant was instructed to successfully identify and strike each stimulus before it changed position. Once a target was struck the Batak™ program immediately lit the next target. Each participant was permitted one attempt for familiarisation, then three consecutive 60s attempts were completed. The number of lights extinguished was recorded for each attempt with a mean of the three attempts recorded for data analysis as per Ellison (2015).

Figure 3.1: Batak^{TM} Board (Batak 2015)

3.2.8 Sit and Reach Test

The sit and reach test is a measure of hamstring and lower back flexibility (ACSM 2009) and is present in many health related fitness test batteries because of the role that increased hamstring and low back flexibility has on the prevention of acute and chronic musculoskeletal injuries, postural deviations, gait limitations, and risk of falling (ACSM 2009). The validity and reliability of sit and reach test protocols have been reported (Hoeger and Hopkins 1992), the most common assumption when interpreting sit and reach flexibility test results are that participants with better scores possess a higher degree of trunk and hip flexibility than those with low scores (Bandy et al. 1998). Trunk and hip position have been reported to be an indicator of elite performance in riders (Lovett et al. 2005) and so this test was selected to measure hamstring flexibility within an equestrian population.

The sit and reach test was performed using the procedures outlined in the American College of Sports Medicine manual (ACSM 2009). A standard sit and reach box was placed on the floor. Three trials were performed and the average of the three trials were used for subsequent analyses. Attempts which did not make the toe line were recorded as negative reach scores and reaches beyond the toes were recorded as positive scores. The participants sat with their feet approximately hip-wide against the testing box. They kept their knees extended and placed the right hand over the left, and slowly reached forward as far as they could to the nearest 0.5 cm using the scale on the box.

3.2.9 Isokinetic Dynamometry

Traditionally one repetition maximal (1RM) testing has been the standard measure for dynamic muscular strength in both the upper and lower body (Braith et al. 2003). The 1RM is the greatest resistance that can be moved through a full range of motion. However, 1RM testing may not be recommended for some populations including the un-trained, sedentary, elderly and cardiac patients. For these populations other options include, muscle function tests, 1RM prediction equations or isokinetic dynamometry (ACSM 2009).

Isokinetic dynamometry has widespread applications in sport, exercise and also pathological conditions for measures of muscular strength, the assessment of training and the prediction of sports performance (Balzopoulos 2008). There are many factors that can affect measurements and as such potential methodological problems, for example participant positioning and joint alignment requires protocol standardisation. Correction methods have been devised for the effects of gravitational moment and must be used routinely (Baltzopoulos 2008). Good test reliability (Kramer 1990; Kannus 1994) permits widespread application of isokinetic dynamometry for muscle testing. The studies which have examined the accuracy of peak torque, work and power have shown correlation coefficients between 0.93 and 0.99 (Magnusson et al. 1990). Advantages to using this equipment for dynamic muscle testing is that it produces maximal loading throughout the range of motion, and that it is objective, reliable, and quantifiable. Many studies have reported high correlation between isokinetic measurements and isokinetic performance such as sprinting (Delecluse et al. 1995) and swimming (Mookerjee, 1995). The reliability and validity of isokinetic dynamometry made it an appropriate measure to asses strength within this thesis. The overall design of the fitness test battery, in terms of test duration and application to the field must be considered. As such, strength of the knee flexors and extensors in an equestrian population was assessed using isokinetic dynamometry in addition to methods that are more applicable to in field based measures to asses core and upper body strength.

Dynamic leg strength was assessed using an isokinetic dynamometer over more traditional 1RM, this method of testing in addition to previous advantages was adopted due to the untrained equestrian participant population, and strong validity and reliability of isokinetic dynamometry as a measure to asses strength. Isokinetic concentric and eccentric knee extension peak torque (N) were measured using a Cybex isokinetic dynamometer (Cybex International, Medway, MA). After calibration of the dynamometer, participants were seated in the adjustable chair and the thigh, hip, and chest were stabilised using straps. The axis of rotation of the knee joint was aligned with axis of the dynamometer lever arm. The force pad was placed 3–4 cm superior to the medial malleolus with the foot in plantigrade position. Participants performed 4 sub-maximal repetitions, before completing 5 maximal repetitions, on each leg, for each contraction type, at each speed. During the testing the participants were asked to perform knee extension as forcefully and quickly as possible through a complete range of motion. Five attempts were carried out at low (60 degrees.sec^{-1}) and moderate (180 degrees.sec^{-1}) angular velocities for both concentric and eccentric muscular contractions. The low and high speeds selected were used to asses knee flexion and extension in two situations that may arose during riding; slow, for example during walk, trot and canter and high during jumping efforts. The trial proceeded from the lower to the higher angular velocity. Verbal encouragement was provided during the trials. A rest period of 2 minutes was allowed before and between the attempts. All torque measurements were gravity corrected.

3.2.10 Isometric Wall Squat

Sport specific fitness variables and resistance based training programmes often incorporate the squat as a dominant exercise as it improves muscular strength of the lower limbs and is a useful index of lower muscle strength (Demura et al. 2010). It has been suggested that exercise mode (contraction type: isometric, concentric, eccentric) and movement pattern of strength tests should be similar to sports specific training. Isometric methods to asses lower body strength are often selected based on the high test-retest reliability and correlation to 1RM tests (Blazevich et al. 2002) in addition to simple administration, and reduced risk of injury. Research indicates adaptations to training are specific to movement patterns utilised and that testing should be reflective of this particular nature.

Equestrians, particularly event riders adopt both a seated (throughout the DR phases), and an un-seated squat position (throughout the Jumping disciplines). The nature of horse-riding requires sudden, dynamic knee and hip flexion and extension, such as in jumping events, yet also controlled and skillful movements where isometric tension is required particularly at the knee for lengthy periods of time. Dynamic and isometric leg strength in equestrians are purported to be specific modes of exercise in this sport and it was appropriate to test both accordingly. Therefore, to asses isometric leg strength a single leg isometric wall squat was selected.

The single leg wall squat was determined by ensuring the anterior surface of the knees were not translating beyond the distal end of the toes at the lowest position of the wall squat. This position is typically discouraged by clinicians and trainers. A knee angle of 60° was ensured using a goniometer (66Fit, China) to mimic a position that riders commonly are seated at (Lovett et al. 2005). Prior to commencement of the actual test, a 15s trial was allowed for familiarisation followed by 60s rest. Time to task failure (movement from the position) was recorded in seconds. Testing started with the dominant leg and then the non-dominant leg. Thirty seconds rest was allocated between testing sessions. Termination of the single leg isometric squat tests was considered when compensatory events occurred included lifting the hands off the iliac crests, stepping or stumbling and moving hip into more than 30° of flexion or abduction.

3.2.11 Modified Press-Up Test

Muscular endurance is the ability of a muscle group to execute repeated contractions over a period of time. In addition to the previously discussed 1RM testing and isokinetic dynamometry to measure dynamic muscle strength, push up tests have been used broadly to asses muscular endurance of the upper body. The use of press ups in fitness test batteries is based upon the ability of this measure to predict performance on more elaborate measures of strength such as the 1RM bench press (Mayhew 1991), also because it is an easily learned exercise, requires minimal equipment and is adaptable depending on the population of athletes. Unfortunately, very few muscle endurance or strength tests control for repetition duration or range of motion and thus results can be difficult to interpret (ACSM 2009). Conditions in these types of test should be standardised to ensure validity. ACSM (2009) guidelines suggest standardisation conditions include strict posture, full range of motion, equipment familiarisation, and standardised warm up, permitting tests are standardised reliability of data can be ensured. Press ups were a method selected to assess upper body strength in riders within the fitness test battery. The limitations regarding the standardisation of this measure were accepted, the selection of this press ups to asses upper body strength was based upon its application to testing of athletes in a field based setting, the ability of the test to predict 1RM and additionally to compare to research of Meyers and Sterling (2000) who used press ups to asses upper body strength in collegiate equestrians.

Push up measurements were administered using a modified 'knee' push up position. A true push up was considered when the participant's chest reached a foam roller (12cm). The numbers of true repetitions in one minute were recorded.

3.2.12 Grip Strength

Handgrip strength assessment is commonly measured via handheld dynamometry and validity and reliability of this method of strength assessment have been confirmed (Mathiowetz 2002). Handgrip strength tests are simple, quick to asses and can be used in both field and laboratory settings. The decision to measure grip strength in riders was in response to the research of Roberts et al. (2010) where grip strength using a handheld dynamometer was collected in the left hand in a simulated one-day Event. Upon critique of their methodology this thesis includes the measurement of grip strength in both the dominant and non-dominant hand post warm up and post each competition phase during the Novice one-day event.

A handheld dynamometer (Takei, Japan) was used to obtain maximal voluntary isometric force of dominant and non-dominant handgrip muscles (GS) averaged over three trials in both dominant, and non-dominant hands. Grip strength was reported as maximal voluntary contraction (MVC) in kg.

3.2.13 Core Strength

Core strength is considered a key component in the training programmes of individuals aiming to improve fitness and an important component of clinical rehabilitation of competitive athletes (Liemohn et al. 2005). The ability of the lumbopelvic skeletal structures and musculature to withstand compressive force on the spine and return the body to equilibrium after perturbation is an essential component in the successful performance of activities of daily living and athletic pursuits (Kibler et al. 2006). Poor core strength is a risk factor for back and lower extremity injury in athletes; to reduce the risk of injury, athletes are strongly encouraged to add core stability exercises to their strength and conditioning program (Kibler et al. 2006) as thus a measure to asses and individuals core strength is necessary.

Isokinetic trunk flexor and extensor testing for measuring strength is considered ‘gold-standard’ primarily due to its reliability (Delitto et al. 1991) however as indicated previously the overall design of a fitness test battery must consider robust field testing methods to asses components of physical performance, particularly where athletes will undertake multiple tests in one occasion. Cowley et al. (2009) developed a field test that correlates well with isokinetic measures called the front abdominal power test (FAPT) and as such this measure was selected to asses core strength.

Cowley et al. (2009) found that of two field tests, and isometric plank to fatigue (PTF) and front abdominal power test (FAPT)) the FAPT was highly reliable test of core stability. This finding is in agreement with Cowley and Swenson (2008) who reported high reliability of the FAPT in young women with a reported intra-class correlation coefficient of 0.95. In addition to the FAPT Cowley et al. (2009) investigated the plank to fatigue test. The PTF tests the ability of the participant to maintain a neutral back position. Though this exercise is frequently adopted within training programmes, academic investigation concerning this isometric trunk strength measure is limited. Despite clinical trials yet to conclude its reliability, research has included this measure, Basset and Leach (2011) used the PTF test as an isometric strength measure to investigate the efficacy of an eight-week core stability strength training programme in gymnasts. The limitations regarding reliability and validity of the PTF method were accepted and this test was incorporated within the fitness test battery in addition to the FAPT.

Within this chapter, isometric core strength was measured using the PTF and FAPT using the methods developed by Cowley et al. (2009). The PTF was performed with the toes and forearms in contact with the floor, positioning the elbows directly underneath the shoulders so the upper arms are perpendicular to the floor. The hips were positioned so that a straight line could be drawn from the shoulders to the ankles through the hips. The test required participants to hold the prone plank position for as long as possible. To ensure that the participants maintained the plank position throughout the test, they completed a 15s practice trial plank using a vertical rod to determine the hip height they would be required to maintain during the test as developed by Cowley et al. (2009); 1 rod was adjacent to the side that the researcher was conducting the test. Plank height was recorded by placing a marker on the rod (Cowley et al. 2009). Verbal feedback regarding deviation from the starting position was given to each participant, and an inability to correct the deviation signified the end of the test. Only one deviation was allowed prior to test termination. Participants were verbally motivated throughout the test but were not informed of the elapsed time. Time to task failure was recorded in seconds.

In addition to the PTF, participants were also tested using the FAPT. Participants were instructed to lay with their back on a mat, arms along the sides, and feet shoulder width apart. Knees were then bent to 90 degrees, at which point the tips of the feet were aligned with the end of the mat. Participants then raised their arms over their head by flexing the shoulder; elbows and wrists were extended with the hands supinated and thumbs from the left and right hands touching. A 2-kg medicine ball was placed in the supinated hands, which then cradled the ball. From here, the participant was instructed to keep the shoulders, elbows, and wrists locked in this position with the medicine ball securely cradled in the hands. The participant was then instructed to perform an explosive concentric contraction of the abdominal and hip flexor muscles while using the arms as a lever to project the medicine ball. The feet and buttocks remained in contact with the floor. The medicine ball was released out of the hands when they were over the participant's knees. The distance the medicine ball was projected was recorded and measured from the tip of the feet to where the medicine ball landed (Cowley et al. 2009). The participant was given three practice trials and then performed three trials of the front abdominal power test with a rest period of 2 minutes between trials. The average of the three trials were used in the data analyses.

3.2.14 Physiological Testing

Peak oxygen consumption ($\dot{V}O_{2peak}$) and lactate threshold were determined using a continuous, incremental protocol on a cycle ergometer (Exaliber Sport, Lode). During the test, expired gas was analysed and heart rate (HR) and rating of perceived exhaustion (RPE) were recorded each minute (outlined in the following paragraphs). Heart rate, RPE and BLa were recorded throughout the last 30s of each incremental stage. Lactate

Threshold (LT) was considered as the power output where BLa increased at least 1mmol.l^{-1} or more above resting. Upon completion of the exercise test, participants were encouraged to pedal at a light resistance (20W) to aid recovery.

Reporting peak oxygen consumption ($\dot{V}O_{2peak}$) as opposed to maximal oxygen consumption was discussed in Chapter Two. Peak oxygen consumption was determined using a continuous, incremental protocol on a cycle ergometer (Exaliber Sport, Lode). The test commenced with each participant completing a five minute warm up and familiarisation at 20W. Initial resistance was set at 60W and was increased in 4-minute intervals by 25W until identification of the lactate threshold (LT). Upon identification of the LT (outlined in the following paragraph) the resistance was increased by 25 watts every minute until the participant reached volitional exhaustion. Throughout exercise, respiratory and pulmonary gas exchange variables were measured using an Oxycon Pro breath by breath gas analyser (Oxycon, Viasys). Before each test the O_2 and CO_2 analysis systems were calibrated using ambient air and gas of known O_2 and CO_2 concentrations, according to the manufacturers' instructions. A post BLa sample was extracted 4 minutes post completion of the test protocol to identify peak BLa concentration. The $\dot{V}O_{2peak}$ was identified as the highest 5 second value reached during the incremental test, additional indicators were achieving a respiratory exchange ratio (RER) greater than 1.15, a BLa concentration of 8mmol^{-1}, or a peak HR of 90% of the age predicted maximal value (Noble et al. 1983; Caputo et al. 2003).

Exercise intensity at lactate threshold is a powerful predictor of endurance exercise performance (Fay et al. 1989) and as such was used in this thesis in addition to oxygen uptake during maximal exercise testing. The definition of lactate threshold throughout available literature is varied, a given blood lactate can be defined (e.g. 4mmol.l^{-1}) or an individual value (baseline + mmol.l^{-1}) can be achieved, either by incremental or discontinuous long step protocols. Pre-selecting a reference blood lactate concentration to define the lactate threshold can be used to circumvent problems associated with subjectivity or rapidness of test progression, for example, pre-defined concentrations of 2.5 mmol.l^{-1} (Hurley et al. 1984) and 1mmol.l^{-1} above resting levels (Coyle et al. 1983) are reported amongst the literature. During data collection in the studies within this thesis, laboratory exercise testing was often conducted by a sole researcher and as such a pre-selected reference blood lactate concentration was justified to reduce subjectivity when interpreting the lactate threshold.

Rating of perceived exertion (RPE) is a recognised marker of intensity and homeostatic disturbance during exercise (Kang 2003). It is commonly used in conjunction with measures of physiological intensity and is a rating to assist in understanding the participants' psychophysiological response to an exercise or task. The Borg 6-20 RPE Scale is the most widely used scale to assess the perception of effort during exercise, regardless of gender, physical activity level (i.e., sedentary, physically active and athletes) and age (i.e., young and adults). There is substantial evidence for the validity of using RPE to control exercise intensity in treadmill (Eston et al. 1987; Dunbar et al. 1992; Kang et al. 2003) and cycle ergometry modes which were used throughout this thesis and was the justification for the selection to use RPE in addition to other methods to investigate physiological load in equestrian athletes throughout this thesis (Kang et al. 1998; Kang et al. 2009).

The Borg 6-20 RPE Scale was used to assess the perception of effort during all the studies. In all studies within this thesis participants were familiarised with the Borg 6-20 RPE scale and were given instructions on how to report their overall feelings of exertion which takes into account how hard breathing feels, and how hot the participant feels and general muscular fatigue (RPEo) and peripheral exertion e.g. the feelings of exertion in their arms or legs (RPEp) (Borg 1998).

The participants were read the following excerpts to explain the differences in RPEo and RPEp modified from Faulkner and Eston (2007). RPEo: When you report RPEo what you feel should reflect an overall feeling of fatigue combining all sensations of physical stress and effort. Try not to focus on one factor but in general how you are feeling, overall. RPEp: The RPEp should reflect the feeling of fatigue, discomfort and stress present in your legs.

The Borg 6–20 RPE scale was in full view of the participant during each exercise test in laboratory tests. Participants reported their RPEo and RPEp at the completion of the exercise tests/competition phases and in the remaining 20 s of each minute and each stage during the laboratory, horse simulator and live horses exercises tests. Where both overall

RPE and peripheral RPE were collected, for all occasions RPEo was collected first and was the data used for analysis, if referred to as RPE only it will be RPEo.

3.2.15 Equestrian Training and Competition Practices

In addition to the physical test battery, participants completed a questionnaire to document equestrian training and competition practices. A self-reported survey to asses specific demographic and training load data was designed as this method is considered a suitable approach to document specific information regarding athletic training of an individual (Turocy 2002). The use of a questionnaire with pre-defined standardised questions was designed as opposed to an interview, to ensure no interviewer bias (Turocy 2002). A questionnaire was adapted with the authors permission from the questionnaire design of Ebben and Blackard (2001) from research investigating strength and conditioning practices.

A questionnaire was developed and divided into four main sections of enquiry (Appendix Two) a) general demographics, b) work-related physical activity, c) equestrian mounted training, d) additional un-mounted training. Seven questions related to participant demographics and competitive background and 6 to document intensity and duration of physical activity related to their working day. In addition, 11 questions primarily focused on the intensity and duration of time spent training for the DR, SJ and XC phases. Lastly, 19 questions focused on duration and intensity of additional un-mounted training.

3.2.16 Statistical Analysis

Data are presented as mean±SD throughout. A one-way ANOVA was used to compare means between level of performer (current competitive level affiliated with British Eventing). Within the analysis, if assumptions of sphericity were violated a Greenhouse and Geisser correction was applied. There were no outliers (assessed by boxplot) and all data were normally distributed (Shapiro-Wilk test $p>0.05$). If significant differences were observed with ANOVA, a Bonferroni post hoc text was used to locate those differences. An alpha level of <0.05 was taken to show statistical significance. Descriptive data analysis was used to report questionnaire data; a paired t-test was used for comparisons of between riders that completed un-mounted training to those that did not. Data were analysed using Statistical Package for Social Sciences (SPSS) for Windows, version 19.

3.3 Results

3.3.1 Performance Tests

Table 3.1 shows the comparison between novice, intermediate and advanced riders anthropometric and performance tests. There was a significant difference between the plank to fatigue test and level of rider $f_{(2,23)} = 4.107$, $p<0.05$. The difference was located between Novice and Advanced riders ($p=0.03$). There was also a significant difference between time to fatigue in the isometric wall squat on the non-dominant limb $f_{(2,23)} = 4.648$, $p<0.05$. The difference was located between novice and advanced, and between intermediate and advanced but not between novice and intermediate. Interestingly advanced riders had a considerably greater time to failure compared to novice and intermediate riders, however mean time to fatigue decreased in the intermediate riders. There was no significant difference between level of rider and time to failure on the isometric wall squat on the non-dominant limb

Table 3.1: Anthropometric and performance test characteristics of Novice, Intermediate and Advanced Event riders (Mean±SD).

*p<0.05 significantly difference from Novice riders. **p<0.05 significantly different from Novice and Intermediate riders.

	Novice (n=11)	Intermediate (n=8)	Advanced (n=7)
Age (years)	33.4±9.0	28.6±9.7	34.9±11.6
Height (cm)	164.7±3.4	169.5±5.6	168.6±9.9
Mass (kg)	65.7±8.9	66.6±8.1	62.6±10.4
BMI	24.1±3.2	23.1±2.0	21.9±1.6
% Body Fat	30.1±12	28.6±5.2	26.9±5.0
Balance Dominant Leg (s)	66.5±84.1	74.5±84.7	79.1±75.1
Balance Non-dominant Leg (s)	57.1±62.8	63.8±55.2	60.2±75.1
Sit and Reach Score (cm)	24.7±7.8	22.8±8.0	20.4±7.7
FAPT (cm)	133.5±46.7	124.6±38.7	161.1±43.3
Plank to Fatigue (s)	63.5±27.3	100.3±60.0	146.7±91.9*
Grip Strength Dominant (kg)	31.3±4.9	28.3±4.7	28.5±6.2
Grip Strength Non-dominant (kg)	29.9±5.0	28.5±2.7	27.4±6.8
Isometric Wall Squat Dominant leg (s)	65.1±34.8	59.1±21.4	118.1±63.5**
Isometric Wall Squat Non-dominant leg (s)	56.1±21.1	86.0±48.6	90.0±15.0
Modified Press Up (#repetitions)	29±9	25±8	28±7
Batak wall score (#hits)	62±6	65±5	64±5

Isokinetic concentric and eccentric peak torque are displayed in Table 3.2. There were no significant differences in peak torque between levels of performer in both concentric and eccentric muscle contractions at both slow and moderate speeds ($p>0.05$)

Table 3.2: Isokinetic concentric and eccentric strength in dominant (D) and non-dominant (ND) leg (quadriceps and hamstring) flexors and extensors at 60°·sec-[1] and 180°.sec^{-1} in novice, intermediate and advanced event riders

	Novice (n=11)		Intermediate (n=8)		Advanced (n=7)	
	D	**ND**	**D**	**ND**	**D**	**ND**
Concentric						
Peak Torque (Nm)						
Extensors 60°.sec^{-1}	107±24	104±39	95±21	114±17	119±17	128±17
Extensors 180°.sec^{-1}	69±17	65±19	59±18	58±23	86±32	81±20
Flexors 60°.sec^{-1}	57±16	52±28	58±8	59±8	68±13	69±10
Flexors 180°.sec^{-1}	40±14	39±14	33±14	43±20	45±18	45±14
Eccentric						
Peak Torque (Nm)						
Extensors 60°.sec^{-1}	135±43	134±26	121±31	133±35	113±33	139±42
Extensors 180°.sec^{-1}	112±38	91±43	119±24	116±18	97±42	117±25
Flexors 60°.sec^{-1}	68±31	75±21	69±14	70±16	85±42	103±47
Flexors 180°.sec^{-1}	66±25	60±26	70±8	67±5	50±31	67±10

Descriptive statistics for the cycle ergometer test are reported in Table 3.3. There were no significant differences between variables collected throughout the cycle ergometer test and level of performer (P>0.05).

Table 3.3: Descriptive statistics for physiological variables collected throughout the cycle ergometer test

	Novice (n=11)	**Intermediate (n=8)**	**Advanced (n=7)**
$\dot{V}O_{2peak}$ (ml.kg.min^{-1})	44.2±6.0	41.3±5.5	42.5±2.8
RPE	18.2±0.9	17.6±1.2	18.6±0.5
PO @ LT (W)	133±28	135±42	128±28
%MaxWatt@LT	63.4±12.8	64.4±11.4	63.3±13.1
Max HR (beats.min^{-1})	188±7	184±12	183±12

3.3.2 Questionnaire Results

All participants completed the equestrian and additional training load questionnaire (n=27). Of the n=27 participants 11 (42%) were competing at Novice level. Of these riders 100% wanted to compete at a higher level of competition. Fifty-four per cent of novice riders completed additional un-mounted training, and of the 45.5% that did not, 75% indicated that the horses programme was more important than their own, with the remaining 25% stating that they did not have time to train themselves off of the horse.

Intermediate riders accounted for 31% of the study sample and of these riders 100% wanted to compete at a higher level of competition. Sixty-two per cent of intermediate event riders completed additional un-mounted training and for the 37.5% that did not, they attributed it to not having time (66.7%) or the horses programme being more important (33.3%).

Advanced riders accounted for 27% of the sample and of these riders 85.7% wanted to compete at a higher level. A lower percentage of advanced riders completed additional un-mounted training (35%) in comparison to the other athletes, and of those that did not they recognized it to be due to not having enough time (33%) the horses programme being more important (33%) or other (stated as being lazy).

Table 3.4 summarises item responses between Novice, Intermediate and Advanced athletes. There are no significant differences between item responses and level of performer ($p>0.05$).

Table 3.4: Summary of item responses between Novice, Intermediate and Advanced athletes (Novice n=11, Intermediate n=8, Advanced n=7).

General	Novice	Intermediate	Advanced
Years of Training	12.9±7.1	9.8±5.1	15.6±10.3
Number of Competitive Rides in 2010-11 season	18.6±19.2	17.3±10.4	21.3±12.7
Physical Activity			
Time spent on an average day in a normal week in the last month doing vigorous activity as part of daily work (mins)	26.8±33.6	15.7±67.3	35.7±57.7
Time spent on an average day in a normal week in the last month doing moderate activity as part of daily work (mins)	161.4±240.8	98.6±103.5	60±67.1
Equestrian Training			
How many DR training sessions completed in a normal week in the last month.	7.6±10.7	6.6±5.7	11.6±10.7
In a normal week in the last month how much time spent on vigorous DR training (mins)?	37.3±52.3	38.8±49.4	27.9±25.2
In a normal week in the last month how much time spent on moderate DR training (mins)?	194.6±277.6	185±215.6	212.8±298.8
How many SJ training sessions completed in a normal week in the last month.	2.45±2.5	3.0±1.9	3.3±2.1
In a normal week in the last month how much time spent on vigorous SJ training (mins)?	30.0±70.4	26.3±42.7	37.1±64.0
In a normal week in the last month how much time spent on moderate SJ training (mins)?	66.4±51.7	83.1±87.9	62.9±54.3
How many XC training sessions completed in a normal week in the last month.	2.1±2.3	3.8±6.7	3.3±2.1
In a normal week in the last month how much time spent on vigorous XC training (mins)?	50.5±82.2	67.9±145.7	10.0±22.4
In a normal week in the last month how much time spent on moderate XC training (mins)?	75.9±86.4	94.4±205.2	158.6±132.4
Additional Un-mounted Training (Novice n=6, Intermediate n=5, Advanced n=3)			
How many additional training sessions completed in a normal week in the last month.	7.0±8.4	3.2±0.8	3.3±2.5
Time spent training balance (min) in a normal week in the last month.	13.3±12.1	12.0±13.0	26.0±30.7
Time spent training flexibility (min) in a normal week in the last month.	25.0±33.9	28.0±21.7	30.0±30.0
Time spent training core (min) in a normal week in the last month.	15.0±16.1	28.0±30.3	31.0±41.0

Time spent training vigorous strength (min) in a normal week in the last month.	1.67±4.0	18.0±26.8	7.5±10.6
Time spent training moderate strength (min) in a normal week in the last month.	30±50.9	18.8±28.4	50±14.1
Time spent training vigorous endurance (min) in a normal week in the last month.	3.3±8.2	52±46.0	7.5±10.6
Time spent training moderate endurance (min) in a normal week in the last month.	130±50.9	38.0±42.6	170±183.8
Time spent training vigorous intervals (min) in a normal week in the last month.	20.0±48.9	13±26.4	45.0±21.2
Time spent training moderate intervals (min) in a normal week in the last month.	0	14±26	30±0
Total time in a normal week in the last month spent equestrian training (min)	454.5±410.2	495.4±620.1	414.2±398.5
Total time in a normal week in the last month spent additional un-mounted training (min)	269±283.0	242.0±137.2	250±0

3.3.3 Additional Un-Mounted Training

There were no significant differences in variables collected in the fitness battery aside from grip strength in the non-dominant hand in riders that completed additional training (26.8±3.3) to those that did not (31.1±5.5); t (24) = -2.46, p=0.22. Interestingly grip strength was greater in riders that did not complete additional training. The riders that completed additional un-mounted training did not embark on programmes that were specific enough to improve cardiovascular fitness, or strength parameters that were measured in the fitness test battery, when compared with riders that did not complete additional un-mounted training.

Table 3.5 summarises questionnaire item responses between riders that completed additional un-mounted training to those that did not. There was a significant difference between amount of time spent training DR at moderate intensities between those that completed additional un-mounted training (t (26) = -2.39, p=0.024). Those that did not complete additional training spent more time in DR and XC training (t (26) = -2.58, p=0.016) at moderate intensities. Those that did not complete additional training spent a much greater amount of time equestrian training than those that completed additional un-mounted training (t (25) = -2.27, p=0.032).

Fifty per cent of riders that did not complete additional un-mounted training attributed this to be due to believing the horses programme was more important, 42% indicating that they did not have time, with the remaining 8% as 'other' which riders stated as being 'both not having time and the horses programme being more important'. The riders believing the horses programme being more important corresponds with them spending more time in the saddle.

Of the riders that did complete additional un-mounted training they spent the 39.3% of total training time on moderate intensity endurance training which included running (96%) and spin classes (4%). Of riders that completed strength training the most common listed exercise was the squat (29%), followed by lunges (12%), deadlifts (12%) and press ups (12%). The most common methods for interval training were running, including hill sprints (80%) followed by skipping (20%). The main exercises for training the core were sit up variations (50%) isometric prone plank holds (30%) and exercises on an exercise ball (20%). To improve or maintain flexibility riders suggested they embarked in non-specific stretches when cooling down post work out (50%), Yoga (38%) and Pilates (12%). To train balance most riders (88%) indicated they did not train balance specifically but as a result of some of their strength based training such as single legged exercises and exercises within yoga and pilates or work involving an exercise ball, with 13% of riders working on exercises on a balance board specifically aiming to improve their balance.

Table 3.5: Summary of questionnaire item responses between riders that completed additional un-mounted training to those that did not.

Did you complete additional un-mounted training?	**Yes (n=13)**	**No (n=14)**
Years of Training	12.4±7.8	14.3±7.8
Number of Competitive Rides in 2010-11 season	17.8±10.8	25.3±23.0
Time spent on an average day in a normal week in the last month doing vigorous activity as part of daily work (mins)	40±55.8	65.4±127.2
Time spent on an average day in a normal week in the last month doing moderate activity as part of daily work (mins)	78.85±161.9	139.3±173.6
Equestrian Training		
How many DR training sessions completed in a normal week in the last month.	5.5±6.6	13.1±12.9*

In a normal week in the last month how much time spent on vigorous DR training (mins)?	34.29±40.6	41.8±51.1
In a normal week in the last month how much time spent on moderate DR training (mins)?	98.6±122.9	358.6±387.8*
How many SJ training sessions completed in a normal week in the last month.	2.7±1.7	3.4±3.1
In a normal week in the last month how much time spent on vigorous SJ training (mins)?	15±31.8	53.6±74.2
In a normal week in the last month how much time spent on moderate SJ training (mins)?	71.8±69.3	87.9±95.4
How many XC training sessions completed in a normal week in the last month.	1.29±1.2	5.0±5.1*
In a normal week in the last month how much time spent on vigorous XC training (mins)?	30.71±63.9	54.9±116.8
In a normal week in the last month how much time spent on moderate XC training (mins)?	45.4±48.9	171.8±176.3*
Total time in a normal week in the last month spent equestrian training (min)	295.7±217.2	744.5±706.1*

*Indicates a significant difference ($p<0.05$) between those that completed additional un-mounted training and those that did not.

3.4 Discussion

This study was the first investigation to compare the anthropometric characteristics, and test performance of core strength, leg and upper body strength, hamstring flexibility, hand-eye reaction time, balance and training histories of female Novice, Intermediate and Advanced Event riders. The first hypothesis can be accepted in part, there were many physical tests that did not differentiate between levels of competitor, however isometric thigh and trunk strength were significantly different depending on the competitive level of performer. These results are discussed and interpreted in greater detail below.

The body composition of Event riders was not significantly different between levels of competitor and data presented within this study does not support work by Roberts et al. (2010) that Event riders have a lower BMI and body fat percentage than riders of other equestrian disciplines as discussed within Chapter Two. The lack of difference in body composition between competitive level further supports the notion that the body composition of riders is not a primary consideration for successful performance. This is not surprising due to the various variables influencing performance outcomes of the horse and rider partnership. As presented within the introduction, it would seem an important factor for overall performance to consider the mass during physical preparation of a rider. Although there is limited research focus to date, early work of Stenfansdottir et al. (2017) indicated that the physiological demand placed upon the horse is greater when carrying a rider of increased mass. A reduction in the work required of the horse may result in enhanced performance of the horse and rider combination and warrants future investigations, particularly in a sport where risk and fatality rates are high for both the horse and rider are high (British Eventing 2017).

Within this study, two isometric strength endurance tests were incorporated based upon early work investigating muscle actions during riding suggesting isometric dominance (Terada et al. 2006). A sport specific test has yet to be developed and tested for reliability and validity within an equestrian population and so methods to assess isometric core (PTF) and thigh strength (isometric wall squat) were included based on methods utilised within previous sporting literature. The results demonstrated differences between competitive standard for time to fatigue on the isometric prone plank hold, and dominant leg isometric wall squat tests. The values reported in Novice Eventers for the plank to fatigue test (65.5s) are below those reported in young active females and Advanced riders (146.7s) (Caputo 2003) but comparable to riders at Intermediate level as no significant difference was located between these two performance levels (100s). These data suggest that not only do advanced Event riders have superior isometric core strength to their intermediate and novice counterparts, but also have greater isometric core strength in comparison to a normative population of active and non-specifically trained females (111s) (Caputo 2003). The specificity of tests of course can be questioned as the role that isometric endurance plays during horse riding is not well documented. One of the primary objectives of both Event riding and travel based sports that horse riding has been classified within is stabilisation i.e. remain on the horse which explains the requirement for isometric muscular contraction. Though yet to be investigated in Event riders, earlier EMG investigations of the riders' muscles during walk and trot gaits indicate isometric muscle activity predominates and as noted by Trowbridge et al. (2005) and Sainas et al. (2016) this muscle action is a suspected causal factor for elevated physiological responses. Isometric muscle recruitment during riding activities though not comprehensively investigated seems to be a reasonable explanation for enhanced isometric endurance with competitive riding level (Terada et al. 2004). The unilateral isometric squat test was chosen based on the specificity of contraction type, because it is useful index of lower muscle strength and based on the ability of this test to identify strength asymmetry (Ayotte et al. 2007; Demura et al. 2010). In addition, isometric methods are often preferred for their high test-retest reliability and correlation to 1RM tests (Blazevich et al. 2002). Thigh strength endurance assessed using the unilateral isometric wall squat test showed greater isometric strength endurance in Advanced level Event riders compared to Novice and Intermediate Event riders in the dominant limb. Direct comparisons of unilateral wall squat time to fatigue cannot be made directly to other research as the test in this study was conducted using a sports specific knee-hip angle of 60° (Lovett et al. 2005) rather than the standard 90° knee angle often reported (Mackenzie 2005). An isometric wall squat time of longer than 60s with a 90° knee angle is considered excellent in young female populations (Mackenzie 2005), with advanced riders achieving nearly double that time with a 60° knee angle in their dominant limb. From this test, it appears that isometric thigh and glute strength is enhanced, though asymmetrically, with years of training and competitive level in Event riders.

These observable strength-endurance imbalances between dominant and non-dominant limbs in the isometric wall squat that were documented in this study are an important factor for consideration when planning the physical preparation of an Event rider. Interestingly, the isometric single leg squat test data supports the work of Hobbs et al. (2014) where a rider's muscular asymmetry is related to competitive level and years spent riding. Rider asymmetry, where the right side of the rider is tight and blocks movement to the left is also reported by work of Symes and Ellis (2009). Symes and Ellis (2009) and Hobbs et al. (2014) have both expressed concern regarding asymmetry presentation in horse riders and the link to pain development, particularly concerning the lower back which is a prevalent area for pain development in riders (Kraft 2007). Horse riding as a sport is considered to require symmetry and independent control of limbs as essential components for successful performance (Terada 2004), it is likely that a strength imbalance could increase risk of injury, but may also be considered a weakness where an inability to utilise both limbs equally could limit performance. Advanced riders appear to have isometric leg strength asymmetry as a result of more on horse training and competition time and further supports the premise that riders should include an off-horse training programme to address to LTPD specific goals in the 'Training to Perform' section. The LTPD suggests that riders should adopt regular body alignment monitoring and strength and condition themselves off of the horse to increase career longevity (BEF 2013) to offset asymmetries as a result of increased riding (Hobbs et al. 2014; Symes and Ellis 2009).

Grip strength reported non significant differences between levels of performer and was comparable to normal healthy women (32.9kg) and much lower than elite female athletes (44.4kg) indicating enhanced forearm strength is not a requirement of riding. This study did not report any strength difference in the dominant and non-dominated hand which does not substantiate the results of Hobbs et al. (2014) or reflected in rein tension as found by Khunke et al. (2010) in which the dominant hand occurred greater strength outputs and rein tensions. Roberts et al. (2010) measured grip strength in the right hand (dominance unknown) of riders pre and post simulated event competition, as such, asymmetry of Event riders cannot be discussed or compared to our population. Grip strength did significantly decrease post competition and so the ability to offset forearm fatigue may be an important factor to consider when preparing the Event rider for peak performance. Handedness and the relationship to the development of postural and dynamic asymmetry during riding activities have been recognised (Hobbs et al. 2014). Horse riding is complex in terms of functional and dynamic asymmetry since both the horse and rider can be affected. There is evidence to suggest that harmony between the horse-rider dyad is enhanced in more experienced riders (Peham et al. 2001; Bystrom et al. 2009) but the supposition that increased competitive level and experience of a rider will relate to increased symmetry is not supported by quantitative data (Hobbs et al. 2014), in fact, increased asymmetry is developed as a result of increased years of training and riding horses. This further supports the notion that riders should focus their off horse training strength and conditioning programme off of the horse to increase career longevity through purposeful body alignment monitoring and development of symmetry or correction of asymmetry as previously discussed.

It appears that isometric core strength-endurance is enhanced in Advanced Event riders, and isometric strength endurance is enhanced in the lower body, although asymmetrically so with competitive standard. It is important to note here, that there were no significant differences in dynamic strength for the core or thigh musculature. There were no significant differences in eccentric or concentric leg strength in collegiate and non-competitive equestrian population using isokinetic dynamometry. Leg strength in riders has only been reported in one study (Alfredson 1998) to date, data from this chapter cannot be directly compared to Alfredson (1998) due to different speed selections of $90°\cdot sec^{-1}$ and $225°\cdot sec^{-1}$ compared to $60°\cdot sec^{-1}$ and $180°\cdot sec^{-1}$. Despite the methodological differences, our data reports much lower peak torque values at the selected 'low' and 'high' speeds for all standards of rider when compared to Alfredson (1998). This result is in contrast to Holmes and Alderink (2013) where un-trained females were compared to Event riders who demonstrated greater peak concentric torque in the knee flexors and extensors at both $60°\cdot sec^{-1}$ and $180°\cdot sec^{-1}$ in both dominant and non-dominant limbs. It is likely that lower peak torque is produced by Event riders as a reflection of isometric muscular demand recruited via training and supported by isometric leg strength data. The FAPT scores although not different between level of event rider and did not discriminate between levels of performance for event riders, were lower than reported for un-trained females (201cm) (Cowley 2009) which indicates for this test, event riders report below normal explosive core fitness. This further supports the premise that isometric endurance is more important than dynamic strength output in horse riding based sports.

Lower back pain in riders is reported as high (Kraft et al. 2007) although to date no conclusive pathology has been determined to associate cause and effect in riders. Hobbs et al. (2014) speculated that sub-clinical asymmetry, limited flexibility and muscle stiffness may predispose riders to pain. Increased lower back and hamstring flexibility includes benefits such as the prevention of acute and chronic musculoskeletal injuries, postural deviations and lower back pain development (ACSM 2009). In this study, values for the sit and reach test were lower in Event riders when compared to normal female populations (28±9cm) (Lopez-Minerro and Alacid 2009) and indicate tightness and the potential for pain development within the lower back and hamstring muscle groups, hypothetically due to repetitive seated position with a flexed knee whilst horse-riding (Lovett et al. 2005; Kraft et al. 2007). In addition to tightness in the hamstring riders also reported poor balance in the single leg balance task and thus indicates poor ankle stability and suggests riders are at increased risk of injury (Reimann and Schmitz 2012). Since this is the first physical test battery developed for riders the test selection is preliminary and highlights avenues in which future research may wish to adopt. For this test battery, a single leg blind test on a firm surface was utilised since for sports that require dynamical balance, such as travel sports (Kren et al. 2015) one-legged balance tasks are considered most specific. There would also be merit in exploring functional ankle stability to dynamic and unstable surfaces, since during riding the ball of the foot although in contact with a stirrup, is under constant dynamic stimuli given the nature of the movement stirrup and iron. Our data indicates that a blind single leg balance task is not improved with competitive standard. Since stablisation and therefore balance appears to play an important role during riding (Terada 2006), future research focusing on suitable and sport specific balance tasks outside of a test battery situation would be beneficial since to date we lack a system to quantify sensio-motor and proprioceptive ability in an equestrian population (Reinmann 2000; Lopez-Minerro and Alacid 2009).

For the modified press up test our data reports lower mean values than riders (n=32) reported by Meyers and Sterling (2000) but is comparable to later research by Meyers (2006) who reported number of press-ups per minute as n=30. This data also indicated that upper body pushing strength is not a necessary component for enhanced performance in Event riders. In line with discussions of Meyers and Sterling (2000) and Meyers (2006) to attain optimal muscular strength, maintain lean body mass and bone density, riders should complete a training regime as riding does not provoke the stimulus required for enhanced dynamic strength.

Our study reported mean $\dot{V}O_{2peak}$ values of ~42 $ml.kg^{-1}.min^{-1}$ in an Event rider population, aerobic fitness was not different between levels of competitive rider. Aerobic capacity in Event riders is in line data reported within available equestrian literature. The data from this chapter indicates that aerobic capacity is not influenced by competitive standard. Since the work of Roberts et al. (2010) indicated that during a simulated one-day Event riders attain high heart rates and oxygen uptakes, specifically during the XC phase, elevated aerobic capacity may have been reasonable to expect within an advanced Event rider population.

Westerling (1983), Devienne and Guzennec (2000), Beale et al. (2015), Cullen et al. (2015) and Sainas et al. (2016) used cycle ergometer protocols to induce fatigue in riders and reported wide ranges in maximal oxygen uptake with 43.8±4.0 $ml.kg.min^{-1}$, 54.9 $ml.kg.min^{-1}$ (converted from $l.min^{-1}$), 37.2±7.4 $ml.kg.min^{-1}$, 54±3.3 $ml.kg.min^{-1}$ and

34.73±7.1 ml.kg.min^{-1} respectively. The range in maximal oxygen uptake is likely affected by protocol design and participant populations. A higher $\dot{V}O_{2max}$ was reported by Cullen et al. (2015) in male race jockeys, a greater value would be expected in a male sample due to heterogeneous exercise and training responses. Treadmill protocols were used by Meyers and Sterling (2000) and was justified due to equestrians riding the stirrup irons and exhibiting high degrees of upper body and total body work than can be derived from a cycle ergometer which again limit comparability between data. There is no defined justification for the choice of cycle ergometers over treadmills within the available research, perhaps the safety aspects and the seated nature was the motivator as it was for this research, the most appropriate mode has yet to be investigated within an equestrian sample.

This was the first study to investigate self reported durations that event riders spend training on and off of the horse. Interestingly, there were no significant differences between item responses and competitive level. This study reports large ranges in time spent equestrian training ranging from 58 minutes to 35 hours and 30 minutes training per week. There are large variations in duration spent training usually dependent on number of horses that rider had in training. Larger amounts of time were committed to DR training for all levels when compared with SJ and XC. There were also large variations between total time spent additional training from 20 minutes per week to 12 hours and 30 minutes per week. Roberts et al. (2010) highlighted that the XC phase was the most physiologically demanding phase when compared to DR and SJ, interestingly, riders on average complete 2-3 focused training sessions on XC per week, including hacking (cantering and galloping on trails etc.) and minimal attention to actually riding XC courses due to limitations in accessibility. This may also explain low aerobic fitness of riders, as they do not expose themselves to tasks that replicate the same physical effort required during competition regularly enough to elicit a training response. The necessity and amount of sports specific off-horse aerobic conditioning is important factor to consider when considering training plans for an Event rider's athletic preparation. A thorough investigation concerning the physiological demands of competitive Event riding is necessary to compliment the work conducted within this chapter and the simulated work of Roberts et al. (2010). Further research concerning the physiological demands of this sport will assist in the analysis of the fitness requirements of Event riders with respect to competition demands and the amount of sport specific training required within their training regimen.

Advanced Event riders had more years of training background and spent more time out competing compared to their Intermediate and Novice counterparts. Of all riders that completed additional un-mounted training, it was Novice riders that completed the most sessions per week. The reason that Novice riders complete more off horse training is not well understood, however riders that considered the horses programme more important spent more time in the saddle and less time training off the horse, indicating Novice riders focus more on their own performance than focusing solely on the horse. Novice riders additional training comprised mostly of moderate intensity endurance and moderate intensity strength based exercise which also included some flexibility and interval based training. Intermediate riders completed more endurance training (consisting of both moderate and vigorous intensities) and also included flexibility and core exercises. The Advanced riders reported a focus on endurance and moderate strength training with the inclusion of vigorous interval based exercises.

Interestingly, when riders were categorised by whether they completed additional un-mounted training or not, there were no significant differences between variables measured in the fitness test battery and therefore it can be concluded that the type, intensity and volume of additional un-mounted training that riders are completing is not specific enough to improve cardiovascular fitness, strength, balance, flexibility or reaction time. The physical fitness tests utilised within this study, aside from isometric endurance tests are not influenced by competitive standard, indicating that these measures are not influenced or required for successful performance in Event riders. It does appear however that isometric strength asymmetry and isometric core strength are defined by competitive status and warrant further explorations. With regards to an off horse training approach, based on the data within this chapter, the focus for athletic preparation should include factors aiming to enhance isometric endurance with a focus on postural symmetry and alignment as opposed to enhancing test performance overall.

3.4.3 Limitations and Future Research

To date in 2017 there is no standardised equestrian performance related fitness test battery. Various measures have been used to characterise fitness traits such as curl ups and push ups (Meyers and Sterling, 2006), isokinetic dynamometry (Alfredson et al. 1998), anthropometrics and aerobic fitness (Westerling 1983; Meyers and Sterling 2006) combining laboratory and field based measurements. Typically, the design of a fitness test should replicate the physiological demands of a sport and as such isometric tests were included into this fitness test battery unlike other equestrian specific research trials to report isometric core and thigh strength. Often sports specific field based tests are designed to replicate demands of a particular sport, for example in sailing fitness tests may include a hiking endurance test (Blackburn and Hubinger 1994), the limitations to this approach however is the lack of trials documenting the reliability and validity.

A limitation of the test battery presented was that the isometric tests chosen have not had their validity and reliability reported (Cowley et al. 2009). Future research should consider a methodological trial to determine the validity and reliability of the plank to fatigue and unilateral isometric wall squat at 60 degrees to ensure the use of these measures in future fitness test batteries are rigorous. The limitations of the questionnaire developed in this study were accepted, although the survey was adapted from a pre validated questionnaire (Ebben and Blackard 2001) it was self developed with no validation or reliability study. As such, data presented though novel, should be interpreted with caution. Future research considering self-reported training in equestrians should consider principles of validating questionnaire design including construct, content and criterion based methods of validation (Turocy 2002).

It would be interesting for future research considering refining a fitness test battery for an equestrian population to document the cardiac responses to isometric performance tests as isometric endurance appears to be as a result of a training effect, albeit asymmetric. For example, more successful sailors resist isometric fatigue better than their novice counterparts (Niinimaa et al. 1977). This research also indicates that in addition to fatigue resistance, the successful sailors also had an enhanced systemic cardiovascular adaptation which would not be identified from dynamic testing alone. Felici et al. (1999) reported increases in left ventricular mass of sailors hearts which suggests that repetitive pressure overload due to isometric muscle work may induce chronic adaptive cardiac effects in sailors.

While horse riding has been suggested to be a physically demanding sport (Westerling1983; Trowbridge et al. 1995; Devienne and Guzennec 2000; Guiterrez Rincon et al. 2000; Roberts et al. 2010; Beale et al. 2015; Sainas et al. 2016) enhanced physical fitness is not evident between competitive levels of Event riders. It is likely that an optimal level of physical fitness and body composition would influence Event riding performance. The ability to recover from a ride would potentially reduce the likelihood of injury resulting from physiological fatigue (Hitchens et al. 2011; Trowbridge et al. 1995); this is particularly important during Event riding where it is common for a rider to compete more than one horse per competition. There is limited research available concerning physiological demands of Event riding (Roberts et al. 2010) however, lower anaerobic and aerobic fitness in jockeys have been associated with a greater risk of falls (Hitchens et al. 2011). Although National Hunt racing is not directly comparable to Eventing there is a component of jumping at speed and high levels of risk within this sport and it would seem reasonable that a level of conditioning to offset fatigue in Event riders is rational. Limited research is available pertaining to the specific physiological demands of Eventing, specifically so within a competition environment and although the results of this research is suggestive that aerobic fitness is not influenced by level of competition, a thorough analysis of competition demands is necessary. Understanding the physiological demands of a sport can allow the development of specific training guidelines.

3.5 Conclusion

Many factors contribute to successful performance in Eventing, from both the human athlete and the horse. The results of this research indicate that aside from isometric endurance, riders anthropometric and physical fitness are not influenced by competitive level of Event riding. Asymmetrical development in isometric leg strength was reported with increased levels of performance. In addition to asymmetric strength development, riders reported below average balance and hamstring flexibility responses indicating limited pelvic and ankle stability, and tightness in the hamstring and lower back. It appears from this study that the physical preparation of an Event rider should include strategies to enhance isometric strength endurance with a focus on postural and strength symmetry as opposed to directing attention on enhancing test performance. As such, off horse strength, flexibility and mobility training can be implemented into this population to maintain career longevity as recommended in the 'Training to Perform' section of the LTPD documentation.

CHAPTER FOUR: THE PHYSIOLOGICAL DEMANDS OF NOVICE ONE-DAY EVENTING AND THE PHYSICAL CHARACTERISTICS OF NOVICE FEMALE EVENT RIDERS

4.1 Introduction

The physiological responses to horse riding are relatively unexplored; available research has investigated the responses to DR riding or general schooling of the horse (Westerling 1983; Devienne and Guzennec 2000; Sainas et al. 2016), SJ riding (Guiterrez Rincon et al. 1992; Perciavalle et al. 2014) and the responses of riders to a generic British Horse Society standard riding lesson (Beale et al. 2015). Knowledge of the physiological demands placed upon the rider during equestrian competition are limited and isolated to; National Hunt Racing (Trowbridge et al. 1995; Cullen et al. 2015), SJ (Gutiérrez Rincon et al. 1992), Polo (Wright and Peters 2008) and a simulated Novice ODE competition (Roberts et al. 2010). A thorough knowledge of the physiological demands of a specific sport can allow the development of specific training guidelines which appears to be important given that early investigations of Roberts et al. (2010) indicate that the physiological demands of Event riding during a simulated competition are high. Despite the national and international popularity of Event riding, the specific physiological demands of this sport remain relatively unknown.

Literature to date indicates that as the horse and rider progress through the equine gaits (walk, trot, canter), the riders heart rate and oxygen consumption increase and aerobic metabolism dominates (Westerling 1983; Devienne and Guzennec 2000; Sainas et al. 2016). It is generally the faster gaits, and jumping such as in SJ and XC that require the rider to adopt a ‘forward’ position where the riders are then un-seated in a semi-squat position, causing weight bearing to be through the rider’s legs (Trowbridge et al. 1995; Roberts et al. 2010; Cullen et al. 2015). It is apparent that positional differences required for fast cantering and jumping significantly increase anaerobic metabolic system requirements with reported increases in cardiovascular load and associated increased blood lactate values (Guitérrez Rincón 1992; Trowbridge et al. 1995; Roberts et al. 2010; Cullen et al. 2015; Perciavalle et al. 2014) and therefore greater physiological strain in these phases of Eventing can be assumed.

Eventing is catergorised into sub-divisions depending on the level of performance of either the horse and rider combination. Novice level Eventing is the division which is considered the first step to success in an Event riders career (Horse and Hound 2017). Novice level Event riding is described as the level that riders progress to should they wish to take their Event riding seriously, amateur or otherwise (Horse and Hound 2017). As such, it is a very large and competitive division and therefore deemed an appropriate starting point to explore the physiological demands placed upon riders within this sport and currently, there is limited amount of information that exists concerning the physiological demands of Novice ODE.

For Novice ODE specifically, the DR phase requires the rider and horse to perform a series of exact movements in a semi-enclosed arena over a period of between approximately 4-7 minutes duration with a percentage of scores attributable to rider posture and or position. This phase assesses the relationship between horse and rider and anecdotally requires postural control and core stability to produce what is termed an 'independent seat' that permits the rider to direct and aid the horse without overt body movement (von Dietze 1999). The SJ phase requires the horse and rider to navigate a course of between 8-12 jumps at a pre-determined height, for approximately 1-3 minutes. This phase requires agility, speed, strength, technique and precision of the rider and horse (Houghton Brown 1997). The third and final stage, the XC phase requires the rider and horse to navigate an undulating course of 1600-2800m comprising of 18-25 natural solid obstacles at a gallop. The XC phase is purported to require rider stamina and strength, particularly in the legs, with core stability suggested as essential for completing the course safely and at speed (British Eventing 2009).

Existing literature has considered equestrians as a population of athletes, rather than investigating the equestrian sports into their sub disciplines e.g. Dressage, Eventing, Show Jumping etc. Due to the vast nature of technical skills and differences between the sub divisions within equestrian sports research investigating discipline specific population groups is required to understand the true competitive demand between levels of athletes, and between equestrian disciplines. Combining heart rate and blood lactate data in real competitive situations should provide a more comprehensive picture of the demands of competitive Novice ODE than previously achieved in laboratory situations and simulated competitions and both are common measures of assessing physiological demand in competition based investigations (Deutsch et al. 1998; Coutts et al. 2003; Krustrup et al. 2005). In addition to physiological measures, Roberts et al. (2010) also included grip strength measures within their simulation ODE investigation. Interestingly, Sainas et al. (2016) speculated that bouts of isometric activity forearm were the main sources of BLa accumulation during horse riding; as such investigating Event riders grip strength would be an interesting performance measure to incorporate.

Physiological indices have not been monitored concurrently, nor fully distinguished within a competitive population and thus further research is needed to quantify the physiological demands of competitive Novice Level Event riding to provide scientific evidence on which to base sport specific training recommendations. The purpose of this study was therefore to determine the physiological demands of competitive one day Eventing in a group of British Eventing affiliated Novice level female riders.

4.1.1 Overall Research Aim:

The aim of this study was to characterise the physiological demands and physical characteristics of Novice level female event riders throughout the three phases of Novice level one-day Eventing.

4.1.2 Specific Research Aims:

1. To identify heart rate, blood lactate concentration and grip strength post warm up and post competition phase in novice one-day Event riders.
2. To identify laboratory reference measures of anthropometrics, maximal heart rate, blood lactate threshold and $\dot{V}O_{2peak}$ in novice one-day event riders.

These study aims translated into the hypothesis as follows:

The Cross Country (XC) phase will report the highest heart rate and blood lactate concentration, and a reduction in grip strength will be reported compared with Show Jumping (SJ) and Dressage (DR) phases.

4.2 Method

4.2.1 Participants

A sample of twenty-seven female adult (mean±SD age 34±10.4 years; height 169.3±6.2 cm; mass 67.4±9.6kg; BMI 23.5±3.2) Event riders competing at BENovice[1] events were studied during competitions under British Eventing (BE) affiliated regulations from April-August 2010. Riders were studied throughout all three phases of the competition DR, SJ, XC. Each rider attempted all three phases at the same event, of the 27 riders; five were either eliminated or retired during the XC phase, data was used for completed phases. Participants that fell (n=3) did not get back on their horse to complete the final phase.

4.2.2 Study Design

There were two aspects of data collection required to investigate the physiological demands of one day Eventing. The first, was field based data collection at competitive events held across the UK, the second, laboratory based testing at the University of Worcester. All participants (n=27) completed field based data collection and were invited back to the University of Worcester to complete a laboratory trial, of the original twenty-seven who completed field data collection, seventeen returned to the laboratory. All participants that completed physiological testing in the laboratory did so within two weeks of completing testing in the field.

4.2.3 Governing Body Consent

Written consent to collect physiological data was granted from British Eventing (BE) the governing body for UK governed events. This initial consent (Appendix 3b) was required due to restrictions on monitoring devices that were in the 2009-2010 rule book. The chief executive of BE allowed a dispensation of rule 3.21 which permitted that all riders involved in the research were permitted to wear the wrist watch during all stages of

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BENovice: Maximum fence height 1.10m XC; 1.15m SJ competition but only with the face blanked out (taped over), making it illegible during competition.

4.2.4 Competition Venue

Measurements were completed at eight BE governed Novice level British Events around the UK (Table 4.1). The nature of competitive sport is that there are variables that athletes are exposed to that will affect the physiological response on the day. It is likely that course specifics will affect the demands placed upon the rider to some extent, however the aims of this research are to document the demands of Novice level Event riding and not the demands of a specific course and thus multiple event collections were justified. Each participant wore standard equestrian attire for each phase as outlined by BE rules 2010. For the DR and SJ phases riders are required to wear a helmet, jacket (unless permitted by the judge otherwise), jodhpurs and long boots. For the XC phase an additional chest protector is required for safety.

Table 4.1: Descriptive information for number of participants collected at each competition venue.

Event Name	Number of Participants	Phases Completed
Eland Lodge (1)	2	All complete
Mattingley	7	1 participant eliminated XC.
Shelford	2	All complete
Ascot Under Whychwood (1)	3	All complete
Milton Keynes (1)	4	1 participant fell XC, 1 participant eliminated XC
Eland (2)	1	Participant fell XC
Upton House	5	1 Participant fell XC
Ascott under Whychwood (2)	3	All complete

4.2.5 Heart Rate

Heart rate was estimated using a coded chest strap transmitter (RS800cx Multi Sport, Polar Electro, Kempele, Finland), which detected the R-R time interval of the electrocardiogram signal, and transmitted this as a single heart beat signal in real-time, via telemetry. This signal was received by a wrist watch (RS800cx Multi Sport, Polar Electro, Kempele, Finland), which was held within a ~3 m transmission range of the chest strap. The accuracy of HR measurement using this equipment, as stated by the manufacturer as ±1 $b.min^{-1}$, with a measureable range of 15-240 $b.min^{-1}$. Continuous heart rate recordings were successful for 25 participants, the data set for two riders lost signal and was discarded. The heart rate monitor was started when the rider was un-mounted and exact time was synchronised using a stop watch. For all competition phases there is a clear start and termination location or identification point. For DR, the start was considered after the judge had signaled their readiness (using the judge's car horn). When the rider entered the arena formally. The end of the phase was considered when the horse and rider halted and saluted the judge. For SJ, the start was considered when the commentator pressed the 'buzzer', and the end when the final jump and been completed. In XC, the start was considered when the green starting light was displayed and the horse and rider combination left the start box. The end was considered when the horse and rider passed the completion point, which in all cases was clearly displayed.

Heart rate zones are often used as a criterion measure for exercise intensity, particularly during competitive environments and are frequently used in conjunction with time-motion analysis to interpret exercise intensity at particular time points (Coutts et al. 2003; Krustrup et al. 2005). Research in high intensity intermittent sports such as netball (Woolford and Angove 1991) and rugby (Deutsch et al. 1998) have categorised zones as; > 95%HR_{max} as maximal (or at maximal oxygen uptake); 85-95%HR_{max} as supra threshold (or an individual's anaerobic threshold); 75-84%HR_{max} as anaerobic threshold (or zone where lactate threshold occurs); <75%HR_{max} as sub-threshold (or aerobic exercise) (Woolford and Angove 1991) which are specific.

Although a more precise categorisation of heart rate zones may allow for increased specificity, researchers must be careful when choosing how to categorise heart rate zones in sports that have received minimal research interest; such as equestrianism. Being too particular could lead to misinterpretation or absence of vital data, yet being too lenient with categorisation could lead to zones being ineffective. The ACSM (American College of Sports Medicine) guidelines classify heart rate intensity zones as very light (<35%HR_{max}), light (35-54%HR_{max}), moderate (55-69&HR_{max}), hard (70-89%HR_{max})

and very hard (90-100%HR_{max}) is a broad categorisation and is suitable for exercise where intensity is anticipated to be varied.

For this study data relevant to exact phase timings was extracted using Polar Trainer (Kemple, Finland) software and transferred to a Microsoft Excel file (Microsoft Office, 2008). The relative and absolute percentage of time spent in each metabolic zone for each warm up phase and each competition phase was computed. Heart rate data were expressed as a percentage of HR maximum (HR_{max}) which was considered as the highest HR value recorded throughout the day, or the age predicted maximum (220-age) (Londeree and Moeschberger 1982), whichever was greatest and classified into the following metabolic zones, based upon the American College of Sports Medicine guidelines: very light (<35%HR_{max}), light (35-54%HR_{max}), moderate (55-69&HR_{max}), hard (70-89%HR_{max}) and very hard (90-100%HR_{max}). In addition to relative and absolute duration in metabolic zones, HR_{mean} was also calculated for each warm up and competition phase. Total warm up and competition duration for each phase was calculated from heart rate data, and verified by exact timings taken on the day itself. Heart rate in the sixty seconds preceding competition were also extracted and averaged to get a pre competition value.

4.2.6 Blood Lactate Concentration

Blood was sampled as outlined in Chapter Three, at baseline prior to mounting, in the final minute preceding competition and six minutes post completion of each competition phase. It has been shown that lactate diffuses from the muscles and has a peak plasma concentration between 3 and 6 minutes after the end of exercise (Gollnick et al. 1986). Due to logistical complexities of completing the phase and dismounting the horse, six minutes post phase sampling was further warranted as it was still within the timeframe for lactate dispersal.

4.2.7 Grip strength

A handheld dynamometer (Takei, Japan) was used to obtain maximal voluntary isometric force of left and right handgrip muscles (i.e. Grip Strength (GS)). Values were measured at baseline prior to mounting, and immediately after blood lactate collection at the completion of each phase, in both dominant, and non-dominant hands, without gloves. Absolute GS was reported as a mean over three attempts on each arm. The changes in GS was reported as a percentage decrease (%decrease) in mean absolute GS for both dominant and non-dominant hands from baseline to post phase.

4.2.8 Duration of Recovery Between Phases

According to the British Eventing rulebook, rule 3.08 ii states that 'each horse should have and interval of at least thirty minutes between finishing one phase and starting the next' (British Eventing 2012). It is common for there to be very large ranges in recovery periods. The duration between DR and SJ was calculated as the end of the DR competition phase (termination point highlighted previously) and the start of the SJ warm up. Similarly, for the duration between SJ and XC, calculations were based on the end of the SJ phase (termination point highlighted previously) and the start of the XC warm up. Due to calculations being based on when the horse and rider started warming up, and not competing, a period of less than 30 minutes may be reported. Duration of recovery between phases was calculated in seconds using exact timings confirmed by HR data and converted to minutes:seconds.

4.2.9 Laboratory Data Collection

Laboratory testing was conducted for each participant within two weeks of completing testing in the field (mean±SD age 36.2±10.9 years; height 169.3±6.2 cm; mass 67.4±9.6kg). All exercise tests were performed in the exercise physiology laboratory at the University of Worcester. All Participants were advised to report to the laboratory rested (i.e. having performed no strenuous exercise in the preceding 24 hours), euhydrated, and at least 3 hours following the consumption of a light carbohydrate based meal (Winter et al. 2007).

4.2.10 Laboratory Measurement

Prior to testing, written consent was obtained and a pre-exercise health screening questionnaire completed for all participants (Appendix 3b). Each participant wore light athletic clothing. Height and body mass was measured, and BMI was calculated as outlined in Chapter Three (Section 3.2.5)

4.2.11 Physiological Testing

Peak oxygen consumption ($\dot{V}O_{2peak}$) and lactate threshold were determined using a continuous, incremental protocol on a cycle ergometer (Exaliber Sport, Lode) as outlined in Chapter Three (Section 3.2.14). During the test, expired gas was analysed and heart rate (HR) and rating of perceived exhaustion (RPE) were recorded each minute (as outlined in Chapter Three, Section 3.2.14). Heart rate, RPE and blood lactate concentration (BLa) were recorded throughout the last 30s of each incremental stage.

Capillary blood was sampled from the earlobe at baseline prior to warm up, at the end of each incremental stage and four minutes post completion of the exercise test to enable peak BLa to be determined (Gollnick et al. 1986). Lactate Threshold (LT) was considered as the power output where BLa increased at least 1mmol.l^{-1} or more above resting (Faude et al. 2009). The absolute and relative percentage of $\dot{V}O_{2peak}$ at LT was also calculated. In the n=17 riders that returned to the laboratory HR at $\dot{V}O_{2peak}$ was used to determine individual and mean per cent $\dot{V}O_{2peak}$ consumption for each phase of competition. Upon completion of the exercise test, participants were encouraged to pedal at a light resistance (20W) until heart rate lowered to ~120beats.min^{-1} and perform some stretching exercises to aid recovery.

4.2.12 Statistical procedures

Data are presented as mean±SD throughout. Repeated measures analysis of variance was used to compare means between rider's heart rate zones for each competition phase, mean blood lactate concentrations, changes in handgrip strength for each phase of competition. Within the analysis, if assumptions of sphericity were violated a Greenhouse and Geisser correction was applied. There were no outliers (assessed by boxplot) and all data were normally distributed (Shapiro-Wilk test $p>0.05$). If significant differences were observed with RM-ANOVA, a Bonferroni post hoc text was used to locate those differences. An alpha level of <0.05 was taken to show statistical significance. If significant differences were observed, a least significant difference post hoc text was used to locate those differences. A one-way analysis of variance was used to compare means for each stage for LT, %$\dot{V}O_{2peak}$ and %$\dot{V}O_{2peak}$ at LT for each phase of competition. Pearsons Product Moment Correlation was utilised to determine whether there were relationships between duration of recovery and change in physiological variables in each phase of a ODE. Data were analysed using Statistical Package for Social Sciences (SPSS) for Windows, version 19.

4.3 Results

4.3.1 Heart Rate

Mean heart rate for the sixty seconds preceding each competition phase is presented in Table 4.2. There was no significant difference reported between mean pre-competition HR and phase (DR, SJ, XC) (p=0.218).

Table 4.2: Mean heart rates in the sixty seconds preceding each competition phase of Novice ODE (mean ± SD) (DR n = 25; SJ n = 25; XC n = 20).

	Heart Rate (beats.min^{-1})		
	DR	**SJ**	**XC**
Mean	148	143	143
SD	18	13	18
Minimum	108	117	95
Maximum	178	175	177

There was no significant difference for mean warm up HR and phase (p>0.05) as displayed in Table 4.2. There were also no significant differences between time spent in relative metabolic zones between the warm ups for DR, SJ and XC (p >0.05) as observed in Figure 4.1. There was no significant relationship between duration of recovery between either DR and SJ or SJ and XC on any of the physiological variables measured (p >0.05). For all phases the majority of time was spent in the moderate (DR=35%, SJ=23%, XC=38% total duration) and hard HR zones (DR=55%, SJ=67%, XC=54% total duration).

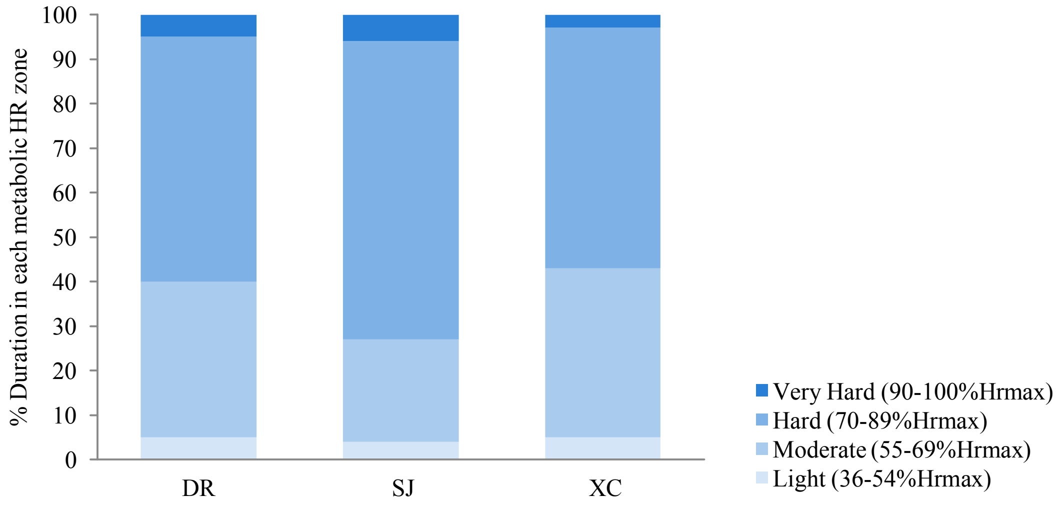

Figure 4.1: Relative duration spent in each of the five heart rate zones (%HR_{max}) for the three warm up phases of Novice ODE (DR n=25; SJ n=25; XC n=20).

There was a significant effect for mean HR and phase ($f_{(2, 19)}$ = 41.31, p<0.001), with the greatest mean±SD observed throughout the XC phase (177±10 beats.min^{-1}) followed by the SJ phase (168±12 beats.min^{-1}), with DR phase producing the lowest mean (160±14beats.min^{-1}) (Table 4.3). There were significant difference for the time spent between the three phases of Eventing both 'hard' heart rate zones (DR 67.3%; SJ 49.4%; XC 24.7%) ($f_{(2, 19)}$ = 15.6 p<0.01) and the 'very hard' heart rate zones (DR 28%; SJ 43.1%; XC 74.8%) $f_{(2, 19)}$ = 18.67, p<0.01) (Figure 4.1).

Table 4.3: Heart rates (beats.min^{-1}) throughout the three phases of Novice ODE (mean ± SD) (DR n = 21; SJ n = 21; XC n = 21).

	DR WU	DR Comp	SJ WU	SJ Comp	XC WU	XC Comp
Mean	138	160	143	168	140	177
SD	15	14	15	12	18	10
Minimum	108	123	106	145	109	154
Maximum	164	188	166	186	193	177

Figure 4.2 reports that for the DR and SJ phases, the largest proportion of time was spent in the 'hard' (70-89%HR_{max}), metabolic zone (67.3%), (49.4%) respectively, whereas for the XC phase the majority of time was spent in the 'very hard' (74.8%).

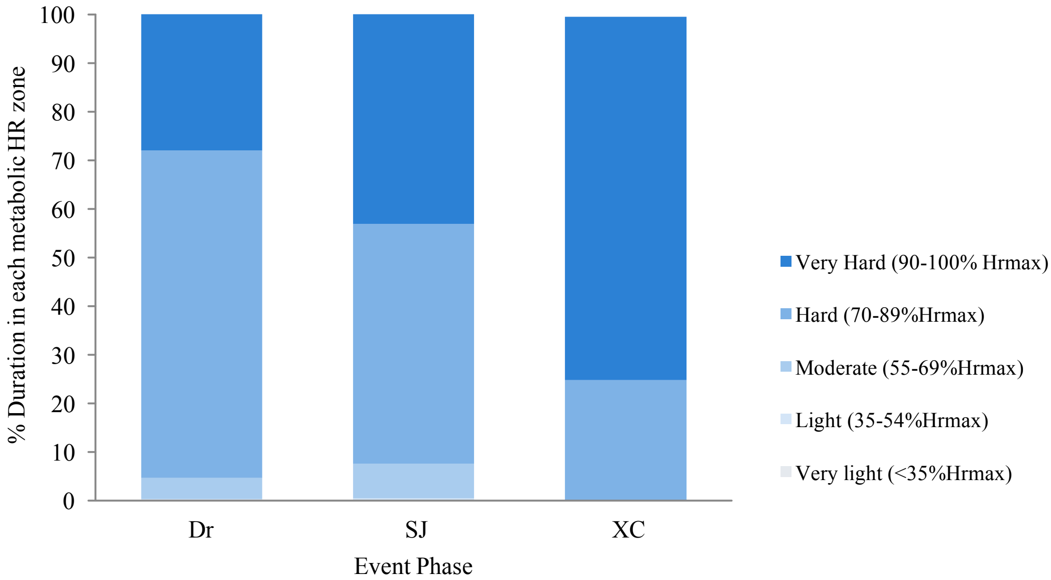

Figure 4.2: Relative duration spent in each of the five heart rate zones (%HR_{max}) for the three phases of Novice ODE (DR n=25; SJ n=25; XC n=20).

4.3.2 Blood Lactate Concentration

There was no subsequent significant difference between post warm-up BLa that were sampled in the 1-minute preceding competition (p=0.899), displayed in Table 4.4 and Figure 4.3. The higher exertion in XC and SJ phases was supported by their respective post competition blood lactate concentrations (Figure 4.3). There was a statistical significance for BLa between phases (DR 2.2 ± 1.1; SJ 3.5 ± 2.2; XC 4.7 ± 1.8) ($f_{(2, 25)}$ = 20.27, p<0.01). Peak BLa were recorded for SJ (9.9mmol l^{-1}) followed by XC (7.9mmol l^{-1}) and then DR (4.8mmol.l^{-1}).

Table 4.4: Blood lactate concentration pre and post competition throughout the three phases of Novice ODE (mean±SD) (DR n=25; SJ n=25; XC n=20).

	Blood Lactate (mmol.l^{-1})					
	DR WU	**DR Comp**	**SJ WU**	**SJ Comp**	**XC WU**	**XC Comp**
Mean	1.3	2.2	1.7	3.5	1.7	4.7
SD	0.6	1.1	0.7	2.2	0.7	1.8

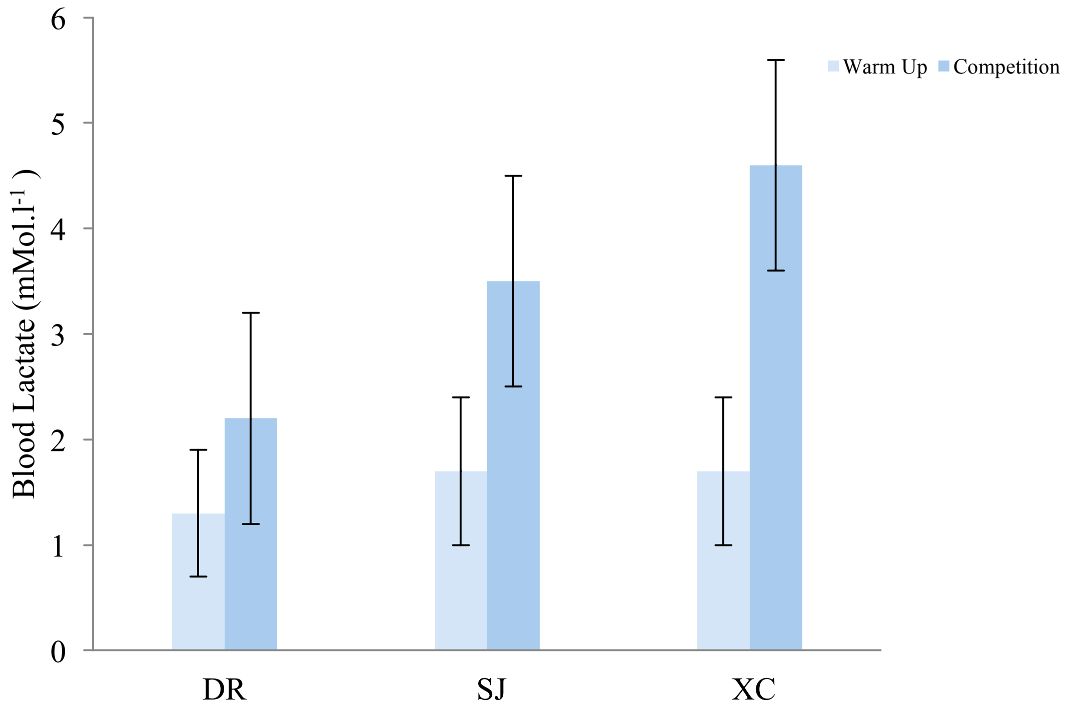

Figure 4.3: Mean (± SD) blood lactate concentration (mmol l^{-1}) for the three phases of Novice ODE riding (DR n=27; SJ n=27; XC n=22).

4.3.3 Grip Strength

Maximal GS decreased in both dominant and non-dominant hands from baseline to completion of the event (post XC phase) but was only significant in the dominant hand ($f_{(2, 25)} = 9.24$, $p<0.05$). The non-dominant hand was not statistically different however, data reports a very close alpha level (p=0.052).

Table 4.5: Mean (± SD) grip strength (kg) and relative changes (%decrease) in dominant and non-dominant hand at baseline, and post the three phases of Novice ODE riding (DR n=27; SJ n=27; XC n=22).

Grip strength (kg) and relative strength changes from BL (%decrease)		
	Dominant Hand	**Non-Dominant Hand**
Baseline	31.2 ± 4.2	27.7 ± 5.2
Post DR	28.1 ± 4.3 (-9.9%)	26.9 ± 5.2 (-3.0%)
Post SJ	29.0 ± 5.3 (-7.1%)	27.2 ± 5.5 (-1.1%)
Post XC	26.8 ± 6.2 (-14.1%)	25.2 ± 6.1 (-9.0%)

For the dominant hand, statistical differences were identified between baseline and all three phases ($p<0.05$) and between the SJ and XC phase (Table 4.5). In the non-dominant hand, statistical significance was identified between XC and all other phases, and also between baseline and SJ ($p<0.05$). There was a significant difference between dominant and non-dominant handgrip strength values at baseline ($p<0.01$). Data also reports statistical difference between mean dominant and non-dominant hand post the SJ phase ($p<0.01$). Relative strength changes from baseline (%decrease) indicate that the dominant hand fatigued more than the non-dominant hand.

4.3.4 Duration of Phases

There was a statistical difference between duration of Event phase ($f_{(2, 19)}$) = 54.28 $p<0.001$), these differences were identified between DR and SJ and between SJ and XC ($p<0.05$), but not between DR and XC. Data reports high standard deviations, indicating large variation in phase duration between participants (Table 4.6).

Table 4.6: Mean (± SD) duration (minutes:seconds) of the three phases of Novice ODE riding for warm up and competition (DR n = 25; SJ n = 25; XC n = 20).

	Duration (minutes:seconds)					
	DR WU	**DR C**	**SJ WU**	**SJ C**	**XC WU**	**XC C**
Mean	15:06	5:09	9:06	2:31	7:40	5:45
SD	6:20	1:15	4:54	0:46	4:42	1:25

4.3.5 Duration of Recovery Between Phases

Descriptive data for duration of recovery between phases can be seen in Table 4.7. The mean duration of recovery was longer between DR and SJ than between SJ and XC. There are large ranges in reported recovery time (Table 4.7).

Table 4.7: Mean duration of recovery (hour:minutes:seconds) between the DR and SJ phase and between the SJ and XC phase.

	Duration (hour:minutes:seconds)	
	DR and SJ	**SJ and XC**
Mean	1:15:3	0:31:08
SD	0:48:57	0:15:17
Minimum	0:13:52	0:10:52
Maximum	3:14:4	1:16:08

Correlation analyses of duration of recovery between phases and the individual variables of BLa, distribution of time in each metabolic HR zones, and Mean HR reported no significant relationships (p>0.05).

4.3.6 Laboratory Data Collection

The descriptive statistics for physiological variables reported at the termination of the cycle ergometer test can be observed in Table 4.8. Matched field and laboratory data can be observed in Table 4.9.

Mean predicted $\%\dot{V}O_{2peak}$ utilised for each phase was calculated using heart rate at maximal oxygen consumption during laboratory trials for n=17 participants. Mean predicted $\%\dot{V}O_{2peak}$ utilised was lowest for DR (91.89±7.52 %), which increased in the SJ (94.72±6.58 %) and in the XC (101.12±4.03 %) (Table 4.9). There was a significant difference between mean $\%\dot{V}O_{2peak}$ and phase ($F_{(2, 14)} = 29.88$, $P<0.001$). These differences were identified between DR and XC ($p<0.001$) and between SJ and XC $P<0.001$), but not between DR and SJ ($p=0.744$).

Absolute predicted exercise intensity during each phase was calculated based on heart rate at $\dot{V}O_{2peak.}$ There was as expected a significant difference between absolute predicted work rate and competition phase with mean values of 38±8 ml.kg.1.min^{-1} for DR, 39±8 ml.kg-1.min^{-1} for SJ and 42±8 ml.kg-1.min^{-1} for XC ($f_{(2, 14)} = 24.42$, $p<0.001$). These differences were identified between DR and XC ($p<0.001$) and between SJ and XC ($p<0.005$), but not between DR and SJ ($p=0.896$

Table 4.8: Descriptive statistics for physiological variables collected throughout and at the termination of the cycle ergometer test (n=17).

	V̇O2peak (ml.kg^{-1}.min^{-1})	LT (mmol.l^{-1})	Watt at LT	Max Watt (W)	%V̇O2peak at LT)	O2 consumption at LT (ml.kg^{-1}.min^{-1})	RPEmax	RERmax	HRmax (beats.min^{-1})	HR at V̇O2peak (beats.min-1)	Stages past LT	Post BLa (mmol.l^{-1})
Mean	42	2.8	127	202	69.9	29	17	1.16	177	170	3	7.6
SD	8	0.9	28	32	12.6	7	1	0.08	8	13	1	2.6
Min	29	1.6	85	135	54.7	22	15	1.05	144	129	1	3.4
Max	56	5.2	200	260	94.9	40	19	1.29	189	187	6	12.8

Table 4.9: Descriptive statistics for measured and estimated based on laboratory equivalent physiological in-field data (n=17).

	Mean HR Dr (beats.min-1)	Mean HR SJ (beats.min-1)	Mean HR XC (beats.min-1)	Relative Work Rate DR (%V̇O$_2$peak)	Relative Work Rate SJ (%V̇O2peak)	Relative Work Rate XC (%V̇O2peak)	Absolute Work Rate DR (ml.kg^{-1}.min^{-1})	Absolute Work Rate SJ (ml.kg^{-1}.min^{-1})	Absolute Work Rate XC (ml.kg^{-1}.min^{-1})	BLaDr (mmol.l^{-1})	BLaSJ (mmol.l^{-1})	BLaXC (mmol.l^{-1})
Mean	159	165	177	91.89	94.72	101.12	38.28	39.46	42.14	1.85	3.20	4.36
SD	15	13	10	7.52	6.58	4.03	7.75	7.62	7.90	0.86	1.89	2.04
Min	123	146	154	68.82	81.32	85.93	25.91	26.15	28.45	0.80	0.80	1.00
Max	183	186	192	125.23	127.64	131.79	50.76	52.31	55.27	3.90	8.20	7.90

4.4 Discussion

This study was designed to provide a scientific evidence base to determine the physiological demands placed upon Novice female ODE riders during a competitive event allowing for the future development of sports specific physical preparation strategies. The aim of this study therefore, was to characterise the physiological demands and physical characteristics of Novice level female event riders throughout the three phases of Novice level one-day Eventing. For all three ODE phases heart rate and estimated $\%\dot{V}O_{2peak}$ were found to be high and increased from the DR phase through the XC phase. The moderate blood lactate response observed for all three ODE phases did not match the effort suggested by the other physiological variables, though did indicate the importance of Event riders being able to tolerate blood lactate levels near to threshold levels. The findings of the current study do suggest that Eventing is physically demanding and requires high cardiovascular effort, however the results require further discussion as there are many variables that should be considered that may have affected the data, and thus the interpretation of it.

4.4.1 Physical Characteristics

The present study shows the sample population to have a mean age of 36 years, mean height 169cm and mean mass of 67kg. In comparison to research in a simulated Novice ODE in non-competitive riders there are considerable differences in age, height and mass reported. Roberts et al. (2010) report mean±SD age of 25 years, height of 167cm and mass of 60kg in 16 collegiate riders. There are also differences when comparing our results to data in other equestrian populations: Westerling (1983) reported mean age of 21 years and mean mass as 62kg in 13 experienced riders; Alfredson et al. (1998) report mean age as 18 years, mass as 6kg and height as 165cm in 20 collegiate riders; and Meyers and Sterling (2000) report mean age as 24 years, mass as 65kg and height as 162cm in 24 collegiate riders. The salient point is that our participant demographics are a true representation of competitive riders, compared to the convenience sampled methods used in prior literature. The most obvious variation is the reported mean age between previous research and our findings, with our mean age reported as over 10 years older than the previous studies. Our participant population being reflective of actual competitive riders versus collegiate riders can explain these results; data saw riders with an age range from 20-54 years, demonstrating the actual demographics of Novice ODE riders.

The BMI of Novice Event riders was reported in this study to be 23.5±3.2, and in agreement with previous equestrian literature detailed within Chapter Two and data reported from Chapter Three. The BMI of Novice Event riders is within the normal range (18-24.9) towards the upper limit in the categorisation of what is classified as healthy. For a competitive or 'athletic' population riders are on the upper limit of the weight and height range. With respect to the horse riders, Event Riders have previously reported lower BMI (Roberts et al. 2010) and thus lower body fat than Dressage and Collegiate riders (Devienne and Guzennec 2000; Meyers and Sterling 2000). The BMI reported within this thesis does not support that notion.

The importance of a high $\dot{V}O_{2max}$ for equestrian athletes is uncertain, results in the available literature to date suggest aerobic conditioning a required component based upon a high cardiovascular demand during horse riding activities (Guitérrez Rincón et al. 1992; Trowbridge et al. 1995; Roberts et al. 2010; Cullen et al. 2015; Sainas et al. 2016). Chapter Two discussed the wide ranges in maximal oxygen uptake amongst the available literature (33.4±1.2 $ml.kg.min^{-1}$- 54.9 $ml.kg.min^{-1}$) collected primarily using a CE. The lack of comparability of protocol design and sample population make the data non-comparable between studies. A high heart rate during equestrian related activities indicates a requirement for high maximal oxygen consumption that would presumably transfer into greater aerobic fitness in equestrians but to date the majority of equestrian related literature reports moderate values for aerobic power.

Peak aerobic power of 42 $ml.kg.min^{-1}$ in novice Event riders was observed in this study with mean maximal heart rate reported as 177 $beats.min^{-1}$. Given the low maximal heart rates reported for this study it is likely that our participants did not achieve peak aerobic power close to their maximum ability particularly when the competition maximal heart rates are higher than what was attained in the laboratory. It is likely that if laboratory CE testing did not achieve a near maximal value due to the mode or protocol design that in field estimations presented are inaccurate and the current study suggests that demand for oxygen during event riding is much higher than is actually required. This would partially explain a high cardiovascular demand during competition that does not equate to a high aerobic power during laboratory based tests. This also clarifies why estimated oxygen uptake for each competitive phase was greater than what was reported by Roberts et al. (2010) considering heart rate responses were comparable. It is important that future research explores the effects of laboratory exercise modes on physiological responses in equestrians, particularly as in field estimations of oxygen consumption based from laboratory or field based exercise tests are likely to be common in a sport where wearing gas analysis equipment whilst riding poses a safety risk. The physiological demands and factors that may affect responses are discussed within the following sections.

4.4.2 Physiological Demands

The findings from this study, suggest that Event riding is physically demanding, more so for the SJ and XC phases. The DR phase reports a mean heart rate of 160 beats.min^{-1} and an associated estimated peak oxygen uptake of 38 ml.mg.kg^{-1}. Throughout the DR phase, competitive Novice Event riders spent up to 95% of total duration (4:53 minutes) above 80% of their HR_{max}. The duration of this phase combined with HR indicate a lower overall exertion compared to SJ and XC. Data also supports lower HR and oxygen consumption values reported for this nature of riding in previous research (Westerling 1983; Devienne and Guzennec 2000; Roberts et al. 2010) and confirms the DR phase is predominantly aerobic in nature.

The SJ phase reports a significantly higher mean heart rate of 168±13 beats.min^{-1} compared with the DR phase and is supported by elevated blood lactate accumulation (SJ peak = 9.9mmol.l^{-1}, mean = 3.5±2.2mmol.l^{-1}). Estimated oxygen uptake was reported as 39 ml.kg.min^{-1}. The SJ phase reports that Novice Event riders spent up to 90% of the duration (2:19minutes) over 80% of their HR_{max}. Interestingly, and considering the SJ phase necessitates a forward seat position, more time was spent in ‘hard’ (49.4%) than ‘very hard’ (43.1%) HR zones with a minor proportion of time spent in the ‘moderate’ category (7.0%). This can be partly explained by a much shorter phase duration (2:31minutes) compared to DR (5:09minutes) and XC (5:45minutes).

The XC phase is considered the most physiologically demanding phase, mean heart rate was significantly higher than SJ and DR phases (177±10 beats.min^{-1}) and reported elevated peak oxygen uptake of 42.ml.kg.min. Associated blood lactate was reflective of an increased reliance on anaerobic metabolism (peak = 7.9mmol.l^{-1}, mean = 4.7±1.8mmol.l^{-1}).

This study is novel, no other study has investigated physiological responses of Event riding within a competitive setting; results are in agreement with a high aerobic demand, or at least a high heart rate which has been previously reported within horse back riding sports. The mean HR data from this study during the SJ (168 ±12 beats.min^{-1}) and XC (177±10 beats.min^{-1}) is similar to Westerling (1983) and Trowbridge et al. (1995) who reported values of 176±24beats.min-1 and 136-178beats.min^{-1} throughout Show Jumping and National Hunt racing, respectively. Devienne and Guzennec (2000) reported lower values in walk (106 beats.min^{-1}), trot (131 beats.min^{-1}) and canter (159 beats.min^{-1}), which are more comparable to Sainas et al (2015) where values were (~100beats.min^{-1} during walk, 120beats.min^{-1} during trot peaking during canter (~140beats.min^{-1}). In universal agreement, comparative findings are that heart rate progressively increases with gait of the horse (walk, trot, canter, jump). Direct comparisons between trials are difficult due to the variances within each investigation, including the horse (Devienne and Guzennec 2000) and protocol design. There are also simulation versus competition environmental considerations to consider; it is likely the competitive situations, or simulations that require novel equipment or jumping efforts will induce some psychic stressors that will elevate physiological responses accordingly. These factors have been deliberated in more detail in section 4.4.3.

The values for canter in the Devienne and Guzennec (2000) investigations are comparable to our data for the DR phase in the current study where reported mean HR was 160 beats.min^{-1}. A variation in heart rate response in comparison to previous studies is reflective of specific physiological characteristics of ODE and as intimated likely to be affected by competition environments. Peak and mean BLa in SJ and XC phases from our research (SJ peak = 9.9mmol.l^{-1}, mean = 3.5±2.2mmol.l^{-1}; XC peak = 7.9mmol.l^{-1}, mean = 4.7±1.8mmol.l^{-1}) are similar to those previously observed in equestrian jumping sports. Guitérrez Rincón et al. (1992) found that in a SJ round mean BLa ranged from 4.0-6.3mmol.l^{-1} in equestrians which implies the involvement of anaerobic energy systems and is comparable to our study. Similarly in National Hunt racing Trowbridge et al. (1995) observed mean blood lactate values of 7.1mmol.l^{-1}. The study within this chapter collected earlobe blood samples six-minutes post completion of each phase to allow participants to complete their phase, dismount, and to allow time for lactate to diffuse from muscle to blood, compared to previous research in Event riders who collected samples 1-minute post each phase (Roberts et al. 2010). The differences in sampling method could account for differences seen in mean blood lactate data, and can also be explained by this study being reflective of actual competition rather than non-competitive riders in a simulation environment. Differences in heart rate and blood lactate responses between competition and training may be explained by the effects of adrenaline throughout competition. Adrenaline directly increases lactate release (Gjedstead et al. 2011) and norepinephrine is elevated in competition versus training situations (Hoch et al. 1988). From this data it is reasonable to conclude that a significant amount of BLa is produced from Novice ODE. However, BLa was greater in the laboratory at comparable heart rates. This is presumably due to a lesser muscle mass being recruited during horse riding.

Roberts et al. (2010) reported a mean BLa of 9.5±2.7 $mmol.l^{-1}$ post the XC phase which was twice the value observed in this study. Values were 2.2±1.1, 3.5±2.2, and 4.7±1.8 $mmol.l^{-1}$ for DR, SJ, XC respectively. Roberts et al. (2010) sampled at 1-minute post completion of the phase, compared to our data using a 6 minute post phase completion sampling method which may have a direct impact on the difference in reported findings. If the sampling duration was responsible for differences, the direct sampling method of Roberts et al. (2010) would have been expected to be lower and not higher as it would be due to wash out. Roberts et al. (2010) did not report data on the warm ups, the authors asked the participants to warm up as they would at a competition. There is no documentation by Roberts et al. (2010) of BLa pre phase and so it is unknown whether BLa returned to baseline levels with rest between phases or whether BLa has accumulated as a result of limited rest periods. The duration and intensity of each warm up and unknown rest periods between phases may have impacted the BLa collected for each phase.

Sainas et al. (2016) utilised a $CO_{2excess}$ method to asses anaerobic contributions and reported that anaerobic glycolytic energy sources were indeed recruited and significantly increased during cantering. This parameter however remained below the anaerobic threshold suggestive that anaerobic energy sources were not required to a large extent and were only moderately activated during riding; which is in agreement with Guitérrez Rincón et al. (1992), Trowbridge et al. (1995) Roberts et al. (2010) and Perciavalle et al. (2014) and the current study. The research conducted on blood lactate during equestrian activities indicates that jumping horses requires anaerobic metabolism of the rider and as the duration and number of jumps increase (e.g. during a national hunt race or during the cross country phase in Eventing) the reliance on the anaerobic pathways increases as a higher blood lactate concentration is reported.

Roberts et al. (2010) measured oxygen consumption throughout the three phases of a simulated Novice ODE and reported mean values of 20, 28, 31 $ml.kg^{-1}.min^{-1}$ for DR, SJ and XC respectively. Sainas et al. (2016) reported oxygen uptake increase from walk 13.5 $ml.kg.min^{-1}$, trot 15.3 $ml.kg.min^{-1}$ and canter, 22 $ml.kg.min^{-1}$. Both studies report oxygen uptake values which are much lower than our estimated data, there are distinct differences between the two research investigations, one investigates gait of the horse and the other mean oxygen uptake throughout a phase of a simulated event which provides explanation for the differences. The oxygen uptake data as reported by estimate within the current study is far greater and questions the validity of it. Due to logistics of data collection during competition this study did not measure oxygen consumption directly during the ODE. This study did however estimate $\%\dot{V}O_{2peak}$ and oxygen consumption based upon HR at $\dot{V}O_{2peak}$ from laboratory measures. Based on this method our study reports data as 38, 39, 42 $ml.kg^{-1}.min^{-1}$ for DR, SJ and XC respectively. This is an interesting finding as mean HR and phase duration are comparable to that of Roberts et al. (2010) yet oxygen consumption data was lower and indicative that the estimations are over predictions and thus not reliable data. In addition, blood lactate was greater for Roberts et al. (2010) which indicates that either the population used were less aerobically conditioned than our sample population, or that estimations from laboratory predictions are inaccurate. The sub-maximal values attained on the cycle ergometer in the study population within this chapter is a likely contributor and questions the appropriateness of CE as a mode of exercise testing. The majority of equestrian related research has used a CE to induce maximal exercise despite known under-reporting of maximal values in comparison to TM exercise. There are safety advantages to using a CE, that and the seated nature of equestrian sports has permitted the CE to be a mode for investigation, however the results from this study questions the suitability as a laboratory reference method in equestrians.

When considering grip strength, a mean decrease was observed post competition, suggesting a degree of fatigue. Data is in agreement with Roberts et al. (2010) that mean GS decreases from baseline to post competition phase. However, our data also suggests that it is the XC phase that causes significant fatigue in both hands. This is interesting as the DR and XC phase are comparable in duration, yet a decrease in strength post XC suggests that GS is used more throughout this phase. The other probable causal factor for decreased strength may possibly be local cumulative muscular fatigue throughout the phases of ODE. Interestingly, Sainas et al. (2016) speculated that bouts of isometric forearm strain as the main sources of BLa during horse riding, suggesting that fast twitch fibers utilised within the forearm produce more lactate than slow twitch fibers (Saltin 1985). It is therefore reasonable to consider that arm muscle activity contributes to lactate production during riding; given the decrease of grip strength as a result of the XC phase, elevated BLa within this phase may be related to forearm muscle activity.

When considering relative decrease in GS it is interesting that our data showed the dominant hand to fatigue more than the non-dominant hand (post XC; dominant -14.1%, non-dominant -9.0%), and suggests that the dominant hand is recruiting a higher muscular demand than the non-dominant hand. Riders were, along with asymmetric fatigue, shown to be initially asymmetric in strength between dominant and non-dominant hands at baseline. Recent research in rein tension between right and left-handed riders indicates that different utilisation of reins is influenced by laterality and asymmetry in riders (and the horse), which subsequently increases asymmetry of rein tension applied. The horse is ideally trained to pressure in the mouth through the bit, which is guided by the pressure placed on the reins from the rider's hands. Strength asymmetry that is not recognised by the rider negatively influences training success (Khunke et al. 2010). It is thus in a rider's interest to incorporate strength training to improve both strength and symmetry of the forearms and upper body.

4.4.3 Factors affecting physiological mechanisms

Heart rate and %$\dot{V}O_{2peak}$ consumption during all three phases of the ODE were near maximal and sometimes even greater. Lactate data however were approximately near 4mmol.l^{-1}. The high heart rate and moderate BLa throughout all three phases was intriguing. With such high heart rates throughout competition a more marked blood lactate concentration would be expected to match the near maximal cardiovascular demand (Lind1983). In the laboratory when heart rates and oxygen consumption were comparable to the field, blood lactate concentration was much higher.

Sainas et al. (2016) investigated the cardio-metabolic responses to horse riding in n=19 (9 male, 10 female) horse riders during a live horse test comprising of 10 minutes walking and 10 minutes trotting followed by five minutes in canter. A consistent elevation in heart rate during the trial was observed (~100beats.min^{-1} during walk, 120beats.min^{-1} during trot) peaking during canter (~140beats.min^{-1}) which is comparable to available comparative findings. It was noted by the authors that heart rate was significantly elevated compared to other cardio-metabolic variables such as oxygen consumption, blood lactate and ventilation and thus using heart rate as a method for determining physiological load is misleading as it was out of proportion in comparison to other physiological variables. It is important to note the protocol design when considering heart rate responses to the trial. The protocol was designed in a consecutive order i.e. walk, trot, canter as opposed to a randomised order which the authors note may induce cardiac drift. Cardiac drift is whereby there is a gradual increase in heart rate unrelated to energy expenditure caused by dehydration, hyperthermia and cardiac pre load (Crisafulli et al. 2006a; Tocco et al. 2015). Sainias et al. (2016) concluded that the short duration (20 mins) and moderate intensity was an unlikely contributing factor during this protocol. Sainas et al. (2016) report that heart rate and oxygen uptake increase from walk (Heart rate ~110 beats.min^{-1}; $\dot{V}O_2$ ~13.5 ml.kg.min^{-1}) through trot (Heart rate ~128 beats.min^{-1}, $\dot{V}O_2$ ~15.3 ml.kg.min^{-1}) and canter, with physiological variables being substantially greater during canter (heart rate 158 beats.min^{-1}; $\dot{V}O_2$ ~22 ml.kg.min^{-1}). Note the approximations as Sainas et al. (2016) reported data graphically so given numbers are estimates, additionally Sainas et al. (2016) presented $\dot{V}O_2$ data as ml.L^{-1} and so data has been converted to ml.kg.min^{-1} using the samples mean body weight for comparison. The data from this study and other equestrian literature are comparable for both heart rate and $\dot{V}O_2$ data. This further supports that during actual riding there is a higher heart rate than what would be expected to match for oxygen uptake on conventional exercise modes. Interestingly this research noted that estimating physiological demands from heart rate only is misleading during riding and that caution should be used when estimating the energy from heart rate as their data suggests that deriving energy expenditure from heart rate introduces a substantial overestimation. There was minimal discussion concerning the causal factors for elevated heart rates however and since it appears to be a common theme within the literature there is justification for future research to have a more comprehensive understanding of the use of heart rate monitoring in equestrian sports.

As introduced within Chapter Two, a high heart rate with moderate blood lactate has been documented in other sports such as motocross (Konittinen et al. 2002; Konittinen et al. 2007; Konittinen et al. 2008) rock-climbing (Sheel et al. 2004) and sailing (Vogiatziz et al. 2002; Cunningham and Hale 2007). Researchers have identified that physiological data were not matched i.e. heart rate was higher than necessary for recorded oxygen uptake with moderate blood lactate concentrations. These sports mentioned all require a high degree of isometric muscle contractions. Such isometric muscle activity is considered to simulate chemical afferents via the muscle metaborereflex which to date has explained a dissociation between heart rate and oxygen uptake (Konittinen et al. 2002; Konittinen et al. 2007; Konittinen et al. 2008). These physiological responses are not apparent in dynamic sports where a rise in heart rate is linear to oxygen consumption and where a more marked blood lactate concentration is apparent.

Motor-cross, rock-climbing and sailing require continuous intermittent but predominant isometric muscle contraction, e.g. when landing after jumps on the bike, when gripping in rock climbing and when performing tacking and hiking maneuvers in sailing (Vogiatziz et al. 2002; Cunningham and Hale 2007). Unlike many sports, where the primary aim is destabilisation i.e. running, throwing etc. one of the primary objectives of both Event riding and the above named sports is to stabilise and thus remain on the horse, vehicle or boat which explains the requirement for isometric muscular contraction (Konttinen et al. 2007; Konttinen et al. 2008). Though yet to be investigated in Event riders, earlier EMG investigations of the riders' muscles during walk and trot gaits indicate isometric muscle activity predominates (Terada et al. 2004). The conclusions given for the disparity in heart rate and oxygen consumption may provide an additional explanation as to why reported data for estimated $\dot{V}O_2$ to be so high in comparison to previous studies (Roberts et al. 2010).

The relationship between isometric muscle contraction and cardio-respiratory factors may explain the responses of HR, BLa and $\%\dot{V}O2_{peak}$ during Novice ODE. Where repeated intermittent isometric contractions are required it is reasonable to expect that blood pressure and heart rate would steeply rise out of proportion to $\dot{V}O_2$ (Sheel et al. 2003). In response to isometric handgrip exercise, there has been a reported increase in cardiac output and preferential re-distribution of blood flow to working skeletal muscle (Sheel et al. 2003). It is well-established that isometric handgrip exercise causes a disproportionate rise in heart rate compared with oxygen consumption that is not observed with dynamic exercise (Sheel et al. 2003). Isometric contractions hinder local blood flow whereas dynamic exercise facilitates circulation. The heart rate response to isometric exercise is also dependent on the size of the contracting muscles. Muscle receptors are sensitive to metabolic changes related to muscle activity (Sheel et al. 2003) and during isometric contractions of increased intensity. With increased muscle mass the metabolite production is greater which may, as a consequence, increase activation of the muscle metaboreflex and result in higher heart rates than the $\%\dot{V}O_{2peak}$ observed (Lellamo et al. 1992; Fisher and White 2004).

Throughout Eventing, it is likely then that a similar phenomenon may exist due to the requirement for repeated isometric muscle activity to stabilise the trunk upon landing after jumps, upon absorbing impact with the horses gait and with repetitive forearm contractions (Sainas et al. 2016). This provides a principle to explain the high heart rates combined with concomitant low BLa. It may also elucidate the elevated $\%\dot{V}O_2$ and estimated absolute $\dot{V}O_2$ data that are not comparable with work previously done on Event riders (Roberts et al. 2010) or equestrian populations (Westerling 1983; Devienne and Guzennec 2000).

Future research should determine if heart rate is elevated compared with other physiological variables during gaits and positions utilised during Event riding by analysing the relationship between heart rate and oxygen consumption in a simulation setting. Furthermore, simultaneous EMG analysis will provide an idea of the frequency and duration of isometric muscle activity which may further explain the HR-$\dot{V}O_2$ response during ODE. Our data indicates that heart rate and blood lactate analysis alone may not be a true indicator of physiological responses to horse riding.

As intimated in the review of literature, psychic stress during competition elevates circulating catecholamines (Baumingather et al. 1988; Dimsdale et al. 1980) which stimulate respiratory, cardiovascular, metabolic and thermoregulatory function. It is likely that heart rate was affected by competition adrenaline and in addition to the potential disproportion of heart rate with other physiological variables as a result of muscular activity. Interestingly, heart rate and blood lactate data reported in this chapter were comparable to previous literature that was not conducted in a competition situation (Roberts et al. 2010; Beale et al. 2015; Sainas et al. 2016) which is supportive of the notion that factors such as muscle activity in addition to competition adrenaline may be affecting physiological responses observed.

4.4.4 Competition Considerations

It is interesting to note that the warm up times for each corresponding phase of evening are ~15mins, ~9min and ~7mins for DR, SJ and XC respectively. This means that the actual times spent practicing and performing for each individual phase are ~20mins, ~12mins and ~12mins for a total on horse time of ~44mins. The warm up durations accumulate to more time than the actual competition and it is worth considering the compounding affect this may have on fatigue. It has also been noted that the relative intensity of each phase increases throughout the day and interestingly recovery time between DR and SJ are ~1hr 15min and there is ~30mins between SJ and XC This thesis reports the least physiologically demanding phase (DR) has the most recovery and the most physiologically demanding phases have the least amount of recovery in absolute time. When considering these times as relative, the work-to-rest ratios are the same both showing 1:15; the large amount of absolute time between DR and SJ allows for the rider to gain passive rest and opportunity to refuel and rehydrate which are important considerations for successful performance. There is limited time between SJ and XC and increased time demands due to the requirements of re-dressing (both rider and horse) and preparation for the ensuing phase. This limited window of recovery may have a subsequent effect on performance and more worryingly on the most physiologically demanding phase of the event. In the development of future research concerning rider performance, these considerations are worth addressing and accounting for in the overall demand of the ODE to assist equestrian athletes to physically perform to the best of their ability for each individually phase. In addition to the considerations of warm up and rest durations that lend to the overall physiological demand, Event riders may well ride multiple horses within one competition. Though this was not the case for this research, it is common practice to ride multiple horses and it is very practicable that a rider may ride multiple phases not in order of each other (e.g. due to the timings a rider may ride one horse in the Dr and SJ, then the second in the SJ, the first XC then the second SJ and XC, for example) in one day and is a consideration when interpreting and using the data within this study detailing the demands of Novice Event riding and applying it to the general Eventing population.

4.4.5 Limitations and Further Research

The present study has provided novel data, there are however a number of limitations that should be considered and acknowledged in future studies, some of which have already been considered and discussed. One of the main limitations of this study was the use of predictions to estimate oxygen consumption during each phase of the ODE competition. Predicted $\%\dot{V}O_{2peak}$ utilised for each phase was calculated using heart rate at maximal oxygen consumption, given that heart rate maximum was relatively low for the laboratory reference test it is likely that field estimations presented of $\%\dot{V}O_{2peak}$ are over-estimated. For this competition based study, measuring oxygen uptake during the phases was not appropriate and thus an estimation based method was justified. Future research should concentrate on measuring oxygen uptake in a live horse setting but instead of solely reporting and averaging data over a simulated phase such as the study of Roberts et al. (2010), the relationship between HR and O_2 should be investigated in relation to muscle activity. This specific research focus will determine if physiological data presented in this study is reliable and to further understand the response to equestrian activities.

As discussed, there are factors that may have affected the physiological responses in this study; the physiological demands of Event riding were assessed over multiple competition venues, which had variations regarding DR test, SJ and XC courses that would account for some variation in the responses documented. As stated within this chapter, the use of multiple courses was justified to document the demands of Event riding rather than to investigate the demands to one particular course.

This discussion highlighted and questioned the use of CE in equestrian sports as a mode to attain aerobic power despite the popularity of its use in riders to date. The use of cycle ergometry from the data in this study suggests that it may have under-reported true heart rate maximum and peak oxygen uptake based on non maximal values achieved in the laboratory and has affected in field estimations of workload.

4.5 Conclusion

This study was the first to report actual physiological data collected during a competitive ODE. These findings show that physiological strain during ODE is considerable and wide ranging, heart rate and absolute and relative oxygen consumption data estimated from incremental cycle ergometry suggest that Eventing, particularly during the XC phase elicits near maximal cardiovascular demand. This study suggests that heart rate is not a reliable measure to use for the interpretation of physiological demand in Eventing, since it is elevated in comparison with other physiological variables. Blood lactate concentration is approximately near to $4 mmol.l^{-1}$ and increases throughout the progression of competitive phases despite returning to mean baseline levels in-between and is a more reliable indicator of physical stress. The BLa response suggests an increased reliance on the anaerobic system throughout SJ and XC probably as a result of repeated and prolonged isometric contractions, particularly of the trunk and thigh musculature. Blood lactate concentrations were lower than would be expected for near maximal heart rates, but is presumably due isometric contractions and a smaller muscle mass being recruited than would be for dynamic sports.

The novel data presented on the physiological demands of Novice level Event riding may be used as a guideline for the interpretation of physical requirements in this sport. The data does present many questions however, as the use of heart rate as a marker for exercise intensity in Eventing is questioned based on a high heart rate in comparison to other physiological variables. There are factors that may affect an elevated heart rate; competition adrenaline, horse and competition variability and heat stress for example. This physiological response has however been reported in other sports where isometric muscle action predominates. The causal factor for elevated heart rates in comparative literature has been concluded to be as a result of a dissociation between heart rate and oxygen consumption. As such, it is recommended in addition to the aforementioned research focusses, that further investigation of the physiological responses to horse-riding are undertaken, specifically concentrating on determining the relationship between heart rate and oxygen consumption, and the affect of muscle activity on this relationship in an equestrian population to further determine and document the physiological demand associated with this sport.

CHAPTER FIVE: THE PHYSIOLOGICAL AND NEUROMUSCULAR DEMANDS OF A LIVE HORSE EXERCISE TEST

5.1 Introduction

The high heart rates, high relative (estimated) $\dot{V}O_{2peak}$ with only moderate BLa throughout all three phases of a Novice ODE as reported in Chapter Four is not a typical response to exercise. With such high heart rates throughout a Novice Eventing competition, a more marked BLa concentration would have been expected to match the maximal demand. The results reported in Chapter Four have been supported by more recent literature whereby heart rate has been reported to be out of proportion to other physiological responses to a riding situation. Sainas et al. (2016) also indicated that during the gaits of walk, trot and canter, heart rate was considerably high when compared to other cardio-metabolic parameters. The authors also suggested that caution should be used when estimating energy expenditure from heart rate as it introduces a substantial over estimation in energy expenditure which corroborate the results reported in Chapter Four. There are multiple causal factors for the elevated heart rate reported during riding, factors such as competition anxiety and heat stress are variables that may contribute to a heart rate that is not reflective of true energy expenditure. In addition to aforementioned variables, existing literature intimates that muscular activity may be a contributing factor for the evidenced elevated heart rate.

Equestrian disciplines are considered to be travel sports, where the primary goal is stabilisation of the rider as opposed to destabilisation of the athlete, which is seen in most dynamic sporting activities. The common performance factor in travel sports is that due to their stabilitative nature, many are reliant on isometric activity (Bompa and Haff 2009). A complete electromyographic profile of muscular activity during horse-riding is absent and isolated to walk and trot. Terada (2004) concluded that muscle activation patterns of a rider's upper body were consistent throughout the same phase of the trot and the horses movement patters were somewhat responsible for muscle activations patterns of the rider in walk and trot. The horses gait pattern will affect general motion patterns of the rider and, due to muscular control, expert riders will appear less shifted in their mounted positions.

During the SJ and XC phase of an Event, the rider must adopt two main positions, seated; displayed in walk, sitting trot and canter, and the light seat[2]; seen in faster canters/gallops or where jumping is involved. During these phases where a light seat is required, the rider presumably (based on joint movements) exhibits prolonged isometric efforts of the lower (knee flexion within the range of ~65°) and upper limb muscles (elbow flexion at ~90°) (Lovett et al. 2005). The light seat canter position has yet to be investigated, its seated counterpart was reported to have a limited (~5°) range of motion at the lower leg (relative to the horizontal), thigh (measured at knee relative to the horizontal) and trunk (measured at hip relative to the horizontal) which suggests a large proportion of muscle activity would be isometric in nature. Based upon the biomechanical information available, it was considered pertinent to investigate muscle activation patterns of the *rectus abdominis*, and *rectus femoris* in riders. The *carpi flexor radialis* has an important role in forearm flexion, Chapter Four highlighted significant decreases in strength from baseline in GS and thus this muscle was selected in addition to allow work to be comparable to that of Terada et al. (2004). The *latissimus dorsi* is one of the largest muscles in the back and plays an important role in extension, adduction and transverse extension of the shoulder and is the only muscle connecting the spine to the arms. As such, this muscle was considered important in riders to identify muscle action of the riders back. Due to the nature of a large area of the rider's body being in contact with the horse during riding, sEMG measurement has its limitations and muscles such as *gluteus medius,* the adductors and *gastrocnemius* are not able to be recorded due to the interference the sEMG electrodes would have with equitation technique.

Though the responses to isometric muscle action on physiological responses of horse-riders has not been investigated, there has been some research reported in other travel sports including motor cross riding, rock climbing, sailing and kitesurfing whereby physiological responses such as elevated heart rates are combined with low $\dot{V}O_2$ and BLa

[2] Light seat canter is where the rider has feet in the stirrups and where weight bearing is through the rider's legs and there is no contact with the riders seat and the saddle.

concentrations that do not match a profile reported during dynamic activity are seen. The repetitive isometric contractions in these sports stimulate chemical afferents via the muscle metaboreflex, which explains reported heart rate-$\dot{V}O_2$ dissociations (Konittinen et al. 2002; Cunningham and Hale 2007; Vogiatziz et al. 2007; Callewart et al. 2013).

It is established that isometric exercise causes a disproportionate rise in heart rate compared with oxygen consumption that is not linear as observed for dynamic exercise (Sheel et al. 2003). This disproportionate rise in HR and not $\dot{V}O_2$ is is due to isometric muscle contraction hindering local blood flow in contrast to dynamic exercise where the movement facilitates local circulation. The heart rate response to isometric exercise is also dependent on the size or the magnitude of activation of the contracting muscles. Muscle receptors are sensitive to metabolic changes related to muscle activity and during isometric contractions of increased intensity and increased muscle mass the metabolite production is greater which may as a consequence increase activation of the muscle metaboreflex (Lellamo et al. 1992; Fisher and White 2004). Considering that heart rate substantially increases during light seat canter and jumping (Chapter Four, Devienne and Guzennec 2000; Guitérrez Rincón et al. 1992; Trowbridge et al. 1995; Roberts et al. 2010; Sainas et al. 2016) it is presumed that as the rider progresses through the gaits of the horse the alteration in muscle activity is partly responsible for the increased physiological response.

There have been studies that aim to characterise physiological responses of riding to gait of the horse since the completion of this body of research, yet to date have not been matched with investigating muscular responses. It is not possible to measure variables such as oxygen uptake nor muscle activity during a competition environment and thus a simulation trial is appropriate. Though a mechanical horse simulator may seem like an appropriate tool to standardise variables, the use of mechanical horse simulators to determine physiological responses to riding have been criticised (Appendix 1). Walker et al. (2016) noted that the use of mechanical horse simulators should be used with caution based on simulators producing incorrect movement patterns. To date, research indicates that general riding, show jump and racehorse simulators have their merits in training riders but do not replicate the physiological nor the biomechanical demands of actual horse riding. The lack of comparability in the movement patterns between the mechanical horse simulator and to riding a live horse presumably require different amplitudes of muscular activity, and possibly different muscle recruitment and thus is not an appropriate tool to investigate physiological or muscular responses to riding.

As such, it seems pertinent to develop a live horse test in a controlled simulated environment to determine the affects that gait and position combinations utilised during a novice one-day event have upon the heart rate, oxygen consumption, BLa and sEMG responses to riding a live horse, particularly where a light seat and jumping efforts are included since this is where the marked physiological responses occur.

5.1.1 Aims

The aim of this study was to determine the physiological demands and muscle activity of riders on live horses in a variety of equine gaits and rider positions utilised during a Novice ODE, including jumping efforts.

5.1.2 Objectives:

1. To determine heart rate, blood lactate concentration, oxygen uptake, and RPE responses of horse-riders to a live horse exercise test during walk, trot (rising and sitting), canter (seated and un-seated) and during the jump.
2. To determine relationships between heart rate and oxygen consumption during riding a live horse.
3. To determine composite and mean muscle activity of the *rectus abdominis, latissimus dorsi, flexor carpi radialis and rectus femoris* of horse-riders during a live horse exercise test during walk, trot (rising and sitting), canter (seated and un-seated) and during the jump.
4. To determine the relationship between composite muscle activity and physiological variables.

These study aims translated into hypotheses are as follows:

1. Heart rate, oxygen consumption, blood lactate and RPE will increase as the on-horse exercise test progresses through the set stages.

2. There will be a non-linear relationship between heart rate and oxygen uptake during riding a live horse.
3. Composite muscle activation will increase according to the stage (and thus gait of horse and/or position of the rider) during an on-horse exercise test.

5.2 Methods

5.2.1 Participants

Thirteen females (mean±SD age 24.2±5.9years; height 164.2±4.4cm; mass 64.4±8.2kg) actively engaged in horse-riding for a minimum of three times per week for a minimum of two years participated in this study.

5.2.2 Study Design

Participants completed two independent exercise tests on different modes of exercise; a treadmill (TM) and a live horse (H), justification and test outline is presented in section 5.2.4. Participants were assigned to the order of each of the exercise modes in a counterbalanced design, with a maximum of one week and a minimum of three days between each test situation. All participants were advised to report to the laboratory or field test rested (i.e. having performed no strenuous exercise in the preceding 24 hours), euhydrated and at least 3 hours following the consumption of a light carbohydrate based meal (Winter et al. 2007). Each participant wore light athletic clothing for the TM test. Full riding attire was required for the live horse test including a hat, gloves, long boots and a body protector was recommended.

5.2.3 Anthropometrics

The experimental protocols received Institutional Ethics Committee approval, written consent and a pre-exercise health screening questionnaire was obtained for all participants (Appendix 3c). Each participant wore light athletic clothing. Height and body mass was measured, and BMI was calculated as outlined in Chapter Three (Section 3.2.5).

5.2.4 Physiological Monitoring

For both test situations heart rate (HR) was monitored continuously using telemetric heart rate monitors (Polar RS800CX Multi, Polar Electro, Kempele, Finland) sampling at 2-second intervals throughout. Heart rate was averaged over the last 30s for each stage, RPEo, RPEp and BLa concentration were sampled during the last 30s of each stage (as outlined in Chapter Three). Stage specific heart rate was considered the highest value reported for each phase. Throughout exercise, respiratory and pulmonary gas exchange variables were measured using an Oxycon Pro Mobile breath by breath gas analyser (Oxycon, Viasys). Before each test the O_2 and CO_2 analysis systems were calibrated using ambient air and gas of known O_2 and CO_2 concentrations, (O_2 19.4%, CO_2 0.6% and Nitrogen balance) according to the manufacturers' instructions. A post BLa sample was extracted immediately upon completion of and four minutes post the test to identify post-test BLa. The $\dot{V}O_{2peak}$ in all stages was identified as the highest 5 second average value reached during the test, having reached two $\dot{V}O_{2max}$ criteria of; a respiratory exchange ratio (RER) greater than 1.15, a BLa concentration of $8mmol.l^{-1}$, or a peak HR of 90% of the age predicted maximal value (Noble et al. 1983; Caputo et al. 2003).

An additional study was conducted throughout the development of this thesis entitled 'A comparison of mechanical horse, cycle ergometer and treadmill exercise modes on heart rate, oxygen uptake and blood lactate response in female horse-riders'. The complete study is presented within this thesis and can be read in Appendix 1. The results of this trial reported that of the three modes investigated, that a TM would be the most suitable mode for laboratory reference testing in horse-riders, based on the ability for it to attain a higher $\dot{V}O_{2peak}$ value at comparative heart rates. The use of a TM to attain $\dot{V}O_{2peak}$ as evidenced in Appendix 1, is a more accurate measure compared to CE modes which under-reported $\dot{V}O_{2peak}$ in an equestrian population. The TM mode gives the opportunity to present a more accurate relative percentage of maximum of physiological demand that riders are exposed to during on-horse exercise. As such, this definitive investigation uses a TM to investigate peak oxygen uptake as opposed to a CE which was utilised in Chapters Three and Four as is the recommendation for future research investigations.

Peak oxygen consumption ($\dot{V}O_{2peak}$) was determined using a continuous incremental exercise test on a motorised treadmill (Woodway, USA). Participants were familiarised with the treadmill, which included a safety briefing and allowed a five minute warm up (ACSM 2009). Participants commenced the test at an incline of 1% at 7.0km/h. Speed was increased by 1km/hr every minute until RPEp outlines in detail within Chapter Three) reached 15/16 on the Borg scale. At this point, speed remained the same and incline was increased by 0.5% until volitional exhaustion occurred. Prior to the increase in stage, RPEp (recorded for the working muscles) and RPEo (general cardiovascular exertion) were recorded. Where RPE is reported within the results, it is RPEo since RPEp was only used for the assessment of incline increases. Upon completion of the test participants were asked to remove the face mask and complete a warm down until heart rate reached below 120 beats per minute (ACSM 2009).

5.2.5 Live Horse Protocol

Participants completed an originally designed, mounted exercise test on a live horse. The testing took place in a 60x80m outdoor equestrian arena at an equestrian centre in the UK, arena set up is presented in Figure 5.2. All horses and riders were invited and attended a habituation situation the week prior to testing commencement. The arena and jumps (Figure 5.1) were available for all riders and horses at a 60-minute time slot to expose themselves and their horses to the test situation. Each horse and rider completed the exercise test stages including mock rest periods to mimic BLa testing, however physiological nor sEMG measures were taken during this habituation period.

Pre-testing, riders were fitted with a heart rate monitor, the breath by breath gas analyser (Oxycon, Viasys) with full facemask, and with eight sEMG electrodes (Delsys® Trigno™). A stopwatch and video were used to synchronise exact timings of each stage and jump take off (jump take off was considered when the horses trailing forelimb lifted off of the floor in all occurrences).

For the day of testing, each of the riders were asked to warm up their horses in both directions in walk (3 minutes), trot (rising or sitting) (3 minutes) and canter (seated or light) (3minutes). They were permitted five minutes to complete three warm up jumps, the first an 80cm cross pole, the second a 90cm upright, the third a 1m oxer[3]. Post warm up, participants were allocated a 5-minute window for time to check equipment and ask any final questions. Each rider rode their own horse; previous literature has shown how different horses responses to the rider's aids affects the riders cardiorespiratory responses (Devienne and Guzennec 2000). Horses that do not react to a rider's aids increases the physiological effort by the rider due to repetitive movements. The nature of this live horse test included fast riding and jumping and so due to safety aspects the decision was made for each rider to rider a familiar horse with their own tack (e.g. the horses own bridle and saddle).

Figure 5.1: Upright, Crosspole and Oxer. NB: These are not images of the actual jumps used throughout testing (Courtesy of the Author 2015)

The direction of the on horse test test took place on the right rein (clockwise direction), riders followed the gaits and positions outlined in Table 5.1 and followed the edge of the arena. For the last stage, which included two 1m oxer jumps (at each long side of the arena), riders came to the inside of the track to clear the jump. If there was a refusal or any disruptive behavior this was noted. There were no rider falls or accidents during this test. Each stage lasted two minutes, post each stage a 30s 'rest' period was included where riders were asked to report RPEo and RPEp, BLa was sampled from the right earlobe, time was recorded and at the 30s rest completion, participants continued to the next stage. A 2-minute stage was used to ensure a steady state would occur and the rider's

[3] **Cross pole**: Two poles crossed over each other with one end of the pole on the floor and one in a jump cup attached to a show jump wing. **Upright:** Also referred to as 'vertical fence'. Where poles or planks are stacked vertically and there is no width to the jump. **Oxer:** Where two verticals are positioned close together to add width to the jump. Also known as a spread.

physiological responses would adapt to the change in gait, and that the responses were reflective of that gait/position combination being monitored. Durations of test stages were kept to the minimum duration to consider the workload of the athletes. Total test duration including all warm up, warm down and rest periods was ~51 minutes and active workload was ~45 minutes in duration.

Upon completion of the active aspect of the test riders were asked to complete a warm down at the horses walk, after four minutes post the Jump stage BLa was sampled. Rider's were then asked to warm their horses down in walk and trot for ten minutes (Table 5.1).

Table 5.1: Gait and position combination descriptions and durations for each stage of the live horse exercise test protocol.

Stage	Gait /Position Combination	Duration	Description
Pre	Warm Up	15 mins	3 min walk, 3 min trot, 3 min canter and 3 jump attempts within 5 minutes.
	Rest	5 mins	Time duration allowance for equipment and tack checking.
1	Walk	2 mins	A four beat equine gait. The rider remains seated in the saddle.
	Rest	30s	
2	Sitting Trot	2 mins	A two beat equine gait where the rider remains seated in the saddle.
	Rest	30s	
3	Rising Trot	2 mins	A two beat equine gait, where the rider rises themselves out of the saddle and back into the saddle with the timings of the trot gait.
	Rest	30s	
4	Canter	2 mins	A three beat equine gait. The rider remains seated in the saddle.
	Rest	30s	
5	Light-Seat Canter	2 mins	A three beat equine gait. The rider remains out of the saddle for the entire duration.
	Rest	30s	
6	Fast Canter	2 mins	Riders were asked to canter/gallop at a pace they felt they would complete around a cross-country course, whilst remaining in control.
	Rest	30s	
7	Jump	2 mins	Riders cantered in a light seat around the edge of the arena, and jumped two jumps at each of the long sides of the arena.
	Rest	30s	
Post	BLa Sampling	4 min	Four minutes post stage 7 rest period, Bla was sampled.
	Warm Down	10 min	Equipment was removed and this was period for riders to fully warm down themselves and their horses.

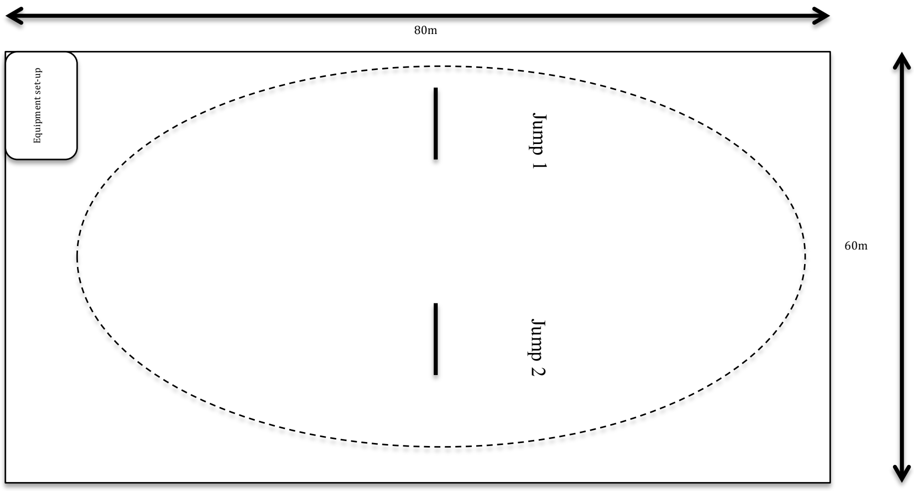

Figure 5.2: Figure to Demonstrate Equestrian Arena Set-up.

5.3.7 Electromyographic Recordings

The decision to use surface electromyography (sEMG) within this chapter was based on the application sEMG is has as an indicator of muscle activation. Numerous factors affect the reliability of sEMG data collected and influence interpretation of results (Reaz et al. 2006) including electrode placement, muscle fibre profile, training and fitness, nutritional state and the muscles fatigue. When measuring EMG the aim for consistency in the acquired EMG signal and should contain no distortion (Smoliga et al. 2010; DeLuca et al. 2010). Dirt or grease, interference from other equipment, skin or sensor displacement from muscle movement and activity of muscles in close proximity to the one being examined, can generate electrical 'noise' (De Luca and Merletti 1988; De Luca et al. 2010; Bergh et al. 2014) and was considered within the design of the investigation. Sensors should be located over the maximum circumference of the muscle avoiding tendon insertions which can generate noise (Konrad 2005).

There is no accepted gold standard analysis or extraction methods when processing EMG data (Vint et al. 2001; Hug 2011). Evaluation of the gross EMG signal, in real-time can provide valuable descriptive visual information re: onset, offset and timing of muscle activation (Delsys® 2013). Raw EMG data contain both negative and positive values and so data processing is required to fully evaluate muscle responses during analysis (Shaivi et al. 1998). During muscle activity, the amplitude of the EMG signal at any given instant is stochastic and will contain multiple frequencies contributing to the force produced (Hug 2011). The 'usable' EMG signal associated with human movement is considered to exhibit frequencies between 20 and 250Hz (Felici 2006; Hug et al. 2011). Filters are usually applied to ensure only relevant frequencies that contribute to the event being assessed are analysed reducing the potential for misinterpretation of data (Winter 2009; Kamen and Gabriel, 2010). Ideal filters have brick wall responses to cut-off frequencies i.e. a 20Hz low-pass filter would remove all frequencies <20 Hz (De Luca 2003; Kamen and Gabriel 2010). Mean Absolute Value (MAV) is similar to average rectified value. It is calculated using the moving average of full-wave rectified EMG, e.g. it is calculated by taking the average of the absolute value of sEMG signal. It is an easy way for detection of muscle contraction levels and it is a popular sEMG analysis technique and was selected for analysis in this thesis (Phinoyomark et al. 2009).

Interpretation of sEMG data is acknowledged as challenging as a number of factors can influence the resultant signal (Reaz et al. 2006). Variation in signal amplitude may be attributed to an increased number of active motor units (MUs) being recruited or to a change in the frequency of activation i.e. the firing rate has increased but the same number of MUs are being recruited (Stegeman et al. 2000; Konrad 2005). Muscle fibre profile will also influence the EMG profile (Kamen and Gabriel 2010). An elevated amplitude of the sEMG signal could be related to an increase in fast-twitch fibre recruitment or a higher firing rate in slow-twitch fibres related to synchronised firing at the onset of muscle fatigue (Rahnama et al. 2006; Staudenmann et al. 2010). Synchronisation of EMG data collection with kinematic analysis or time-motion analysis increases specificity between muscle recruitment and locomotion (Hug 2011) promoting accuracy and improving the reliability of sEMG (Hug 2011).

It is common to use a maximal voluntary contraction to normalise data in many sports but in horse-riders this method of normalisation has not been used (Terada 2004). Terada (2004) suggests that the static position of the rider's body segments during riding suggests that it is inappropriate to measure maximum voluntary contraction for the muscles being studied. In this study as per Terada (2004) muscles activities were normalised to a percentage of the maximal muscle activity (%MAV) for each muscle over the live horse exercise test.

Electromyographic recordings were sampled continuously during the live horse exercise test from the left and right side of the riders body for the *latissimus dorsi*, *rectus abdominis*, *flexor carpi radialis* and the *rectus femoris* muscles (Figure 5.3). Motor Unit Action Potential (MUAP) of each muscle throughout testing was recorded at a sampling rate of 2000Hz per channel using a Delsys® Trigno™ Wireless EMG system. To minimise skin impedance between electrodes, the skin was wiped with alcohol swabs (DeLuca 1997, 2002, 2003). Then 10mm electrodes were placed on the longitudinal midline of each muscle bilaterally mid-way between the origin and insertion point (DeLuca 2003). Each surface electrode was kept in place using adhesive bandages to ensure that electrodes were not lost during the test in such a large open space.

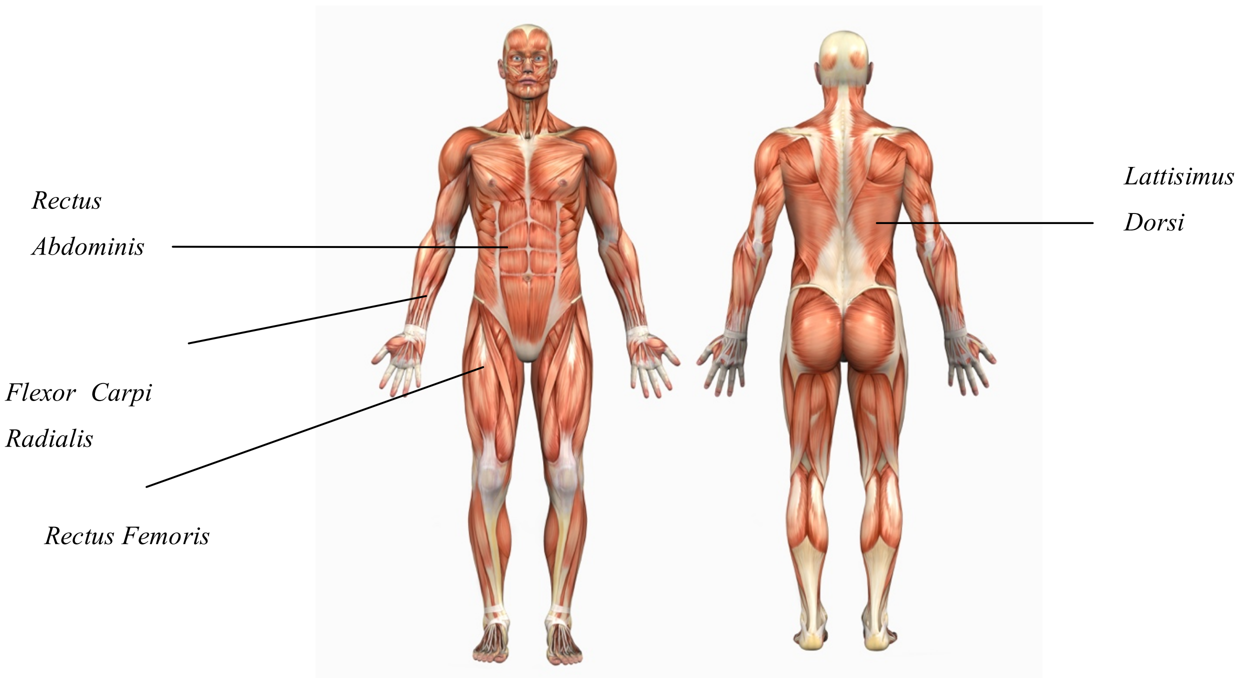

Figure 5.3: Muscular anatomy to identify muscles analysed during the riding test (Image purchased from www.Bigstockphoto.com)

The last 30s of data from each stage was extracted for analysis (Keenan and Valero-Cuevas 2008). Analysing the last 30s was chosen for two reasons 1) data would match the sampling epoch used for physiological data, 2) it has been suggested that using a longer epoch is recommended to reliably estimate average muscle force during an activity (Keenen and Valero-Cuevas 2008). Delsys EMG Analysis software was used to rectify the raw bipolar signal to calculate the mean rectified absolute values (MAV) for each 30s data segment for both the right and left muscles in all 7 stages (gait/position stages) for each participant. This process resulted in each participant having 28 MAV means (364 MAV means in total). Delsys EMG Analysis software calculate MAV using the following equation:

$$MAV = \frac{1}{S}\sum_{1}^{S}\left|f(s)\right|$$

MAV - Mean Absolute Value

S - Window Length (Points)

f(s) - Data within the Window

In addition to a mean MAV, a maximum MAV was calculated for both right and left muscles in all 7 stages. From this a mean relative MAV (%MAV) was calculated and reported as a mean percentage of maximal activity for each stage and also a trial maximum for each muscle: (%MAV=meanMAV/maxMAV*100). As previously intimated, it is common to use a maximal voluntary contraction to normalise data in many sports but in horse-riders this method of normalisation has been cited as not particularly useful due to muscular activity being used for control rather than for power generation (Terada 2004). It must be noted that these observations of Terada (2004) are concluded from the walk and trot gaits and further research is required to transfer these conclusions to horse-riding in general, particularly where jumping is included

In addition to mean MAV and %MAV EMG data has been reported as a composite meanMAV and composite %MAV to get an understanding of total muscular activity for each stage. A description of each method of analysis can be seen in Table 5.2. A Sony Handycam DCR-SX15E (Sony, Tokyo, Japan) recorded each live horse test continuously to synchronise rider activity, specifically to document jumping efforts. During the jumping stage, the point of take-off was visually identified as the suspension (where the forelimbs have no contact with the surface) of the forelimbs prior to the jump, whilst the hind limbs remained in contact with the arena surface.

Table 5.2: A description of the EMG analysis methods used.

Method of Analysis	Description
MeanMAV	This is the mean activity for the last 30s data for each stage and is reported for all four muscles bilaterally.
MaxMAV	This is the maximum activity for each muscle over the entire trial.
%MAV	This is the relative intensity of muscle activity compared to each muscles maximum for the trial. **%MAV=MeanMAV/MaxMAV*100**
Composite Mean MAV	This is the sum of all 4 meanMAV bilateral muscles sampled (8 mean composite MAV's).
Composite %MAV	This is the sum of all 4 %MAV bilateral muscles sampled (8 % composite MAV's)

5.2.8 Statistical Analysis

Data are presented as mean±standard deviation (SD) throughout, alpha value is $p<0.05$ (confidence interval 95%) throughout unless otherwise stated. A one-way repeated measures ANOVA was used to determine whether there were statistically significant differences between BLa_{peak}, HR_{peak}, $\dot{V}O_{2peak}$, $\dot{V}O_{2max}$, VE_{peak} $RPEo_{peak}$, $\%MAV_{MAX}$, and exercise test stage. Within the analysis, if assumptions of sphericity were violated a Greenhouse and Geisser correction was applied. There were no outliers (assessed by boxplot) and all data were normally distributed (Shapiro-Wilk test $p>0.05$). Pearsons Product Moment Correlational analysis was used to investigate and interpret relationships between physiological variables for each exercise stage. A paired t-test was used for comparisons of mean muscle activity between left and right muscles during each stage. Data were analysed using Statistical Package for Social Sciences (SPSS) for Windows, Version 22.

5.3 Results

$\dot{V}O_{2peak}$, VE_{peak} HR_{peak} and BLa_{peak} for TM and live horse testing are presented in Table 5.3. This data was used to express live horse data as a relative percentage of maximum. The maximal values achieved from the live-horse exercise test are presented in Table 5.4. The values for $\dot{V}O_{2peak}$, VE_{peak}, HR_{peak} and BLa_{peak} were all reported from the jump stage and are presented as a percentage of laboratory maximum in parenthesis.

Table 5.3: Physiological reference data obtained in the laboratory and test data obtained during the live horse exercise test.

Variable	TM	H
$\dot{V}O_{2peak}$ ml.kg^{-1}.min^{-1}	41.9±4.9	24.9±5.5 (59%)
HR_{peak}beats.min^{-1}	191±9	170±15 (88%)
BLa_{peak} mmol.l^{-1}	8.3±1.8	3.6±1.3 (43%)
VE_{peak} l.min^{-1}	79±17	48.9±15.9 (62%)

Table 5.4: Descriptive data for physiological variables throughout the live horse test.

	1 W	2 ST	3 RT	4 C	5 LC	6 FC	7 J
Absolute Values							
Mean BLa mmol.l^{-1}	1.1±0.3 º△^+**	1.7±0.7 º+**	1.7±0.7 º***+	2.0±0.5 º***	2.3±0.9 º* ▲△	2.8±1.0 ▲△^+**	3.6±1.2 *▲△^+**
Mean RPEo Score	6.5±0.5 ▲^+	8.4±1.3 *	7.3±0.9 +	8.0±0.8 *	9.5±1.1 *▲△^+	10.6±1.3 *▲△^+**	12.4±1.6 *▲△^+**
Mean HR beats.min^{-1}	114±15 *▲△+** º º	140±11 *+** º º	132±15 *+** º º	153±13 *▲△+** º º	162±12 *▲△+	165±15 *▲△+	170±15 *▲△+
Mean $\dot{V}O_2$ ml.kg^{-1}.min^{-1}	8.6±3.1 *▲△^+**	19.3±6.3 *º	19.4±6.0 *º	21.0±6.3 *º	18.3±3.8 *º	20.5±5.6 *º	24.9±5.5 *▲△^+**
Mean RF breath.min^{-1}	30±7 ▲△^+**	40±5 *º	39±6 *º	43±4 *º	41±6 *º	43±7 *	46±4 *▲△^+
Mean VE l.min^{-1}	23.9±8.5 △^+**º	38.3±13.3 º	38.4±11 *	40.6±16.2 *	43.0±13.3 *	42.9±11.7 *	48.9±15.9 *▲
Relative Values to TM Data							
% BLamax	14±5	21±9	19±8	22±6	27±10	33±10	42±11
% HR max	60±7	73±6	69±8	80±7	85±6	86±7	89±8
%$\dot{V}O_2$max	15±10	34±23	36±24	39±26	33±20	38±25	48±28
%RFmax	52±12	65±16	70±16	70±18	66±20	77±14	81±14
%VEmax	29±17	35±14	41±17	43±17	45±14	52±25	62±26

*Significantly different from walk, ▲Significantly different from sitting trot, △Significantly different from rising trot, ^ Significantly different from canter, +Significantly different from light canter, ** Significantly different from fast canter, º Significantly different from jump

There were significant differences in $\dot{V}O_{2peak}$ between TM and live horse test $f_{(3.0,33.3)}$ = 37.03, p<0.005 (Table 5.3). There were differences in $\dot{V}O_{2peak}$ observed between walk and all other stages, and between jump and all other stages (p<0.05) (Table 5.4). There were also significant differences in heart rate between each stage of live horse exercise test $f_{(2.2,26.5)}$ = 84.56, p<0.0005 (Table 5.4). Post hoc analysis reported differences in heart rate between all stages apart from between the light seat canter, fast canter and jump (p<0.05). Post hoc analysis identified the jump was different from all other stages p<0.05 (Table 5.4). Blood lactate concentration was not significantly different between the light seat canter, fast canter and jump (p>0.05). Jump stages were significantly different from all other stages p<0.05 (Table 5.4) but not between sitting trot to fast canter (p>0.05).

Figure 5.4 reports heart rate, oxygen uptake and ventilation during the live horse test. Heart rate and ventilation increased between the stages of rising trot to fast canter, however oxygen consumption does not follow the same pattern and in fact decreases. Ventilatory threshold during the live horse test (the point at which ventilation increases at a faster rate than oxygen uptake) was identified at the light canter. Metabolic and ventilatory loads are well below maximum $\dot{V}O_2$ and VE correspond to 48% and 52% of maximum respectively during jumping. Tidal volume increased progressively (W= 0.79, ST = 0.95, RT = 0.98, C = 0.94, LC = 1.04, FC = 0.99 J = 1.06 $l.min^{-1}$) an increase in tidal volume at LC followed by a decrease at FC was observed. During LC tidal volume increased and respiratory frequency decreased causing a maintenance in ventilation during this stage.

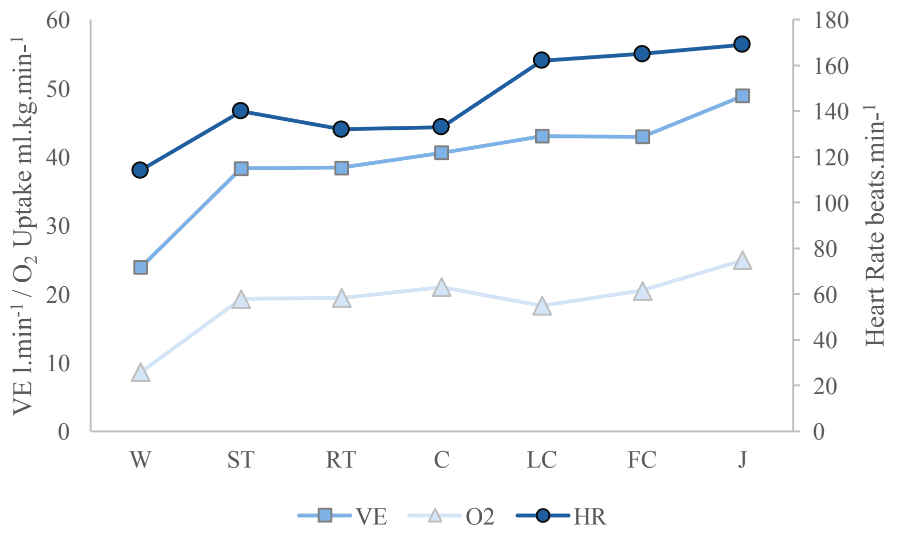

Figure 5.4: Mean $\dot{V}O_2$, HR and VE for each stage on the live horse test; Walk (W), sitting trot (ST), rising trot (RT), canter (C), light seat canter (LC), fast canter (FC) and jump (J).

Table 5.5 reports the bivariate relationships during the live horse exercise test, since a specific aim of this study was to determine relationships between heart rate and oxygen consumption during riding a live horse Figure 5.4 and Table 5.5 highlights the low-moderate relationship between these two variables.

Table 5.5: Live horse test bi-variate data and associated r values

Bi-variate Data	r value
HR/ $\dot{V}O_2$	0.441
HR/BLa	0.652
HR/RPEo	0.636
$\dot{V}O_2$/RPEo	0.360
$\dot{V}O_2$/BLa	0.419
RPEo/Bla	0.700

There were weak to moderate strength significant correlations between all bi-variables during the live horse exercise test, $p<0.05$ (Table 5.5). Where $\dot{V}O_2$ was an included variable within the analysis, the strength of the relationship was lower. The strength between RPEo and variables of heart rate are moderate indicating actual and perceived effort where heart rate is concerned are not matched. There is a stronger significant relationship between RPEo and BLa, indicating BLa is more reflective of exercise intensity compared with heart rate and $\dot{V}O_2$.

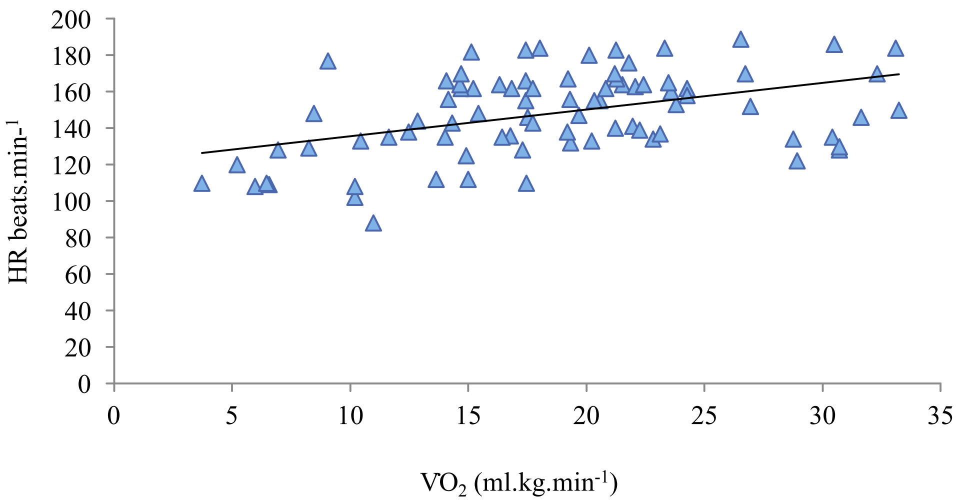

Figure 5.5: Scatter plot of $\dot{V}O_2$ and HR during the live horse exercise test.

5.3.1 Electromyographical Analysis

The EMG data from the composite muscle activity is presented in Table 5.6. There is no significant difference in mean composite muscle activity between the stages of the live horse test (*p*=0.524).

Table 5.6: Descriptive data for composite muscular activity.

	W	ST	RT	C	LC	FC	J
Mean Composite MAV (mV)	0.6±1.0	0.7±1.3	0.5±0.8	0.6±1.1	0.5±1.2	0.5±1.2	0.6±1.1
Max Composite MAV (mV)	2.4±2.8	3.0±3.3	2.1±3.0	2.3±3.2	2.0±3.1	1.7±2.9	3.5±3.5
% MAXMAV Composite	31.8±13.6	27.1±5.7	25.9±4.2	29.3±6.6	33.3±5.1	33±7.9	22.9±6.5

There were no significant relationships between composite muscle activity and the variables of heart rate, oxygen consumption, blood lactate $p>0.05$.

5.3.2 Individual Muscle Analysis

The *rectus femoris* muscle was the most activated during the live horse exercise test particularly concerning the left leg (Figure 5.6). Composite muscle activity did not differ significantly with stage (p>0.05), peak %MAV_{MAX} was observed in light canter (Figure 5.6). The *rectus abdominis* was the second most activated, particularly concerning the right side, differences were located between left and right muscles in walk, canter and light canter (Figure 5.6). Muscle activity in the *rectus abdominis* did not differ significantly with stage (p >0.05), %MAV_{MAX} was observed in sitting trot followed by jump (Figure 5.6).

The *flexor carpi radialis* also demonstrated asymmetry between left and right sides in walk, sitting trot, rising trot, fast canter and jump (Figure 5.6). In walk %MAV_{MAX} peaks in the left side compared to the right (Figure 5.6) no significant difference in muscle activity was reported at any stage.

The *latissimus dorsi* was the least involved although it displayed a more symmetrical and consistent activation pattern between left and right muscles throughout the gaits ranging between 8-14% MAV_{MAX} for both left and right muscles but with no significant difference in muscle activity was reported at any stage (Figure 5.6).

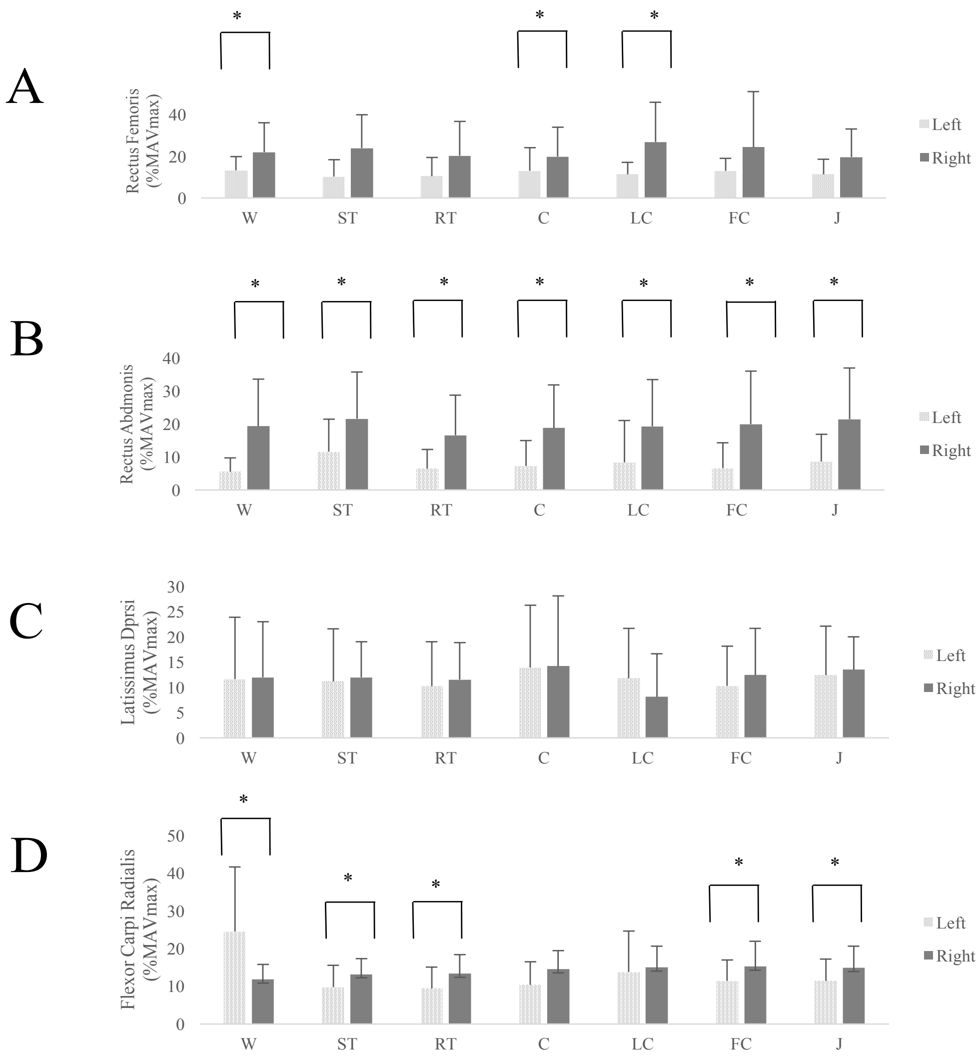

Figure 5.6: Comparison of EMG for the four individual muscles during each stage of the live horse protocol A) *rectus femoris* B) *rectus abdominis* C) *lattisimus dorsi* D) *flexor carpi radialis.* *$p<0.05$.

Figure 5.7 displays a representative EMG trace (n=1) of bilateral muscle activity during the jump stage of the live horse exercise test since this is where peak physiological responses were reported. The vertical lines represent point of take off for the jump identified upon visual identification of the horses leading limb suspension prior to the jump.

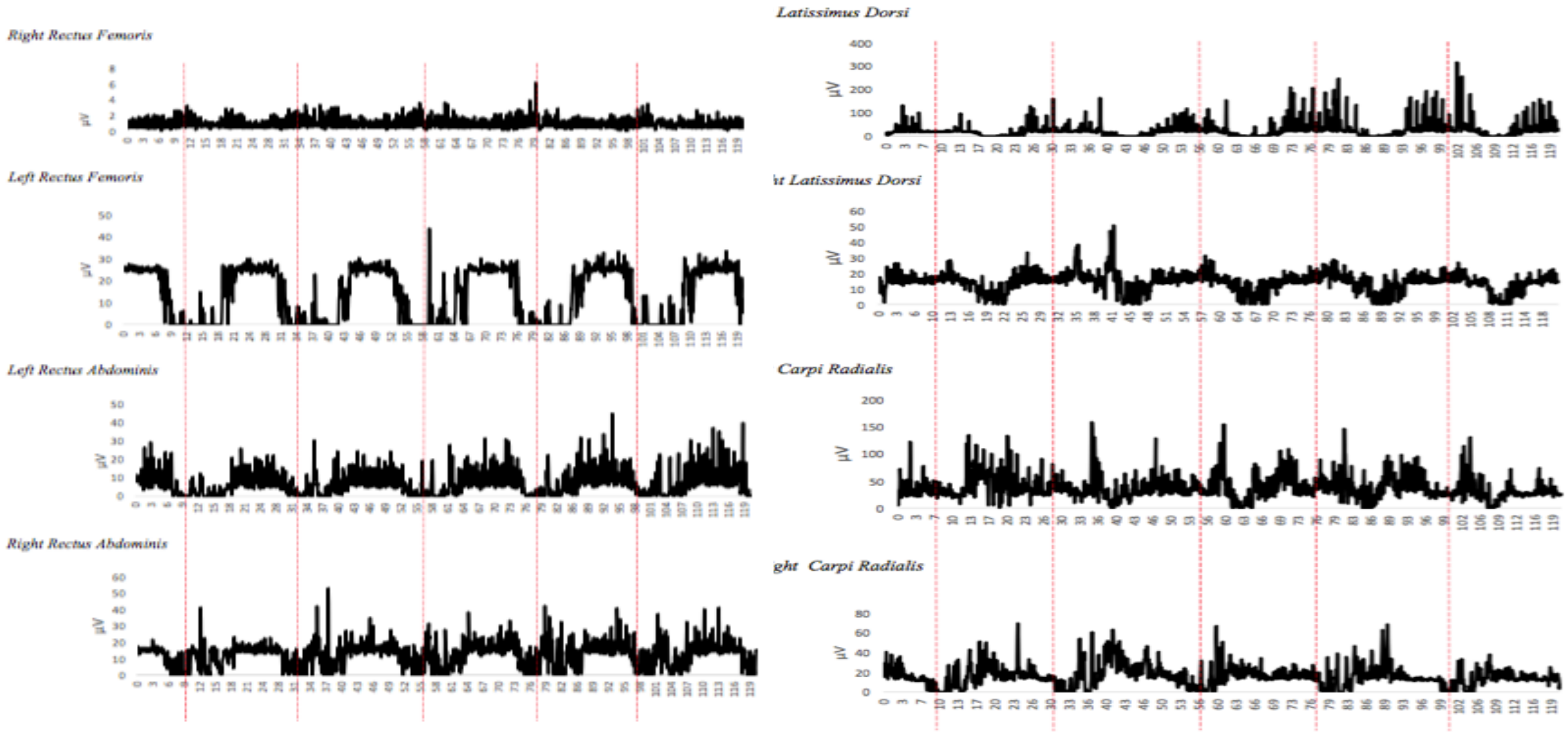

Figure 5.7: Representative bilateral EMG trace (n=1) during the jump stage. Red vertical lines indicate point of take off.

The left *rectus femoris* was activated at a lower mean relative intensity compared to other muscles (Figure 5.7) yet this muscle has periods of higher amplitude activity sustained for ~10s that coincided between jumping efforts, which decreases ~5s prior, during and post the jump. The right *rectus femoris* had a consistent low amplitude for the entire duration.

The *rectus abdominis* muscle reported a similar pattern to the *rectus femoris* where higher amplitude activity for ~10s between jumps and decrease activation ~5s pre and post the jump were observed.

The *lattisimus dorsi* showed the opposite pattern where muscle activated approximately 5s pre, during and post the jump, which reduced in amplitude between jumps. The *carpi flexi radialis* reports peak activity approximately five seconds prior to a jumping effort and then remain relatively consistent in the right arm. The left *flexor carpi radialis* reports a more erratic pattern with a higher amplitude compared to the right though peaks are still reported ~5s pre jump.

5.4 Discussion

This study introduced a novel attempt to investigate the physiological responses across all equine gaits and rider positions, including jumping efforts. Additionally, this study is the first to document muscle activation in the lower body and upper body of riders during canter and jumping. Key findings were that heart rate demands were elevated more so that associated physiological variables of oxygen uptake, muscle activity during all stages was predominantly isometric and displayed periods of low amplitude isometric muscle work followed by periods of high amplitude muscle work.

5.4.1 Physiological Responses to Riding During a Live Horse Exercise Test

This study reports significant and specific physiological and muscular activation patterns whilst horse riding during a live horse exercise test. The values for $\dot{V}O_2$ uptake during actual riding in this study were dissected into stages to allow a comprehensive analysis of the effect of rider position, horses gait and muscle activity upon the physiological variables measured. Oxygen uptake increased from walk to jump, however there was no increase in uptake between sitting trot, rising trot and canter. During the light seat canter when the rider adopted an un-seated position oxygen uptake decreased and followed by an increase during a faster canter and reached peak values during the jumping phase (24.9 $ml.kg.min^{-1}$.). Interestingly, values for oxygen uptake were lower in this study compared to earlier work of Westerling et al. (1983) and Devienne and Guzennec (2000) yet more comparable to more recent research of Beale (2015) (where values for walk and trot were 17.4 $ml.kg.min^{-1}$ and trot and canter were 18.4 $ml.kg.min^{-1}$) and Sainas (2016) (Walk = 13.5 $ml.kg.min^{-1;}$ trot = 18.4 $ml.kg.min^{-1}$ and Canter 22 $ml.kg.min^{-1}$). Peak oxygen uptake during the live horse exercise test (24.9$ml.kg.min^{-1}$) was comparable to data reported by Roberts et al. (2010) during the DR and SJ phases of a simulated Novice ODE (20.4 $ml.kg.min^{-1}$ and 28 $ml.kg.min^{-1}$ respectively). This novel in field equine exercise test produced comparable results to event riding and indicates there is indeed scope to adapt an on horse fitness test for horse riders.

In a laboratory setting, peak oxygen uptake values during the live horse test (21.2 $ml.kg.min^{-1}$) were more in line (yet still greater) with peak data for mechanical horse output in Appendix 1 (15.6 $ml.kg.min^{-1}$) than TM or CE modes. Despite peak oxygen uptake having more comparability to mechanical horse data, heart rate peak was not comparable during actual riding (169 $beats.min^{-1}$) compared to peak mechanical horse responses (119 $beats.min^{-1}$). A study presented within Appendix 1 criticizes the use of mechanical horse simulators to mimic physiological testing of riders since the responses are not replicable to actual riding, hence the investigation of a novel live horse test being necessary. Heart rate responses to the live horse exercise test reported that heart rate increased throughout test and on average peaked at 88% of participants maximum as quantified by a laboratory treadmill test. Heart rate was always above 80%HR_{max} when participants were in canter or jumping stages and in agreement with previous literature noting these gaits that demonstrate marked increases in heart rate (Guitérrez Rincón et al. 1992; Trowbridge et al. 1995; Devienne and Guzennec 2000; Beale et al. 2015; Sainas et al. 2016).

Mean BLa concentration increased from baseline to post-test, there was no elevation in BLa between stages 2 and 3 however. As the horses gait increased in speed and as the rider adopts an un-seated position the anaerobic pathway was utilised more. In terms of RPEo, a difference in RPEo from walk (~ 6.5) to jump (~ 12.4) was reported indicating the riders also perceive the jump to be ‘somewhat harder’ than the earlier stags of the live horse test which supports physiological findings. Overall RPE has a stronger relationship to BLa than HR or $\dot{V}O_2$ suggestive that BLa is more reflective of actual intensity of exercise compared with the other variables during horse riding activities. Since heart rate does not appear to be an accurate representation of physiological demand, blood lactate may be a more accurate description of actual exercise intensity for this population.

Throughout the test from walk to jump there was a weak positive relationship between heart rate and oxygen consumption indicating that there are other more impactful variables in addition to heart rate that has affected the relationship to oxygen uptake during horse riding, particularly when the faster gaits of canter and where jumping efforts are concerned. As previously intimated throughout this thesis, there are factors such as psychological responses to novel environments and heat stressors that may have affected the data and will be discussed accordingly.

This study confirms that during horse riding, heart rate demands are far greater during riding (80%HR_{max}) than the oxygen requirement (48%$\dot{V}O_{2max}$) observed in addition to moderate blood lactate concentration (3.6mmol.l^{-1}) and considerable respiratory strain (62%VE_{max}; 81%RF_{max}) which is supported by work of Sainas et al. (2016) post the completion of the body of this research. These physiological responses have been reported in other travel sports including Sailing (41%$\dot{V}O_{2max}$; 70%HR_{max}, Vogiatziz et al. 2002) Windsurfing (77%$\dot{V}O_{2max}$; 87%HR_{max}, Perez-Turpin et al. 2009), Kitesurfing (74%$\dot{V}O_{2max}$; 83%HR_{max}, Vercruyssen et al. 2009) and Motorcross (69%$\dot{V}O_{2max}$; 96%HR_{max}, 62%VE_{max}; 106%$RF_{max;}$ 31%$BLa_{max,}$ Konittinen et al. 2007) also.

As suggested throughout this thesis and the data reported within this chapter, there are factors that may have affected heart rate aside from physical exertion itself which are important to the interpretation of the data collected. Though the investigation within this chapter is not a competition environment, the presence of cognitive anxiety may still be present. Any stressing situation can have the potential to elevate circulating catecholamines, and it is likely that as an experimental situation with new test equipment and jumping in front of a researcher (Zohaul et al. 2008) this has occurred. A habituation to the test environment was included within this investigation as this has been reported to reduce adrenaline concentration (Sheurink et al. 1989), and directly influence circulating catecholamine responses to exercise (Zohaul et al. 2008). Without measuring catecholamine levels, it must be assumed that heart rate is partly elevated in response to cognitive anxiety associated with partaking in a novel task both with regards to environment and test equipment.

It is well documented that heat stress affects physiological mechanisms and depending on the situation can elevate metabolic rate and anaerobic contributions during exercise (Sawka et al. 1993). The attire for riders within this experimental trial included protective headwear, full length jodhpurs and full length riding boots, riding gloves and a body protector. Nearly the entire body of the rider is covered; a helmet alone can reduce evaporative cooling by 20-40% (Liu and Holmer 1995) and research has evidenced that physiological strain can be elevated in fully clothed individuals (Fogarty et al. 2005). When riding in addition to potential of heat stress due to clothing, there is the additional potential for heat absorption emitted from the heat of the horse underneath the rider that must be considered when interpreting physiological responses. Since neither of these were controlled variables, elevated heart rate may have been affected by heat stress related to clothing requirements and the horse itself.

It seems pertinent to note within this discussion, that the existing literature and the data reported in Chapter Four and Five indicate that heart rate is high during horse riding. Regardless of the causal mechanisms, equestrians are going to have to be able to cope with an elevated heart rate despite the other physiological demands being relatively moderate and is a practical consideration when preparing the rider for optimal competition fitness.

Heart rate can also be influenced by the muscular recruitment and thus position of the athlete, a dissociation of heart rate from oxygen consumption has been reported in sports that involve a high isometric environment including cycling, motorcross, windsurfing, kitesurfing, rock-climbing and sailing as presented within the review of literature. As such, this study included EMG to investigate muscle activity in response to riding positions.

5.4.2 Electromyographical Responses of Riders During a Live Horse Exercise Test

This research is the first to document muscle activity in the trunk, lower and upper body of riders during all gait and position combinations including jumping. The sEMG results analysis reveal that composite muscle activity does not alter as the stages of the live horse exercise test progress. It presents novel muscular profiles and differences in muscle activity in response to different gaits during the live horse exercise test which are discussed in relation to the physiological profile presented.

The *rectus femoris* muscle was the most activated during horse-riding reporting left leg bias. The *rectus abdominis* was the second most activated, and in contrast to *rectus femoris* reports a right side bias. The *rectus abdominis* muscle recruits the highest amplitude of activity throughout the sitting trot. The *flexor carpi radialis* demonstrates asymmetry in recruitment between left and right reins and reports peaks in the left rein. The *latissimus dorsi* is the least involved and displayed a more symmetric and consistent activation pattern between left and right muscles throughout the gaits. This suggests that the *latissimus dorsi* has an underlying importance because of its low level and consistent activation, instead, local differences occur in the peripheral muscle groups of the forearm.

The *rectus femoris* and *flexor carpi radialis* report a left side bias whilst the right side dominates for the *rectus abdominis.* Considering the riders are on a right (clockwise rein) this profile of activity can be explained by the rotational movement of the trunk towards the right to direct the movement of the horse. The left (also referred to as 'outside') leg acts to indicate to the horse that the rider wishes the horse to keep their hindquarters on a bend, which explains increased activity in the left *rectus femoris.* The left *flexor carpi radialis* reports a less stable pattern with a low average activity with greater spikes. The left arm (outside arm) controls both then bend of the horse and the horses pace, when turning to the right an aid called the 'half halt' is used to indicate to the horse to expect an aid. The half-halt is a specific riding aid given by an equestrian to the horse, whereby the driving aids and restraining aids are applied in quick succession. On the right rein a quick increase followed by release of pressure on the left rein would indicate to the horse they should slow the pace and rebalance before another aid is to be applied. Thus clockwise direction of the test indeed affected muscle activation patterns in response to gait and stage of exercise test.

During jumping the lower body, as indicated by *rectus femoris,* was activated prior to the jump to guide the horse, the *latissimus dorsi* was activated during the jump for control of the trunk and upper body, and the lower body is then activated on landing for control and direction of the horse post jump. Figure 5.6 evidences periods of ~10s of low amplitude isometric muscle work pre, during and post jump, followed by ~ 10s of higher amplitude isometric activity between jumps in both the *rectus femoris* and *rectus abdominis*. It appears that once the rider has set the horse up for the jump muscle activity decreases and remains isometric necessary to maintain stability and balance, post jump amplitude of isometric muscle activity increases as a response to landing mechanics and re-stabilisation of the torso after trunk perturbations. The nature of the interplay between high amplitude and low amplitude isometric work suggests the muscle action is not continuously isometric in all muscles (right *rectus femoris* appeared to be in continuous isometric activation throughout the jumping phase) which is supported by biomechanical data and range of motion at the riders' joints during jumping as described by Nankervis et al. (2015).

Until recently, the biomechanics of the rider had not considered the position of riders during the jump. Nankervis et al. (2015) was the first to report jumping position between elite and non-elite show jumpers and reported that hip angle (relative to the shoulder and knee) was a discriminating technical factor between levels of rider and further supports previous evidence that trunk (in relation to the hip as described in other research) control is an important indicator for performance in jump riders. Nankervis et al. (2015) reported that in elite riders jumping a vertical fence, mean ranges of motion at the hip from take-off to landing as 55° (range from 80° to 135°). The trunk angle (relative to the vertical plane) ranged from 15° to 56° with a mean range of motion of 41°. Thigh angle (relative to the horizontal plane) had a range of motion of 22° (from 49° to 71°). The lower limb (measured at the knee using relative markers from the heel and the horizontal plane) showed minimal range of movement as 1° (65° to 66°). The seated canter reports minimal movement at the trunk, thigh and lower limb. The movement is increased during the jump and suggests that although the movement ranges are limited compared to dynamic sports, there is movement around the joints and thus muscle activity in all muscles apart from the right *rectus femoris* are not solely isometric during horse-riding which supports EMG data reported in this chapter. Electromyographical analysis of riders during a live horse exercise test confirms the presence of isometric muscle work in riders. In some muscles, isometric activity is consistent for long durations and in other muscles alternates between period of low amplitude and high amplitude isometric muscle work.

Data from this chapter indicates that there are other variables in addition to heart rate that have affected the relationship between heart rate and oxygen uptake during horse riding, particularly when the faster gaits of canter and where jumping efforts are concerned and one of the potential attributers is isometric muscle activity.

It is well-established that isometric exercise causes a disproportionate rise in heart rate compared with oxygen consumption that is not linear with dynamic exercise (Sheel et al. 2003). This disproportionate rise in HR and $\dot{V}O_2$ is due to isometric muscle contraction hindering local blood flow in contrast to dynamic exercise where the movement facilitates local circulation The heart rate response to isometric exercise is also dependent on the size of the contracting muscles or the magnitude of muscle activation. Muscle receptors are sensitive to metabolic changes related to muscle activity and during isometric contractions of increased intensity and increased muscle mass and individual muscle activation the metabolite production is greater which may as a consequence increase activation of the muscle metaboreflex (Lellamo et al. 1992; Fisher and White 2004).

A disproportionate rise in HR compared with $\dot{V}O_2$ has been observed in sports where the requirement for isometric muscle activity is high. The repetitive isometric contractions in these sports are thought to stimulate chemical afferents via the muscle metaboreflex, which has explained the reported heart rate-$\dot{V}O_2$ dissociation (Konittinen et al. 2002). In addition to work in motor sports there has been research in other travel sports (sailing and kitesurfing) that also report physiological data that is not consistent with findings for dynamic sports (Cunningham and Hale 2007; Vogiatziz et al. 2007; Callewart et al. 2013). These researchers identified that in sailing and kitesurfing physiological data were non linear with intensity, heart rate was higher than was needed for oxygen supply, heightened blood pressure was evidenced, along with high respiratory rates.

The current study reported moderate blood lactate concentration during an on horse exercise test, for the high heart rates reported during riding, blood lactate would have been expected to be higher. This study confirms that heart rate is not reflective of oxygen uptake and there is the potential that isometric activity accounts for blood lactate concentration being lower than initially expected based on heart rate alone. During an isometric contraction sustained at more than 15-20%MVC, muscle blood flow increases several times above its resting levels (Sheel et al. 2003). However, this is not sufficient to meet the metabolic requirement and as a result there is a deficit of oxygenated blood which leads to production of blood lactate, which helps interpret an ample concentration of blood lactate during riding considering low oxygen consumption presented. Interestingly, neither sailing nor horse-riding during the live horse exercise test or the competition study in Chapter Four accumulated high blood lactates. In accordance with the suggestion by Lind (1983) in response to prolonged isometric muscle work higher blood lactates should be expected. Vogiatziz (2008) attributed this moderate blood lactate response to the quasi-isometric concept, first introduced by Spurway (2007) reporting that lower blood lactates than may be expected are as a result of dis-continuous isometric muscle work. In sailors specifically, the discontinuous action is as a result of muscle relaxation as a result of changing position to re-direct the boat. Spurway (2007) concluded that these periods of rest intervals would allow partial restoration of the muscles oxygen accessibility, promoting a more oxidative degradation of glycogen and low lactate concentration. During riding, we report periods of low amplitude activity succeeded by periods of high amplitude muscle activity. Presumably as the rider adapts their position, to account for changes in muscle work, partial restoration of muscle oxygen accessibility occurs and explains blood lactate concentration not continuing to rise.

Though a thorough analysis of muscle activity has been yet to be conducted in an equestrian population, riders in the present study are recruiting an average composite activity relative to maximum voltage of each muscle over the trial of 22-33%. The technique of horse-riding however requires constant small movements to provide aids to the horse and to align the rider over the horses centre of mass and as such is not truly continuous isometric muscle work. The movement patterns of riding a horse, particularly concerning the light seat are more complex than a true isometric movement because it requires isometric efforts but at certain time points also dynamic movements of the limbs and trunk. Referring back to the definition of the quasi-isometric concept; quasi-isometrics is a condition in which the muscles, though not strictly isometric, remain for prolonged periods under load sufficient to restrict blood flow substantially and produce metabolic and fatigue effects which are virtually indistinguishable from those experience during strictly isometric movements sustained for similar times under similar loads. The data from this chapter indicates this partial isometric requirement is true for horse riding during canter and jumping particularly and opens a potential future research avenue to confirm whether blood flow is restricted during this type of equestrian exercise.

During the live horse test, the light seat canter was the position and gait combination that saw diverging responses in heart rate and oxygen uptake. This stage sees a change in position from the rider as they change from a seated position, where the pelvis acts as the base of support, to being un-seated where the rider supports their body weight by the balls of their feet on the stirrups. The stirrup irons are a non-stable base of support and additionally move with the rider's leg and the horse's movements. It is likely the physiological responses to the light seat canter are a reflection of this change in position, as oxygen uptake continues to rise with heart rate in the later stages of the test. There was no significant difference in composite muscle activity between position/stages throughout the on-horse exercise test, which was surprising. Though total muscle composite values do not increase the individual muscular profiles do; in relation to muscular activity within the latter stages of the test (stages light seat canter-jump), data suggests that quadriceps dominance was reduced and activation of abdominal musculature increased from light canter through fast canter and jump (Figure 5.5). This could be as a result of increasing forces transmitted as a result of faster gaits of the horse and landing after a jumping effort (Konittinen 2007).

5.4.4 Limitations and Future Research

Sheel et al. (2003) indicates that where repeated intermittent isometric contractions are required it is reasonable to expect that blood pressure and thus heart rate would steeply rise out of proportion to $\dot{V}O_2$ (Sheel et al. 2003). In response to isometric handgrip exercise alone, there has been a reported increase in cardiac output and preferential re-distribution of blood flow to working skeletal muscle. Isometric contractions hinder local blood flow whereas dynamic exercise facilitates circulation and during isometric contractions of increased intensity and increased muscle mass the metabolite production is greater which may as a consequence increase activation of the muscle metaboreflex (Lellamo et al. 1992; Fisher and White 2004). Unfortunately, this study does not report blood pressure responses to further account for elevated heart rate responses, further research should consider investigating blood pressure responses and potentially blood flow in riders in addition to currently measured variables.

This study only considered riding in a clockwise direction which will have affected individual muscle activation patterns as discussed in 5.7.2. Nevertheless, results from this chapter do report an interesting response to direction and aids of the rider and indicates that future research on muscular activation profiles in riders is warranted. Prior to concluding that direction is solely to account for reported asymmetry in bilateral muscle pairs, an investigation comparing muscle activation patterns on both directions is necessary. As there is a limited amount of research investigating muscle activity in horse-riders the potential for future research is vast. This preliminary data does indicate that muscles respond differently to the aids applied, the direction of the rider and symmetry of muscular development of the rider should be considered both on the ground but also when training on the horse.

With regards to protocol design, in addition to direction, stage progression should be considered with regards to potential influence on physiological demands. The protocol was designed in a consecutive order i.e. walk, trot, canter as opposed to a randomised order, as such the design may have provoked cardiac drift. Cardiac drift is whereby there is a gradual increase in heart rate unrelated to energy expenditure caused by dehydration, hyperthermia and cardiac pre load occurs (Crisafulli et al. 2006a; Tocco et al. 2015). The test was designed to investigate each gait/position progressively however in addition to this research, future investigations may wish to design a protocol to investigate physiological responses to gait and position in a randomised order.

The effects of increased $\dot{V}O_2$ as a response to adrenaline is well established (Ensigner et al. 1993). This chapter did not measure adrenaline response but presumably in addition to isometric muscle work and blood pressure, increased levels of adrenaline would have affected physiological responses collected. Future research may wish to consider physiological responses to horse riding during training and competition to establish whether circulating catecholamines affect physiological data reported (Hoch et al. 1988).

5.5 Conclusion

Physiological data reported in this chapter indicate that heart rate is elevated compared to associated variables of oxygen uptake and Bla and suggest that the physiological responses to horse-riding are more multifactorial than has been considered in previous literature. Data does indeed indicate that as a response to intermittent and prolonged isometric muscle work, horse-riders have an elevated heart rate compared to the oxygen requirements for the activity, in addition to moderate blood lactate concentration, however future research is needed to establish this assumption. This study indicates that the use of heart rate as a marker of exercise intensity during horse riding activities is not appropriate as it is not reflective of actual physiologic demand and that BLa may be a more indicative marker of exercise intensity.

This study offers novel data by providing the first to report the physiological demands by gait and position of the rider complete with a muscular profile. The novel data presented within this study in synergy with data reported throughout this thesis may be used as information for riders to optimal health and preparation for Event riding. Additionally, data from the on horse exercise test reported physiological responses that are comparable to previous literature and data obtained during Eventing, this indicates that there is scope to further develop a live horse exercise test to replicate the demands of Event riding which would prove useful to monitor fitness and training responses in this population of athletes.

CHAPTER SIX: DISCUSSION

The primary aim of this thesis was to investigate the physiological demands of Eventing, an aim that was developed in response to the absence of literature exploring competitive demands of this sport. The specific research aims within Chapters Three and Four were designed to establish an underpinning knowledge of the physiological demands of competition and performance related fitness in Event riders. This data is necessary to provide a required knowledge base for trainers and coaches to ensure off horse athletic preparation for equestrian athletes transfers to on horse performance. The results of Chapter Three and Four established that more research was required to fully interpret the physiological demands of horse riding in a controlled trial to complement the laboratory and in field competition studies conducted. The concluding research investigation in this thesis therefore explored the physiological responses and muscular activation profiles of the different gaits and positions of the rider that are required during Eventing. This detailed analysis of gait and position enabled results in a controlled testing situation to be transferred to the previously conducted data during competition which assisted in the final interpretation of data relevant to the demands of Event riding and conclude where future research investigations should focus.

This chapter will discuss novel findings synergistically across the thesis chapters and with respect to currently available literature. Initially, the physiological responses to riding across all studies will be reflected and novel findings presented followed by the interpretation and application to each individual competition phase during a ODE, and following the limitations are considered and discussed.

6.1 Physiological Demands of Horse-Riding

This thesis investigated specific physiologic responses to competitive Event riding (Chapter Four) and presents detailed physiological responses to each gait and position combination required during Eventing using a novel on horse exercise test (Chapter Five). To present findings synergistically across experimental chapters and considering available literature, this section considers the physiological responses to riding in general (i.e. considering all gait and positions). This itemisation of data with respect to 'intensity' of horses' movement or the riders position provides a platform for interpreting the physiological and muscular responses evident during horse riding. This inclusive presentation of data allows detailed interpretations of the physiological responses with respect to muscle activity and as such the physiological demands of each specific phase of Eventing incorporating findings from the entire thesis can be considered.

6.1.2 Heart Rate Responses

Within the series of studies presented in this thesis, heart rate responses to riding were measured in the field during a Novice ODE for both warm up and competition (Chapter Four) in response to riding a mechanical horse (Appendix 1) and during a live horse exercise test (Chapter Five) using the same measurement methodology throughout the trials. Data from chapters during actual riding support previous literature that heart rate increases and significantly so when the rider adopts a light seat position and raises themselves out of the saddle, or where jumping efforts are concerned. Chapter Four reported mean heart rate during DR (160 beats.min^{-1}) to be lower compared to the SJ (168 beats.min^{-1}) and XC phase (177 beats.min^{-1}). Chapter Five reported comparable heart rate responses to a live horse exercise test, heart rate data increased steadily from walk, trot and canter (144, 140, 133 beats.min^{-1} respectively) then markedly increased when the rider adopted the light seat position in canter (162 beats.min^{-1}) with a further increase to 169 beats.min^{-1} during jumping. Heart rate during the jumping stage is lower than reported for the XC phase but can be explained by duration and situation. The live horse exercise test progressed to a new gait or position every three minutes and within that time frame approximately 10 jumping efforts were made. During a XC course mean duration is five minutes and the number of jumps varies from 18-25 obstacles. It is likely that if an additional two minutes and 8 jumps were included, heart rate would continue to rise.

Ultimately, heart rate responses of the rider increase with the horse's gait and markedly increase in canter and where jumping efforts are concerned (Westerling et al. 1983; Trowbridge et al. 1995; Devienne and Guzennec 2000; Cullen et al. 2015). Factors that may influence heart rate and that have the potential to alter the physiological responses of athletes during training and competition situations such as anxiety and heat stress have been discussed throughout this thesis. Since elevated cortisol levels are a peripheral effect of increased adrenaline (Ensigner et al. 1993), it is likely that physiological data are elevated in response to competition and novel research scenarios also. Heart rate increases significantly during jumping, future research should investigate physiological markers of cognitive anxiety to determine whether heart rate is elevated in response to anxiety related with jumping efforts or a reflection of actual physical demands.

Based on previous literature reviewed in Chapter Two, the increase in heart rate with light seat canter and jumping was not a revelation. What was intriguing, was the considerably high heart rate response to equestrian tasks given the moderate blood lactate reported by previous literature and in this thesis (Chapter Four, Chapter Five) and relatively low oxygen uptake reported by Roberts et al (2010) in a simulated Novice ODE which is discussed in the following sections.

Since the completion of the body of work in this thesis Cullen et al. (2015) and Sainas et al. (2016) have disseminated research documenting the physiological demands of flat racing, and responses during riding respectively. Mean heart rate in male flat racing jockeys during a simulated and competitive race were 77% and 98% of heart rate peak respectively indicating that the light seat position evokes a high heart rate demand. Sainas et al. (2016) reported heat rate data that was in agreement with this thesis and previous research, that heart rate increased from walk (Heart rate ~110 beats.min^{-1}) through trot (Heart rate ~128 beats.min^{-1}) with physiological variables being substantially greater during canter (heart rate 158 beats.min^{-1}) (Sainas et al. 2016).

The research throughout this thesis confirms that heart rate responses to horse riding are more elevated compared to associated physiological variables of blood lactate and oxygen consumption. The causal mechanism to account for dissociation in physiological variables has been explored in other sports but prior to this thesis has not been specifically investigated or applied to equestrian sports. Chapter Four speculated that one variable to be a causal factor for elevated heart rate was muscle activity since heart rate increases substantially during light seat canter and during jumping which is discussed further in section 6.3. The data presented within Chapter Four was a motivation for the development of the concluding experimental trial, Chapter Five established that in a simulation scenario heart rate is also elevated as was reported in the field, the study also documented isometric presence during riding.

6.1.3 Oxygen Uptake

Oxygen uptake has received minimal attention in response to horse riding, what has been conducted has been documented by gait (Chapter Five; Westerling 1983; Deveinne and Guzennec 2000; Beale et al. 2015; Sainas et al. 2016), by competition phase during Eventing (Chapter Four; Roberts et al. 2010) and during race riding (Cullen et al. 2015). The data in Chapter Four reported high predicted oxygen uptake in riders which was speculated to be an over-estimation based on laboratory reference mode used, later confirmed throughout Appendix 1. If Chapter Four results are corrected based on the data in Chapter Six, data (DR 30.8, SJ 32, XC 34.6 $ml.kg.min^{-1}$) are more comparable to research by Roberts et al. (2010) in a simulated ODE (DR 20.4; SH 28.1 XC 31.2 $ml.kg.min^{-1}$). It is expected that values for oxygen consumption in Chapter Four would be greater as research was conducted during actual competition rather than a simulation as per Roberts et al. (2010) and it documented that the effects increased adrenaline response to competition increases physiological variables of oxygen uptake, heart rate and blood lactate (Ensigner et al. 1993).

Where oxygen uptake is reported by gait or position of the rider, it is apparent that oxygen uptake increases from walk to canter, but not at the same elevated rate that is reported for heart rate which was established in Chapter Five. This thesis reports that heart rate is far greater than the oxygen requirement observed in riders and is in agreement with work of Sainas et al. (2016).

6.1.4 Blood Lactate Concentration

Blood lactate concentration has previously been reported in Show Jumping (4-6.3 $mmol.l^{-1}$), National Hunt racing (7 $mmol.l^{-1}$) and simulated ODE riding (9.5 $mmol.l^{-1}$). Data presented in this thesis is in agreement with previous research, that blood lactate concentration is greater where light seat canter and jumping are a requirement. Despite heart rate potentially being elevated by cognitive anxiety and muscle activity within these gaits, blood lactate increases also indicate there is increase physical workload associated for these gaits and positions also. Chapter Four reported mean blood lactate to increase with phase of competition (DR (2.2$mmol.l^{-1}$), SJ (3.5 $mmol.l^{-1}$) and XC (4.7 $mmol.l^{-1}$)). Chapter Five is the first research to report blood lactate concentration throughout the gaits and positions of the rider and established that Canter and Jumping require more involvement from the anaerobic energy system as blood lactate markedly increases in those gaits (W=1.1, ST=1.7, RT=1.7, C=2.0, LC=2.8, FC=3.0 J=2.6 $mmol.l^{-1}$).

Perciavalle et al. (2014) disseminated research concerning blood lactate and attention in Show Jumpers to examine whether in show jumpers a typical course is capable of influencing intensity and selectivity of attention. Twelve participants (n = 6 male, n=6 female) completed an eight obstacle 1.15m show jumping course and fingertip blood lactate samples were taken immediately, 5 and 10 minutes post completion of the course. Three rounds were completed and the best and worst round was used, it is not clear from the research how much rest was given between rounds. An attention and concentration task test was completed 10 minutes prior, immediately upon completion and 10 minutes post the round. Blood lactate was reported as 3.8 $mmol.l^{-1}$ for the riders' best performance and 4.2 $mmol.l^{-1}$ or their worst performance, regardless of performance the blood lactate concentrations post SJ round are comparable to previous research (Chapter Four, Chapter Five, Guitérrez Rincón et al. 1992; Trowbridge et al. 1995; Roberts et al. 2010). Perciavalle et al. (2014) concluded that although the concentrations of blood lactate were moderate, they were great enough to worsen reaction time in riders and provides further justification for riders to condition themselves to off-set the early onset of blood lactate concentration.

6.2 Muscle Activity During Horse-Riding

Chapter Five is the first investigation to quantify muscle activity during cantering and jumping. The *rectus femoris* muscle was the most activated during horse-riding reporting left leg bias followed by *rectus abdominis* which was the second most activated, and in contrast to *rectus femoris* reports a right side bias. The *flexor carpi radialis* demonstrates asymmetry in recruitment between left and right reins and reports peaks in the left rein. The *latissimus dorsi* is the least involved and displays a more symmetric activation pattern between left and right muscles throughout the gaits.

During Jumping the lower body activates prior to the jump to guide the horse, the *latissimus dorsi* is activated during the jump for control of the trunk and upper body, and the lower body is then activated on landing for control and direction of the horse post jump. Muscle activity decreases just prior to the jump and remains isometric necessary to maintain stability and balance of the riders un-seated position over the jump, post the jump amplitude of isometric muscle activity increases as a response to landing mechanics and re-stabilisation of the torso after trunk perturbations. The nature of the interplay between high amplitude and low amplitude isometric work suggests the muscle action is not continuously isometric in all muscles (right *rectus femoris* appeared to be in continuous isometric activation throughout the jumping phase). Chapter Five concluded that isometric muscle activation plays a large role in movement patterns during riding.

Data from Chapter Five has developed and supported research findings from the work of Terada (2000; 2006) who investigated muscle activity in the gaits of walk and trot. The difference in the aims of the research meant that muscle groups chosen were different and thus not directly relatable, yet this thesis ultimately agrees with Terada that the predominant role of muscle action during riding was for co-ordination and postural stabilisation, rather than for the production of power.

6.3 Interpretation of the Physiological and Muscular Responses to Horse-Riding

Though equestrian specific literature does not detail the submaximal relationships between heart rate and oxygen uptake during riding, collective data is in agreement with this thesis (Westerling 1983; Devienne and Guzennec 2000; Guitérrez Rincón et al. 1992; Trowbridge et al. 1995; Roberts et al. 2010; Perciavalle et al. 2014; Beale et al. 2015; Sainas et al. 2016) that data is not representative for what is documented during dynamic exercise where a rise in heart rate is linear to oxygen consumption and where a more marked blood lactate concentration is apparent. High requirements for isometric muscle activity has been purported to stimulate a disassociation between physiological parameters as a response to increases in blood pressure during sports such as motocross, rock-climbing sailing and kitesurfing. (Konittinen et al. 2002; Sheel et al. 2003; Konttinen et al. 2007; Konttinen et al. 2008; Vogiatziz et al. 2007).

This thesis documents that during the penultimate stage (Jumping) of a live horse exercise test, heart rate demands are far greater during riding (80%HR_{max}) than the oxygen requirement (48%$\dot{V}O_{2max}$) observed in addition to moderate blood lactate concentration (3.6mmol.l^{-1}) and considerable respiratory strain (62%VE_{max}; 81%RF_{max}), a heart rate elevated compared with other physiological variables in horse riders is a finding supported by work of Sainas et al. (2016). Canter and jumping predominates throughout the SJ and XC phases of Eventing and as such is an important focus throughout this thesis.

These physiological responses where heart rate is elevated have, as previously discussed, been reported in other travel sports including Sailing (41%$\dot{V}O_{2max}$; 70%HR_{max}, Vogiatziz et al. 2002, 39% $\dot{V}O_{2max}$; 74 %HR_{max}, Vogiatziz et al. 2005) Windsurfing (77%$\dot{V}O_{2max}$; 87%HR_{max}, Perez-Turpin et al. 2009), Kitesurfing (74%$\dot{V}O_{2max}$; 83%HR_{max}, Vercruyssen et al. 2009) and Motorcross (69%$\dot{V}O_{2max}$; 96%HR_{max}, 62%VE_{max}; 106%$RF_{max;}$ 31%$BLa_{max,}$ Konittinen et al. 2007) also. It is apparent compared with these sports, that jumping a horse is comparably as physiologically demanding to Sailing with regards to relative percentage of maximal oxygen uptake and relative percentage of maximal heart rate. Horse-riding requires a lower percentage of maximal uptake and heart rate maximum than Kitesurfing, Windsurfing and Motorcross despite the relative dissociation between heart rate and oxygen uptake being similar. Despite a high cardiac strain during horse riding, oxygen uptake and blood lactate data indicate the physiological demands of Eventing are moderate. That stated, regardless of the causal factors for elevated heart rates, it is a common finding within the literature. Equestrians will still have to manage and train for high cardiac stress within their competition preparation and as such future research is warranted to further decipher the causal mechanism to ensure optimal physiological conditioning is maintained for this population of athletes.

Isometric contractions hinder local blood flow whereas dynamic exercise facilitates circulation. The heart rate response to isometric exercise is also dependent on the size of the contracting muscles. Heart rate response markedly increases during light seat canter and jumping, increases in %MAV_{max} is reported for *rectus femoris* during light seat canter (Figure 5.6) and may have increased activation of the muscle metaboreflex (Lellamo et al. 1992; Fisher and White 2004) further elevating heart rate during these gaits and rider positions.

Chapter Five reported relationships between intensity of riding and the relationship between physiological variables. This chapter identified as suspected based on data within Chapter Three and Four that there are other variables in addition to heart rate that has affected the relationship between heart rate and oxygen uptake during horse riding, particularly when the faster gaits of canter and where jumping efforts are concerned.

Electromyographical analysis of riders during a live horse exercise test confirms the presence of isometric muscle work in riders. In some muscles, isometric activity is consistent for long durations and in other muscles alternates between period of low amplitude and high amplitude isometric muscle work. Based on previous research in travel sports and established heart rate responses to isometrics, this study indicates that isometric muscle work may be a contributing factor for elevated heart rate compared to oxygen uptake during horse-riding.

This thesis reported moderate blood lactate concentration during an on horse exercise test, for the high heart rates reported during riding, blood lactate would have been expected to be higher. This study confirms that heart rate is not reflective of oxygen uptake and gives reason for blood lactate concentration being lower than initially expected based on heart rate alone. During an isometric contraction sustained at more than 15-20%MVC, muscle blood flow increases several times above its resting levels (Sheel et al. 2003). This is not sufficient to meet the metabolic requirement and as a result there is a deficit of oxygenated blood which leads to production of blood lactate, which helps interpret an ample concentration of blood lactate during riding considering low oxygen consumption presented. Interestingly, neither sailing nor horse-riding during the live horse exercise test or the competition study in Chapter Four accumulated high blood lactates. In accordance with the suggestion by Lind (1983) in response to prolonged isometric muscle work higher blood lactates should be expected. Vogiatziz (2008) attributed this moderate blood lactate response to the quasi-isometric concept, first introduced by Spurway (2007) reporting that lower blood lactates than may be expected are as a result of dis-continuous isometric muscle work. In sailors specifically, the discontinuous action is as a result of muscle relaxation as a result of changing position to re-direct the boat. Spurway (2007) concluded that these periods of rest intervals would allow partial restoration of the muscles oxygen accessibility, promoting a more oxidative degradation of glycogen and low lactate concentration. During riding, we report periods of low amplitude activity succeeded by periods of high amplitude muscle activity. Presumably as the rider adapts their position, to account for changes in muscle work, partial restoration of muscle oxygen accessibility occurs and explains blood lactate concentration not continuing to rise.

The movement patterns of riding a horse, particularly concerning the light seat are more complex than a true isometric movement because it requires isometric efforts but at certain time points also dynamic movements of the limbs and trunk. Chapter Five intimated amongst other factors that quasi-isometrics may be a factor for elevated heart rate data compared to other physiological variables. Quasi-isometrics is a condition in which the muscles, remain for prolonged periods isometrically, under load sufficient to restrict blood flow substantially. As a result, quasi-isometric exercise produces metabolic and fatigue effects which are virtually indistinguishable from those experienced during strictly isometric movements sustained for similar times under similar loads.

During the live horse test, the light seat canter was the position and gait combination that saw heart rate increase, yet a decrease in oxygen uptake. This stage observes a change in position from the rider as they change from a seated position, where the pelvis acts as the base of support, to being un-seated where the rider supports their body weight by the balls of their feet on the stirrups. Our data indicates quasi-isometric exercise may be present during horse riding and warrants further investigations.

6.4 The Physiological Demands of Eventing

The primary aim of this thesis was to investigate the physiological demands of Eventing, as such this section incorporates thesis data holistically to report the physiological demands of each phase during a competitive Event. This section also presents practical applications for both coaches and trainers and researchers who may wish to evidence base training interventions in an equestrian population.

The DR phase is the first phase completed during Eventing, and whilst evokes considerable cardiac stress, is the least stressful Eventing phase from a physiological perspective. Though heart rate is reported at moderate to hard intensities, blood lactate rarely accumulates above 2mmol.l^{-1} during both competition and walk – seated canter stages during live horse exercise testing and further supports that this phase is predominantly aerobic in nature.

The SJ phase is the second phase (held during a ODE), the main gait required of the horse throughout this phase is the canter and the rider will adopt a mostly un-seated position. The SJ phase evokes considerable cardiovascular stress more-so than compared with the DR phase. Heart rate is reported as hard to very hard intensities, with blood lactate approximately 4mmol^{-1} during both competition and live horse exercise testing and further supports that this phase is predominantly aerobic in nature supported by anaerobic energy pathways. The risk of jumping to both the horse and the rider is widely reported (Murray et al. 2005) and as such riders being able to tolerate a build up of blood lactate to off-set the effects of fatigue is advisable. The dissociation in heart rate and oxygen consumption evident on a live horse (Chapter Five) is reported in the light seat canter and onwards (fast cantering and jumping), where the rider adopts a light seat position. Considering that SJ only involves these gait/rider positions using heart rate to predict requirements for oxygen should be cautioned.

There is a larger range of movement during jumping at the hip (Nankervis et al. 2015) compared to Dressage (Lovett et al. 2005). Chapter Five discusses muscle activation during the jumping aspect of a live horse exercise test. The *rectus femoris* and *rectus abdominis* are activated with higher amplitudes of isometric activity pre and post the jump compared to low amplitude isometric activity during the jump. The change from high to low amplitude isometric activity is presumably due to the hip flexion/extension reported by Nankervis et al. (2015) to facilitate the rider to position their trunk over the horses centre of mass during the jump. This movement (and likely continuous smaller adjustments for the purposes of stabilisation and balance) is likely to be the ‘quasi’ or ‘dynamic’ aspect of the isometric demand that allows brief muscle relaxation and replenishment (i.e. the movement is mostly isometric but not wholly, or intermittently isometric).

The XC phase is the final phase held during an (ODE) Event. As per the SJ phase, the main gait required of the horse throughout this phase is the canter and the rider will adopt a mostly un-seated position. Unlike the SJ phase, the horse and rider will adopt a faster pace of canter between fences, face multiple gradients and types of terrain e.g. sand, grass, mud, water which will likely affect breaking, acceleration and landing mechanics of riders and ultimately physiological responses. In addition to the surface the XC phase includes a greater variety of fences, including drop jump landings, combinations, jumps on uphill and downhill.

The XC phase of Eventing evokes the highest heat rate and blood lactate response of the three phases. Heart rate is reported at very hard intensities during cross country competition and the gait/position combinations adopted within the cross country phase throughout live horse exercise testing. The heart rate and blood lactate response reports that XC is predominantly aerobic in nature supported by anaerobic energy pathways. The extremely high risk nature of the XC phase which reports multiple injuries and fatalities suggests riders should not only be prepared to tolerate a build up of blood lactate to off-set the effects of fatigue but also to offset the accumulative fatigue that will occur as a result of multiple competitive phases in one day, particularly as the XC phase is the most physiologically demanding, incurs the most risk and is the concluding phase of competition.

As discussed previously, a disproportionate increase in heart rate relative to oxygen consumption is evident on a live horse at the light canter onwards. Heart rate and oxygen uptake increase linearly until the rider adopts a light seated position at the canter. The XC phase almost exclusively recruits this position and gait combination and as such, isometric requirements in this position may affect the heart rate response and riders should be conditioned to account for this. As for SJ, using heart rate to predict requirements for oxygen during the XC phase should be cautioned (Chapter Five). Compared to the SJ phase, there is increased time between jumps and although more jumping efforts in total, the period of relief (i.e. The dynamic shift between period of isometric activity) is further apart (Chapter Four), which may explain the higher blood lactate reported throughout this phase. Less movement would equate to less opportunity for fatigue metabolites to be circulated around the body and as such result in increased lactate concentration.

It is interesting to note that the warm up times for each corresponding phase of Eventing are ~15mins, ~9mins and ~7mins for DR, SJ and XC respectively. This means that the actual times spent practicing and performing for each individual phase are ~20mins, ~12mins and ~12mins for a total on horse time of ~44mins (Chapter Four). The warm up durations accumulate to more time than the actual competition and it is worth considering the compounding affect this may have on fatigue. It has also been noted that the relative intensity of each phase increases throughout the day and interestingly recovery time between DR and SJ are ~ 1hr 15min and there is ~30mins between SJ and XC. This thesis reports the least physiologically demanding phase (DR) has the most recovery and the most physiologically demanding phases have the least amount of recovery in absolute time. When considering these times as relative, the work-to-rest ratios are the same both showing 1:15. The large amount of absolute time between DR and SJ allows for the rider to gain passive rest and opportunity to refuel and rehydrate which are imperative for successful performance in other sports. Opportunity for recovery is not as likely between SJ and XC due to the need of re-dressing and preparation for the ensuing phase and therefore this limited window of recovery may have a subsequent effect on performance and more worryingly on the most physiologically demanding phase of the event. Future research regarding the development of rider performance should consider investigating recovery and demands of warm up on the effects on subsequent performance. Accounting for the overall demand of the ODE may help rider athletes physically perform to the best of their ability for each individually phase.

6.4.1 Practical Applications

The outcomes from empirical chapters within this thesis have implications that inform recommended practices for athletic preparation for training the Event rider. The physiological data and muscular activation profile presented and discussed within this body of research suggests that cardiovascular and strength training should be a part of an Event riders training programme to off-set fatigue (based on the physiological demands reported within this thesis) and reduce risk of injury (based on reports of asymmetry in both position (Chapter Three; Bystrom et al. 2009; Symes and Ellis 2009) and muscular activation (Chapter Five).

The research within this thesis unlike studies of Lee et al. (2015) and Hampson and Randle (2015) has identified specific physiological and performance related fitness characteristics required for Event riding. As such, Table 6.1 highlights specific suggested areas for future research to investigate off-horse training of Event riders.

As a sport that comprises of three disciplines, Event riders should consider the volume and intensity of specific training relevant to their current on-horse training load. For example, Chapter Three reports riders spend more time training on the horse for DR compared with SJ and XC and might indicate the Event rider needs to concentrate their attention on the training recommendations relative to the SJ and XC phase, since an adaptive training stimulus required for competition is unlikely to be produced during on-horse training alone.

Table 6.1: Brief overview of the physiological and biomechanical demands related to each individual phase of a Novice One-Day Eventing and associated suggested training methods or areas for future intervention design.

	Physiological Demand	Suggested Training Method
DR	Moderate to hard heart rate demand, limited blood lactate concentration. Predominantly aerobic sustained for approximately 5 minutes of duration (Chapters 4,5). Trunk position more upright in expert riders (Lovett et al. 2005), muscle activation used for positional stabilisation (Chapter 5, Terada, 2006). Limited range of movement at the joints (Lovett et al. 2005).	Continuous aerobic activity below threshold level (Chapter 4,5) Low intensity isometric holds at the thigh and trunk e.g. isometric plank and squat variations. (Chapter 3)
SJ	Hard to very hard heart rate demand, blood lactate close to threshold levels sustained for 2.5 minutes of duration (Chapters 4,5) The thigh/trunk angle has a large range of motion involved in the flexion extension movement to facilitate rider over the jump (Nankervis et al. 2015). Muscle activation is used for stabilisation of the riders body and follows a pattern of low amplitude isometric activity at the trunk and thigh over the jump and high amplitude isometric activity between jumping efforts (Chapter 5).	Intermittent aerobic exercise at higher intensity above threshold and lower intensity below threshold (Chapters 4,5). Iso-ballistic exercises (isometric holds with intermittent ballistic movements) to introduce the rider to control the bodies stabilitative mechanics to changes in movement patterns observed during the jump e.g. drop jump mechanics, isometric squat to jump squat (Thibaudeau, 2006) Oscillatory isometric exercises e.g. squats with pulses to add a small amount of concentric/eccentric muscle activity in the working muscle (Millar et al. 2014). Quasi isometric movements e.g. plank with limb movement, isometric squats with upper body movement or relief in hold periodically (Vogiatzis et al. 2011)
XC	Very hard heart rate intensities, blood lactate concentration close to or above anaerobic threshold levels (Chapters 4,5) Rider position is the same as outlined for the Show Jump Phase. High amplitude isometric contractions between jumping efforts last for longer durations at this phase (Chapter 4) .	Cardiovascular exercise should be approximately at threshold intensity for continuous duration. Trainers may wish to use cardio as aerobic interference as a tool to increase posture and stabilisation whilst subjected under fatigue i.e. period of cardiovascular exercise between resistance based training methods (Chapters 4,5). Same strength training considerations as outlined for the Show Jump Phase, isometric hold may wish to be held for a longer duration specific to this phase.

6.5 Limitations

As with all empirical research, the studies that comprise this thesis are subject to a number of experimental considerations. As presented within the thesis delimitations there are varying sample populations used across the trials, Chapters Three and Four consisted of Event riders, Chapter Five considered horse-riders who actively engaged in equestrianism but were not Event riders. There were also relatively small samples sizes utilised across all studies and may limit the generalisation to a broader sample as a whole.

Throughout Chapter Four and Five, the investigations of the physiological demands of competitive Event riding and responses to a live horse exercise test were conducted at different times throughout the year, temperature and humidity were not accounted for and may have affected results and interpretation of physiological data. Additionally, riders were required to wear a helmet, full length trousers and tops, often with a body protector on top, and it is likely that variability occurred due to total body area being covered during testing. Future research should consider the effect heat stress may play in the measurement and interpretation of physiological data.

In Chapter Three, a fitness test battery was designed with test selection based upon prior evidenced based methods. It is, however the first known fitness test battery specific to be developed specific to an Event rider population. As such, upon reflection, there is room for modification of tests chosen which can be developed upon in future research and provides a platform for future researchers to expand upon. Based upon research in Appendix 1 a physical test battery should incorporate TM testing as opposed to CE which was used in Chapter Five. Additionally, the plank to fatigue test has not received rigorous scrutiny in terms of test re-test reliability and would be beneficial to future research. Performance related physical adaptations have been reported to athletes habituated to isometric muscle work (Felici et al. 1999) and as isometric training decreases hypertension (Millar et al. 2014) it would be interesting to investigate the cardiac responses during isometric test measures as much as maximal physiological variables in this population.

With regards to reliability of test measures used throughout this thesis, the mechanical horse nor the live horse were tested for reliability and as a result may have affected the data reported. During the live horse exercise test, the clockwise direction of the trial impacted bi-lateral muscle activity. The decision to conduct testing on one-direction was based upon allowing the test to continue in a progressive intensity with minimal interruption. Two minutes at each gait allowed rider position and horses gait to stabilise and allowed blood lactate to diffuse adequately to get a true reflection of blood lactate concentration at each stage. To conduct the test in the opposite direction also was considered too demanding for the horse, the test on one direction was 14 minutes increasing intensity exercise, with eight minutes at canter and jumping gaits and would have required an additional data collection session. It would be pertinent for future research to investigate muscle activation patterns of riders in both directions.

CHAPTER SEVEN: CONCLUSIONS

The primary aim of this research was to investigate the physiological demands of Eventing. A number of field and laboratory based experiments were designed to meet the thesis objectives which inter-linked to further understand competitive demands of the sport, physical attributes in this sport-specific population and detailed evaluation of responses to riding a live horse.

It is evident from the three empirical trials that the most physiologically demanding aspect of Event riding is the light seat canter and where jumping efforts are introduced. When these two gait/position combinations are introduced the following physiological and muscular responses occur; i) high heart rate (heart rate that is far greater than the oxygen demand required), ii) increased blood lactate concentration, iii) periods of sustained high amplitude and low amplitude isometric work notably at the thigh and trunk. These physiological and muscular responses are likely to be as a result of isometric muscle work in addition to environmental conditions

The data in these thesis detailing the physiological demands of riding and physical characteristics of Event riders give a sound basis for the development an effective off-horse training interventions that would increase the potential in the physiological parameters mentioned above and subsequently lower the relative intensity of work during actual riding aiding in the potential improvement in performance.

7.1 Future Research Directions

The investigations concerning the physiological demands of equestrian sport as a whole are in its infancy. There are vast areas of research that could take various different directions, and this thesis provides data on which to base designs for future research. This thesis considers the physiological demands of Novice level ODE, a similar approach could be investigated in both Intermediate and Advanced levels. This assembly of research would assist fitness professionals to meet the governing body requests for specific event preparation outlined within the Long Term Participant Development Model. The future research direction could also include time-motion and notational analysis to further understand proportion of time spent in the different gait and or positions.

The physiological demands of riding in the majority of equestrian sports have not been investigated in a competitive nor training situation. The approach to investigating the demands of riding to date consider leisure riding or riding during gait specific tasks. Whilst this is useful to the interpretation of demands during riding, it is essential that competitive responses are documented. Future research should consider investigating physiological demands and fitness related performance in Dressage and Show Jump riders to complete a detailed understanding of the Olympic Equestrian Disciplines. There are also the FEI equestrian disciplines that warrant future investigations. In short, research concerning the physiological demands and performance related fitness in equestrian sports as a whole are not well understood, there are multiple directions and disciplines that warrant future investigations.

Taking into consideration the results, implications and limitations of the experimental chapters, as well as those of the discussed related literature, there are a number of key questions that warrant further research specific to questions raised during this research that are detailed below:

i. Is blood pressure increased during light seat canter and jumping? Spurway (2007) reported physiological responses as a result of the quasi-isometric concept to be: Heart rate higher than is necessary for oxygen supply; heightened blood pressure; hyperventilation. This thesis confirms that heart rate is higher than is necessary for oxygen supply. Research to date has not measured blood pressure responses and would provide further justification to support the quasi-isometric concept resulting in physiological data currently reported.
ii. Do Advanced Event riders resist isometric fatigue as a result of enhanced systemic cardiovascular adaptation better than their Novice and Intermediate counterparts? Repetitive pressure overload due to quasi-isometric muscle work has been reported to induce adaptive cardiac effect in sailors (Felici et al. 1999) and as isometric training decreases hypertension (Millar et al. 2014) would be an interesting training effect to

monitor or intervention trial to implement in equestrian athletes.

iii. What are the physiological demands in Intermediate and Advanced level Eventing? It would benefit trainers and coaches to have an evidenced based understanding of the sport and how the physiological demands progress or alter as the skill level and technical difficulty is increased.

iv. How does situation affect the underlying psychological and physiological mechanisms in equestrian athletes? Determining the effects of novel stimulus and competition demands compared to training would further assist in determining physiological profiles based on situation.

This thesis provides a major contribution to the body of knowledge currently available and suggests the investigation of physiological demand in equestrian sports is more complex than previously considered. This thesis has determined that heart rate is elevated in comparison with other physiological variables during horse riding and that during riding isometric muscle action predominates in both the upper and lower body. Though this thesis is not able to comprehensively conclude that physiological responses are a direct result of quasi isometrics, the data set does infer this may be a potential contributor and as such is a recommended topic for future research.

CHAPTER EIGHT: REFERENCE LIST

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CHAPTER NINE: APPENDICIES

Appendix 1: Comparison of mechanical horse, cycle ergometer and treadmill exercise modes on heart rate, oxygen uptake and blood lactate response in female horse- riders.

Appendix 2: Equestrian Training and Additional Training Questionnaire

Appendix 3:

a) Chapter Three Study Documentation
b) Chapter Four Study Documentation
c) Chapter Five Study Documentation
d) Appendix One Study Documentation
e) Generic Pre-Test Documentation

APPENDIX ONE

COMPARISON OF MECHANICAL HORSE, CYCLE ERGOMETER AND TREADMILL EXERCISE MODES ON HEART RATE, OXYGEN UPTAKE AND BLOOD LACTATE RESPONSE IN FEMALE HORSE-RIDERS

A.1 Introduction

The need for a study that explores the effect of exercise modes on physiological responses in equestrian athletes arose in response to results from studies one and two indicating that cycle ergometry may not be an appropriate laboratory mode for equestrians. Typically, a treadmill (TM) will attain a greater maximal oxygen consumption ($\dot{V}O_{2max}$) than a cycle ergometer (CE) in untrained populations (Wilson et al. 2012), however in equestrians, Meyers and Sterling (2000) reported lower $\dot{V}O_{2max}$ data using a TM than was using CE as reported by Westerling (1983). Research from study one and study two (which used a CE) reported higher $\dot{V}O_{2peak}$ than Meyers and Sterling (2000). Initially, it appeared that perhaps a CE was more replicative of physiological demands of riding than a TM and was one of the reasons that established a CE as the initial mode of assessing peak oxygen uptake in a horse-rider population within this thesis. It is well established that muscles adapt specifically to certain modes of exercise resulting in improvements in sub-maximal physiological variables (Millet et al. 2009). Trained cyclists will report maximal variables using a CE (Bouckaert et al. 1990) and trained runners will report maximal variables on a TM (Bouckaert et al. 1990) and so an investigation to determine exercise modality that is closest to riding is warranted.

The question of the suitability of the CE as a measure of aerobic power in an equestrian population arose in response to data reported in Chapters Three and Four. The study in Chapter Four reported that mean heart rate, heart rate classified by metabolic zones and per cent contribution of peak oxygen consumption (validated by CE) were near age-predicted maximal throughout all three phases of Event riding and sometimes even greater than in the laboratory. Blood lactate data however, were approximately near 4mmol.L^{-1} during SJ and XC phases. The high heart rate, high estimated oxygen uptake combined with moderate blood lactate concentration throughout all three phases was not expected. With such high heart rates and estimated oxygen uptake reported throughout competition, a more marked blood lactate concentration would have been expected to match the maximal demand. It is possible and likely that if laboratory CE testing did not achieve a true maximal value due to the mode chosen, that in field estimations are inaccurate. If CE did not measure maximal $\dot{V}O$, estimated $\%\dot{V}O_{2peak}$ is greater than is actually required during riding.

Maximal oxygen consumption has been determined using numerous exercise modes that activate large groups of muscle mass, provided the intensity of effort and protocol duration are sufficient to maximise aerobic energy transfer (McArdle et al. 2001). Treadmills and cycle ergometers are the most common modes for attaining $\dot{V}O_{2max}$, though other types of exercise including swimming (Demarie et al. 2001), and rowing ergometry (Metcalfe et al. 2013). At the point of study design and implementation within this chapter (2012), there was no research investigating the physiological responses of riding a mechanical horse simulator and thus the suitability and sport specificity of this mode as a laboratory were unknown. In addition to understanding an individual's maximal oxygen consumption, exercise tests are employed by coaches and researchers to explore additional sub-maximal cardio-respiratory responses and adaptations to exercise and as such a sport specific mode is desirable. For these reasons, it is important to understand sport-specificity related to mode of exercise used for laboratory testing. As a horse simulator is a seemingly specific mode where intensity can be set, it was pertinent to explore the use of the horse simulator to determine whether it can be used as a laboratory mode.

A.2 Overall Research Aim:

This aim of this chapter was to compare physiological responses of horse-riders in three separate exercise modes; a cycle ergometer, a treadmill and a novel test on a mechanical horse simulator.

A.1.3 Specific Research Aims:

1. To identify and compare heart rate, oxygen uptake and blood lactate concentration in horse-riders on a mechanical horse, a cycle ergometer and a treadmill.

2. To investigate which exercise mode achieved the highest $\dot{V}O_{2peak}$ in horse-riders

3. To explore the heart rate-oxygen consumption relationship between exercise modes.

These study aims translated into hypotheses are as follows:

1. $\dot{V}O_{2peak}$ attained on the treadmill will be significantly higher in comparison to the cycle ergometer and mechanical horse.

A.2 Methods

A.2.1 Participants

Eleven females (mean±SD age 27.8±6.5years; height 168.4±6.1 cm; mass 64.0±5.6kg) actively engaged in horse-riding for a minimum of three times per week participated in this study.

A.2.2 Study Design

Participants completed three maximal incremental exercise tests using three different modes of exercise; a CE, a TM and a mechanical horse (MH) in a randomised cross over and counterbalanced design. A maximum of one week (to ensure no training effect had occurred) and a minimum of three days (to ensure recovery from previous maximal exercise test) were required between tests. All participants were advised to report to the laboratory rested i.e. having performed no strenuous exercise in the preceding 24 hours, euhydrated and at least 3 hours following the consumption of a light carbohydrate based meal (Winter et al. 2007). Each participant wore light athletic clothing for each test.

A.2.3 Laboratory Testing

A.2.4 Anthropometrics

Height and Body Mass was measured as outlined in Chapter Three (Section 3.6.2).

A.2.5 Physiological Monitoring

For all three test situations heart rate (HR) was monitored continuously using telemetric heart rate monitors (Polar RS800CX Multi, Polar Electro, Kempele, Finland) sampling at

2-second intervals. Heart Rate, Overall Rating of Perceived Exertion (RPEo), Peripheral Rating of Perceived Exertion (RPEp) (Eston 2012) and blood lactate concentration (BLa) were recorded during the last 30s of each incremental stage (see Chapter Three for increased detail). HR_{peak} was considered the highest value reported for each trial. Throughout exercise, respiratory and pulmonary gas exchange variables were measured using an Oxycon Pro Mobile breath by breath gas analyser (Oxycon, Viasys). Before each test the O_2 and CO_2 analysis systems were calibrated using ambient air and gas of known O_2 and CO_2 concentrations, of O_2 19.4%, CO_2 0.6% and nitrogen balance according to the manufacturer instructions. Capillary blood (5µm) was sampled from the earlobe immediately four minutes post completion of the exercise test to enable peak BLa to be determined (Gollnick et al. 1986). BLa concentration was analysed as outlined in Chapter Three (section 3.6.5).

The $\dot{V}O_{2peak}$ in all modes was identified as the greatest 5 second average value reached during the incremental test, having reached two $\dot{V}O_{2max}$ criteria of; a respiratory exchange ratio (RER) greater than 1.15, a BLa concentration of $8mmol.l^{-1}$, or a peak HR of 90% of the age predicted maximal value (Noble et al. 1983; Caputo et al. 2003).

A.2.6 Cycle Ergometer

Peak oxygen consumption ($\dot{V}O_{2peak}$) was determined using a continuous, incremental loading protocol on a cycle ergometer. Participants were familiarised with the cycle ergometer (Monark, Ergomedic 874E) by verbal explanation of its use (Monark Exercise, Sweden) followed by a five minute warm up at 70W (1 kg resistive load) at a cadence of $70revs.min^{-1}$ (ACSM 2009; Eston and Reilly 2009). During this time the test supervisor showed participants how to safely stop the test when appropriate and how participants were to communicate to the tester throughout the experiment.

The CE test was modified from that of study one and two so that the test commenced at 70W, and was increased by 21W every minute (Winter et al. 2007; Eston and Reilly 2009) until the participant reached termination criteria. The test was modified to match the TM and MH tests as closely as possible and also that the test was not intending to explore LT as per study one and two. During the test, expired gas was analysed and HR and RPE were recorded each minute. RPE was monitored with a Borg 15-point scale, ranging from very light (6) to maximal (20) (Noble et al. 1983) as outlined in section 3.6.4. Upon completion of the test participants were encouraged to pedal at a light resistance (20W) until heart rate reached below 120 beats per minutes (ACSM 2009).

A.2.7 Treadmill

Peak oxygen consumption ($\dot{V}O_{2peak}$) was determined using a continuous incremental exercise test on a motorised treadmill (Woodway, USA). Participants were familiarised with the treadmill, which included a safety briefing and allowed a five-minute walking warm up (ACSM 2009). Participants commenced the test at an incline of 1% at 7.0km/h; RPE was recorded for the working muscles (RPEp) and general cardiovascular exertion within the final 30s of each stage (RPEo). With each minute, speed was increased by 1km/hr until overall RPE reached 15/16 on the Borg scale. At this point, speed remained the same and the incline was increased by 0.5% per minute until volitional exhaustion occurred for safety reasons as the population used were not conditioned to running at maximal velocities. Upon completion of the test participants completed a warm down until heart rate reached below 120 beats per minute (ACSM 2009).

A.2.8 Mechanical Horse Protocol

In addition to a TM and CE test, participants completed a novel test of aerobic capacity to determine the suitability of mounted fitness testing in equestrians on a MH. A Racewood Horse Simulator, Riding Model (Figure A.1 Racewood, Riding Model, UK) was used for this test. The mechanical horse used in this study had the following gait/position combinations available and test commenced in the following order: walk, trot, rising trot, canter, light seat canter. Riders were familiarised with the mechanical horse verbally and were given the opportunity to ride all of the simulator gaits prior to the testing (Table A.1). A five-minute warm up at the 'walk' setting preceded gait/position progressions every minute. These progressions followed the gaits of the mechanical horse (or position of the rider) outlined in table A.1.

Upon completion of the test participants were required to complete a warm down at the 'walk' setting until heart rate reached below 120 beats per minute (ACSM 2009).

Figure A.1: Racewood Mechanical Horse Simulator

Table A.1: Gait and position combination descriptions for each stage of the mechanical horse test protocol.

Test Progression ↓

Gait /Position Combination	Description
Walk	A four beat equine gait, the slowest pace on the mechanical horse. The rider remains seated in the saddle.
Sitting Trot	A two beat equine gait, this pace is the slowest of the trots on the mechanical horse. The rider remains seated in the saddle.
Rising Trot	A two beat equine gait, this setting is slightly faster than sitting trot. The rider rises themselves out of the saddle and back into the saddle with the timings of the trot gait.
Canter	A three beat equine gait. The rider remains seated in the saddle.
Light-Seat Canter	A three beat equine gait. The rider remains out of the saddle for the entire duration for this setting.

A.2.9 Statistical Analysis

Data are presented as mean±standard deviation (SD) throughout, alpha value is $p<0.05$ (confidence interval 95%) throughout unless otherwise stated. A one-way repeated measures ANOVA was used to determine statistically significant differences between BLa_{peak}, HR_{peak}, $\dot{V}O_{2peak}$, RPE_{peak} and exercise mode (CE, MH, TM). Within the analysis, if assumptions of sphericity were violated, a Greenhouse and Geisser correction was applied. There were no outliers (assessed by boxplot) and all data were normally distributed (Shapiro-Wilk test $p>0.05$). Pearsons Product Moment Correlational analysis was used to investigate and interpret relationships between heart rate and oxygen consumption for each exercise mode. Data were analysed using Statistical Package for Social Sciences (SPSS) for Windows, Version 22.

A.3 Results

There were significant differences in $\dot{V}O_{2peak}$ between exercise modes $F(2,20)=103.312$, $p<0.005$, (Table A.2). The TM attained the greatest $\dot{V}O_{2peak}$ (46.0±4.4 ml.kg^{-1}.min^{-1}), the CE reported a $\dot{V}O_{2peak}$ of 38.5±7.1 ml.kg^{-1}.min^{-1}, and the MH reported the lowest $\dot{V}O_{2peak}$ (21.2±1.9 ml.kg^{-1}.min^{-1}). There was a statistical difference between the TM and MH modes (24.8 ml.kg^{-1}.min$^{-1,}$ $p<0.005$). There was also a statistical difference between the MH and the CE (17.29 ml.kg^{-1}.min^{-1} $p<0.005$). A statistical difference was also found between CE and TM (7.54 ml.kg^{-1}.min$^{-1,}$ $p=0.002$).

There was a difference in mean HR_{peak} between TM and MH (68 beats.min^{-1}, $p<0.005$) and between CE and MH (67 beats.min^{-1}, p<0.005) but not between CE and TM (Table A.2). There were reported significant differences in HR_{peak} between exercise modes ($f(1.17,11.7)=162.405$, $p<0.005$, partial $n^2=0.94$ (Table A.2). The TM attained the highest HR_{peak} (188±8 beats.min^{-1}), the CE reported a HR peak of 186±7 beats.min^{-1}, and the MH reported the lowest HR_{peak} (119±20 beats.min^{-1}).

Table A.2: Mean±SD (range) Peak oxygen consumption ($\dot{V}O_{2peak}$), peak heart rate (HR_{peak}) peak RPE (RPE_{peak}) and peak BLa (BLa_{peak}) attained for all three exercise modes.

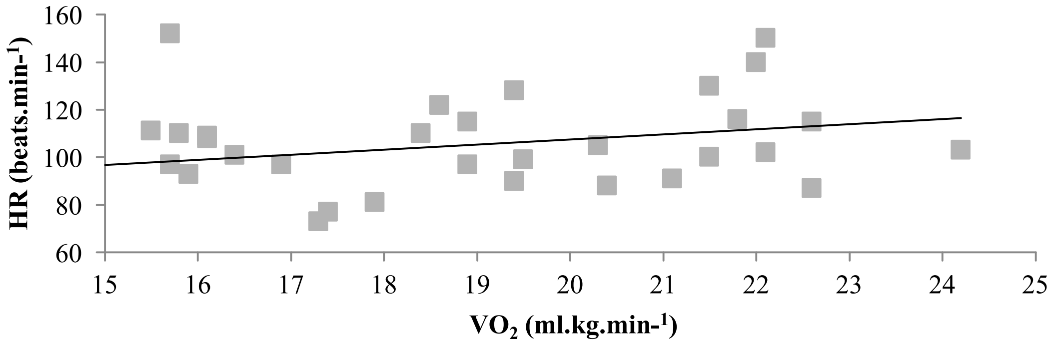
	$\dot{V}O_{2peak}$ ml.kg^{-1}.min^{-1}	HR_{peak} beats.min^{-1}	$RPEo_{peak}$	BLa_{peak} mmol.l^{-1}
CE	38.5±7.1 (28.4-53.3)[a,c]	186±7 (173-193)[c]	18.5±0.7[c]	9.1±2.8 (6.7-16.5)[c]
TM	46.0±4.4 (39.6-53)[b,c]	188±8 (165-196)[c]	18.1±0.9[c]	10.6±1.9 (3.8-10.6)[c]
MH	21.2±1.9 (17.9-24.2)[a,b]	119±20 (92-152)[a,b]	6.6±0.7[a,b]	1.6±0.5 (0.8-2.5)[a,b]

[a] = significantly different to TM, [b] = significantly different to CE, [c] = significantly different to MH.

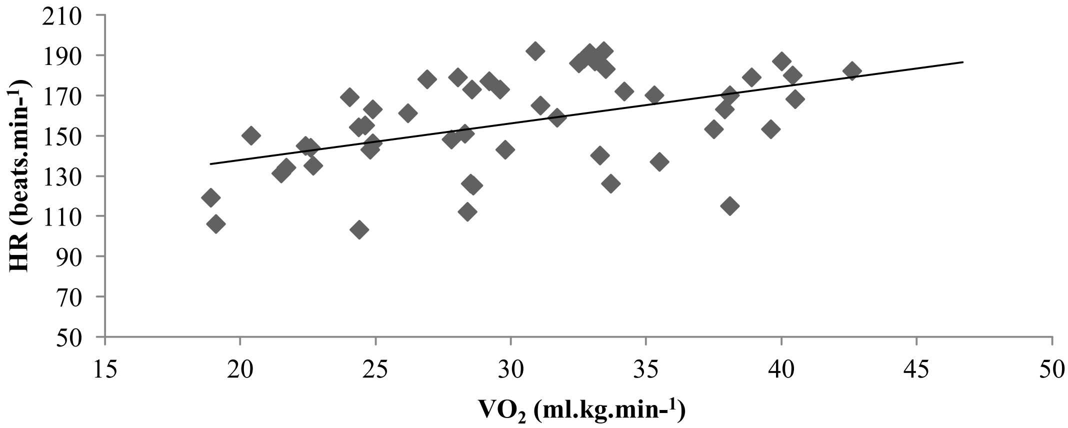
There were significant differences in BLa_{peak} between all three exercise modes *f (*29.9,11.8) = 219.38, *p*<0.005, partial n^2=0.77 (Table A.2). The TM attained the highest BL_{peak} (10.6±1.9 mmol.l^{-1}), the CE reported a BLa peak of 9.1±2.8 mmol.l^{-1}, and the MH reported the lowest BLa_{peak} (1.6±0.5 mmol.l^{-1}). There was a statistical difference in BLa_{peak} between CE and MH (5 mmol.l^{-1}, *p*<0.005), and between the TM and MH (7 mmol.l^{-1}, *p*<0.005). There was no difference between CE and TM (2 mmol.l^{-1}, *p*=0.26).

There were significant differences in $RPEo_{peak}$ between exercise modes *f (*241.2, 2)=385.3, *p*<0.005, partial n^2=0.96. The CE attained the highest $RPEo_{peak}$ (18.5±0.7), the TM reported a $RPEo_{peak}$ of 18.1±0.9 and the MH reported the lowest $RPEo_{peak}$ (6.6±0.7). There was a statistical difference in $RPEo_{peak}$ score between the TM and MH modes (*p*<0.005). There was also a statistical difference between the MH and the CE (*p*<0.005). There was not a statistical difference between CE and TM (*p*=0.084).

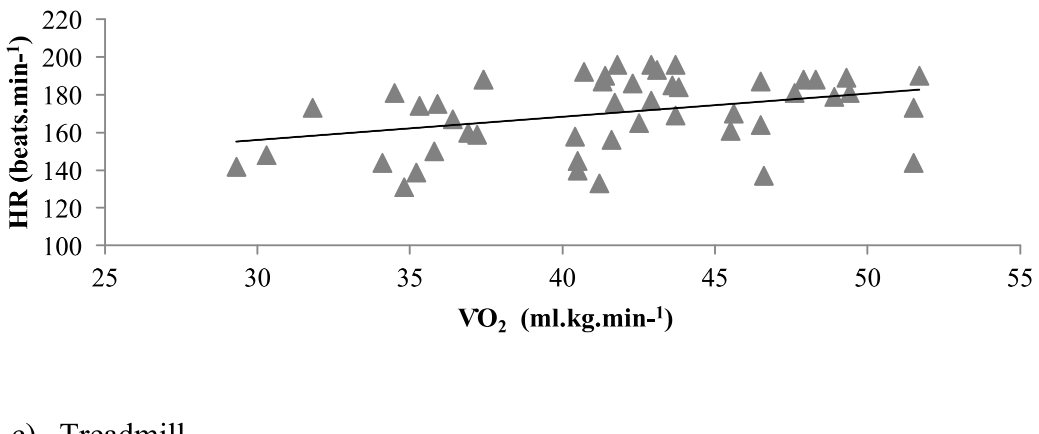
Correlation analysis established a moderate strength of relationship between the bi-variables of heart rate and oxygen consumption for treadmill (r=3.6, p=0.012), cycle ergometer (r=0.47, p=0,001) and mechanical horse (r=0.45, p=0.001) exercise modes. Figure A.2 visually reports that the gradient for all three exercise modes are similar but for the MH results are systematically lower.



a) Mechanical Horse



b) Cycle Ergometer



c) Treadmill

Figure A.2: Scatter plot of heart rate (HR) and oxygen consumption ($\dot{V}O_2$) for all three exercise modes, a) Mechanical Horse, b) Cycle Ergometer, c) Treadmill.

For the MH, data was reported by stage as there were differences in position (e.g. seated and unseated) unlike the CE and TM modes. Data was also analysed by stage to allow for comparison to previous research in live horse riding. It was apparent that stage 3 on the MH (rising trot) had both increases in HR and $\dot{V}O_2$, which decreased into stage 4 (Canter). The stage progressions of the MH do not follow a linear intensity as per the other exercise modes (Table A.3).

Table A.3: Mean oxygen consumption ($\dot{V}O_2$), mean heart rate (HR), mean RPEo (RPEo) and mean BLa (BLa) attained reported by stage of exercise testing for the MH (mean±SD).

Stage of MH	1 Walk	2 Sitting Trot	3 Rising Trot	4 Canter	5 Light Seat Canter
BLa_{peak} mmol.l^{-1}	1.1 ± 0.4	1.2 ± 0.4	1.3 ± 0.4	1.2 ± 0.3	1.7 ± 0.5
$RPEo_{peak}$	6±0.4	7±0.9	6.2±0.4	7.5±0.8	7.5±0.8
HR_{peak} beats.min^{-1}	82.5±13	93±19	109±11	96±22	114±19
$\dot{V}O2_{peak}$ ml.kg^{-1}.min^{-1}	6.6±1.0	8.2±2.2	15.6±2.9	10.7±2.4	12.1±2.6

A.4 Discussion

This study was the first to compare the mode of exercise on the physiological responses to incremental exercise in horse-riders. Additionally, it is the first to document a physiological profile of graded exercise testing using a mechanical horse simulator. Key findings were that there was a statistical difference in $\dot{V}O_{2peak}$ measured between exercise modes with TM being greater than CE and both being greater than MH, the difference between $\dot{V}O_{2peak}$ between TM and CE was significantly different despite HR_{peak}, BLa_{peak} and $RPEo_{peak}$ being the same, and finally that the MH was not physiologically as stressful in comparison to the TM and CE.

A.4.1 Maximal Physiological Responses to Exercise Mode

The greatest mean $\dot{V}O_{2peak}$ was attained on a TM with a mean value of 46 ml.kg.min^{-1} a difference of ~8 ml.kg^{-1}.min^{-1} to that measured on the CE (39 ml.kg.min^{-1}). The values for an age range of females 20-29 years (the mean age for this study was 27.8 years) presented on the TM are considered 'good' in comparison to the CE which reports female equestrians as only having average aerobic fitness levels (Astrand 2003). One other study that has conducted laboratory testing in equestrians using a TM reporting $\dot{V}O_{2peak}$ as 33 $ml.kg.min^{-1}$ and much lower for CE in this thesis and work of Westerling (1983). This study within this chapter concludes that for an equestrian population, maximal values are attained on a TM compared to a CE. Maximal aerobic power reported by Meyers and Sterling (2000) using a TM was lower compared to values attained on a CE reported by Westerling (1983) and within this thesis. As such it can be concluded that equestrians do not display similar local muscle endurance to the CE as previously thought and instead the population of Meyers and Sterling (2000) reported low aerobic fitness compared to that of this thesis and the work of Westerling (1983).

The studies within Chapter Three and Four both reported $\dot{V}O_{2peak}$ on a CE as $42ml.kg.min^{-1}$. The present study identified treadmill $\dot{V}O_{2peak}$ to be 18% greater in the same riding population. The percentage difference is higher than what has been reported in other female non active populations comparing the two modes. Turley and Wilmore (1997) reported that $\dot{V}O_{2peak}$ was 9% higher when a TM test was compared to CE in active adults not undertaking any specific training. Similarly, Miles (1980) reported an 8% difference in a female non active study population. The difference between TM and CE is greater but more comparable to trained participants, for example, Bouckaert et al. (1990) reported that maximal aerobic power in runners and cyclists to both CE and TM modes. Cyclists reported a 11% greater $\dot{V}O_{2max}$ output on a CE and runners reported 14% greater $\dot{V}O_{2max}$ output on a TM. The specificity and development of specific training adaptations to the mode determines the suitability of the test mode and that $\dot{V}O_{2max}$ would be the highest in the exercise mode that the athletes predominantly train in (Moreira da Costa et al. 1984). Chapter Five reported that of the 40% of riders that self-documented that they completed additional off-horse moderate intensity endurance exercise to supplement their riding fitness, 93% of them went running whilst 4% went to spin class.

Despite there being significant differences in $\dot{V}O_{2peak}$ between the TM and CE, HR_{peak}, BLa_{peak} and RPE_{peak} showed no differences between the modes. The recruitment of a smaller muscle mass (Moreira da Costa et al. 1984) and reduced blood flow in the legs during CE compared with TM running likely caused an effect on localised circulation

(Hermansen et al. 1970; Faulkner et al. 1971). Verstappen et al. (1982) purported that a submaximal stimulus of neurogenic origin due to the smaller muscle mass used during CE produces lower heart rate and $\dot{V}O_2$ uptake than those measured on a TM. Research in untrained participants indicates increases in $\dot{V}O_{2max}$ during TM running is associated with increased cardiac output, predominantly as a result of increased stroke volume. An increase in cardiac output is thought to be as a result of limited venous return (Hermansen et al 1970) due to limited lower body blood flow (Hermansen et al. 1970; Faulkner et al. 1971; Laaksanen et al. 2006). Martinez et al. (1993) noted that $\dot{V}O_{2max}$ on a CE is limited by local muscle fatigue in the quadriceps muscle group rather than cardiac factors (Martinez et al. 1993). This would explain oxygen uptake to be lower during CE compared to the TM whilst other physiological variables remain comparable. In populations that are not well adapted to cycling, CE thus has anaerobic limitations that prevent athletes achieving $\dot{V}O_{2max}$ compared to what they could attain on a TM (Martinez et al. 1993). Miles et al. (1980) reported increased blood lactate concentration during cycling at the same intensity during TM running. Local fatigue during CE increases maximal heart rate ~5% compared to TM running in untrained participants (Fernhall and Kohrt 1990).

Peak physiological responses from the MH were not representative of riders' maximal effort (as observed for the TM and CE) and were considerably lower (i.e. 46% of TM $\dot{V}O_{2peak}$; 21 ml.kg.min^{-1}). Additionally, significant differences were reported for BLa_{peak}, RPE_{peak} and $HR_{peak.}$ The MH ultimately did not stress the cardiorespiratory system to a comparable level as the TM or CE. Stage 5 on the mechanical horse is the 'fastest' setting and riders were instructed to adopt an un-seated position to increase physical demand as much as possible based on previous literature establishing that un-seated positions and jumping are the most physiologically demanding (Westerling 1983; Trowbridge et al. 1995; Devienne and Guzennec 2000). Compared to previous research, stage 5 of the mechanical horse 'fast canter', is as physiologically stressful as walking on a live horse as reported by Westerling (1983) (heart rate 108 beat.min^{-1}; Oxygen uptake 9.6 ml.kg.min^{-1}) and Devienne and Guzennec (2000) (heart rate 106 beat.min^{-1}; Oxygen uptake 12.1 ml.kg.min^{-1}). Riding simulators can be used to objectively asses a rider's posture (Longhurst and Lesniak 2013) and can improve physical abilities and co-ordination in the elderly and children with cerebral disease (Mitani et al. 2008; Kim et al.

2013; Lee et al. 2014).

Ille et al. (2014) investigated the heart rate response to riding in riders jumping a course of obstacles on a show jump simulator (thirteen jumps 90-110cm) and during a show jump round (eight jumps 80-90cm) on a live horse. Ille et al. (2014) reported a lower maximal heart rate (123 beats.min^{-1}) on the mechanical horse compared to live horse testing (175 beats.min^{-1}) and concluded that the physical effort of riding a live horse was thus more pronounced than on a simulator although simulators were useful to identify and address the riders position a show jump simulator was not beneficial in terms of physical fitness training. Results from this chapter therefore concur with this study.

The biomechanical similarities between a general model of riding simulator compared to live horse motion has not been investigated. Racing simulator models are commonly used to facilitate jockey training (Walker et al. 2016) as benefits include economically intensive training sessions, reduced risk of injury to the horse or rider falls and if representative of actual riding, a greater scope to physically correct technique while improving muscle and movement-specific fitness (Bailey et al. 1997; Kang.et al. 2010; Hitchens et al. 2012; Kang.et al. 2010). Walker et al. (2016) concluded that a racehorse simulator did not mimic the biomechanics of actual riding, the simulator has a more consistent pattern with less dorso-ventral and medio-lateral but greater cranio-caudal displacement. Walker et al. (2016) noted that simulator training should be used with caution since there is potential for adaption to incorrect movement patterns. To date (2017), research indicates that general riding, show jump and racehorse simulators have their merits in training riders but do not replicate the physiological nor the biomechanical demands of actual horse riding. The lack of comparability in the movement patterns between the mechanical horse simulator and to riding a live horse presumably require different amplitudes of muscular activity, and possibly different muscle recruitment.

A.4.2 Relationship Between Heart Rate and Oxygen Uptake.

The TM, MH and CE had similar relationships between HR-$\dot{V}O_2$. Though the MH was not physiologically stressful enough to be recommended for maximal exercise testing and does not replicate the demands of actual riding, there was a statistically significant relationship between heart rate and peak oxygen consumption attained on the MH. The relationship between heart rate and oxygen consumption on the mechanical horse were systematically lower than achieved on TM and CE modes and non linear. Though there was a relationship between HR-$\dot{V}O_2$, the progression of the test was not linear in terms of heart rate and $\dot{V}O_2$ response. On a live horse, physiological responses increase with gait and it is the faster gaits such as canter and jumping that HR and oxygen uptake (Trowbridge et al. 1995; Devienne and Guzennec 2000; Roberts et al. 2010). For the mechanical horse, during stage 4, (canter), heart rate and oxygen consumption decreased. The lack of comparability in physiological data is likely due to the mechanics of the simulator not replicating real horse motion and not recruiting the same amplitude of muscular activity required during actual riding and additionally the mode being limited by its inability to continue to increase exercise intensity compared to TM and CE modes. It is likely that the biomechanical demands of riding a live horse are not comparable to a horse simulator which accounts for the physiological variables lowering during stage for of the simulator test. Mechanical horse simulators as previously discussed have their place in training both particularly for the nervous rider, the elderly and the impaired, ultimately, MH simulators have their place for technical development in riders but not for assessing their physiological responses.

A.4.3 Implications of Under-Reporting $\dot{V}O_{2peak}$

This comparative study reports that using a CE under-predicts a riders $\dot{V}O_{2peak}$ by ~18% when compared the TM. To accurately predict $\dot{V}O_2$ from HR the recommendation is therefore to use a TM in an equestrian population for laboratory reference testing since it produces greatest $\dot{V}O_{2peak}$ when heart rates are comparable. Chapter Four estimated %$\dot{V}O_{2peak}$ and absolute oxygen consumption based upon HR at $\dot{V}O_{2peak}$ in the laboratory using CE (42 $ml.kg.min^{-1}$). Predicted $\dot{V}O_2$ in Chapter Four would likely be different using a TM mode than the CE mode that was utilised. It is likely that in field estimations of oxygen consumption based from heart rate during laboratory or field based exercise tests will be more common than actually measuring oxygen consumption in the field due to governing body restrictions, high risks of damage to the equipment and risk of additional injury whilst riding and was a motive for determining the most suitable laboratory reference method for this population of athletes.

Classification of intensity of exercise based on $\%HR_{max}$ and the association between heart rate and $\dot{V}O_2$ is well described (Montgomery et al. 2009). Chapter Four reported estimated $\dot{V}O_2$ data for each phase of Novice ODE as: 38.3±7.8; 39.5±7.6; 42.1±7.9 $ml.kg^{-1}.min^{-1}$ for DR, SJ and XC respectively. This data reported is unusual in that the mean $\dot{V}O_{2max}$ investigated on a CE for this population of athletes was 41.8±8.1 $ml.kg^{-1}.min^{-1}$, suggesting riders were working at 91->100%$\dot{V}O_{2max}$. Work by Roberts et al. (2010) reported HR and $\dot{V}O_2$ in a simulated Novice ODE, mean HR and BLa data compared to the data reported in Chapter Four. Roberts et al. (2010) reported mean O_2 consumption to be between 60-93% $\dot{V}O_{2max}$, whereas Chapter Four estimated it based on CE laboratory reference measures as >90%. In Roberts et al. (2010) they measured $\dot{V}O_2$ in the field and estimated $\dot{V}O_{2max}$, whereas Chapter Four measured $\dot{V}O_{2max}$ and estimated $\dot{V}O_2$ in the field. It is also possible and likely based on the results of this study, a true $\dot{V}O_{2max}$ was not attained on the CE which will have affected in-field $\dot{V}O_2$ estimations. If $\dot{V}O_{2max}$ is corrected from Chapter Four using the current TM data, and in field data estimations are the same (as HR_{peak} was not statistically different between CE and TM), the data would be more comparable and actually lower than Roberts et al. (2010) with $\%\dot{V}O_{2max}$ being between 77-85%. The use of different protocols and populations means these corrections are presumptive but highlights that overestimations as suspected are likely based on using the CE. Given that HR and BLa in Chapter Four were lower than Roberts et al. (2010) it appears that the extremely high estimations of $\dot{V}O_2$ whilst horse-riding are as a result of using a CE and under-predicting the highest potential $\dot{V}O_{2peak}$.

A.4.4 Limitations and Future Research

The mechanical horse simulator used was a general model and results can only be applied to this specific type which limits the application of this research. There are, however, more recent developments in research that indicate the physiology and biomechanics of jumping and racing simulators are not replicative of the physiological nor biomechanical variables reported during actual riding (Ille et al. 2014; Walker et al. 2016). This research supports conclusions that though MH simulators are useful in technical riding developments they do not have a place for the physiological assessment of riders.

The general riding model had five speed settings and ultimately limited the potential to reach peak physiological variables. There was a relationship between heart rate and oxygen consumption and although results were systematically lower than reported for TM and CE, it indicates that if intensity progressions could increase, the potential for peak values could have been attained. This limitation is not isolated to this study, but to all uses of mechanical horse simulators. Within this research, the progression was increased every minute to replicate the design of the TM and CE tests. Future research may wish to investigate the physiological responses to mechanical horse protocols that increase duration between progressions to determine whether the intensity can be increased on the mechanical horse.

This research indicates that of the three modes investigated, the TM should be used as the laboratory reference measure for horse-riders. This study identified a relationship between heart rate and oxygen consumption to riding a mechanical horse and was pertinent at this point then to determine if this was also the case during actual riding.

A.5 Conclusion

The approach to maximal exercise testing for equestrian athletes has previously been conducted on treadmills and cycle ergometers, and until this study a comparison between modes of laboratory reference tests had not been conducted. Typically, the mode that an athlete is most habituated to will enable a true maximal reading and provoke a sub maximal response comparable to the test measure. Prior to the design of this study the quantification of the physiological demand of riding a mechanical horse simulator and comparability to a live horse have not been investigated. If a mechanical horse simulator replicated similar loads to a live horse, then it may have had merit as a sports specific laboratory reference measure. This research concludes that a general riding model of mechanical horse simulator does not replicate physiological load of actual riding compared to data from previous research. It also does not elicit maximal demands and has no place as a physiological laboratory reference mode to attain maximal physiological variables for equestrian athletes. The relationship between heart rate and oxygen consumption on the mechanical horse were systematically lower than achieved on TM and CE modes and non linear. The lack of comparability in physiological data is likely due to the mechanics of the simulator not replicating real horse motion and not recruiting the same amplitude of muscular activity required during actual riding and additionally the mode being limited by its inability to continue to increase exercise intensity compared to

TM and CE modes. Future research should document muscle activity to identify if recruitment and amplitude are affecting physiological responses as intimated within Chapter Four. Of the three modes investigated, this research concludes that a TM would be the most suitable mode for laboratory reference testing in horse-riders, based on the ability for it to attain a higher $\dot{V}O_{2peak}$ value at comparative heart rates, and as a result of this is more appropriate to estimate in field $\dot{V}O_2$ using heart rate.

APPENDIX TWO

EQUESTRIAN TRAINING AND ADDITONAL TRAINING QUESTIONAIRE

This questionnaire is part of research entitled 'The physiological and anthropometric profiles of Novice, Intermediate and Advanced Event riders'. We are interested in finding out about your physical training both on the horse, here referred to as 'Equestrian Training' and off the horse, referred to as 'Additional Training'. The questions will ask you about your average training week over the **last month.** **Vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. **Moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal.

Please put something in every space. Put a dash or a zero where necessary so we know you have not missed the question. If you are not sure about something please ask the lead researcher who will be completing the laboratory testing with you.

Thank you for your help!

CONFIDENTIAL DOCUMENT

GENERAL

Name ……………………………………………………

Participant Number …………………………………

Date of birth ____/____/_____

What is your height? _____cm OR _____feet _____inches

What is your usual weight? ____kg OR ____stone____pounds

YOUR OCCUPATION

This first section is about your work. This includes paid or unpaid work.

What is your occupation/s?……………………………………………………………………………………

During the last **month** on how many *days* did you do vigorous physical activities like heavy lifting, as part of your work? Think about those physical activities that you did for at least 10 minutes at a time. These activities should not include your riding (even if it is your occupation) or additional training. You will be asked about these questions later. If you are a professional rider please consider the other activities you do in your working day here.

………..days per week

On an average *day*, how much time do you usually spend doing **vigorous** activities as part of your work?

…….hours per day

……minutes per day

Again, think about those activities that you did for 10 minutes at a time. During the last **month** how many days did you do moderate activities like carrying light loads as part of your work?

……days per week

On an average day, how much time do you usually spend doing **moderate** activities as part of your work?

…….hours per day

……minutes per day

Competition Details from the 2010-2011 season.

These questions all refer to the last Eventing season of **2010-2011.**

What was your highest level of Eventing competition in the **2010-11 season**? (e.g. BENovice)

………

How many **years** have you been training for this sport? ______years.

Please describe your best performance/s in the 2010-2011 season.

Approximate Date	Level	Score	Placing

If you have additional details about your best performances please include them here

....
....

How often did you compete in the **2010-11 season**? Please consider multiple rides at one competition separately. If you rode three horses at one competition please regard this as three competitions.

a) less than once per month **b)**1-3 times per month **c)**4-6 times per month **d)** more than 6 times per month.

Would you consider Eventing as;

a) a hobby **b)** serious competition **c)** a career. *(If you consider both answers b) and c) please choose c).)*

Do you plan to stay competing at the level you are currently at, or do you want to compete at a higher level?

a) yes, I am happy to stay at current level **b)** no, I aim to compete in a higher level of competition

Current Equestrian Training Practise a typical week in the last month.

Consider riding more than one horse per day as individual session.

DRESSAGE/FLATWORK TRAINING (in a mostly seated position in walk/trot/canter including lateral, skill and pole work)

Show total amount of sessions included in training week .... sessions

Show total time of:

Vigorous Riding (work without stirrups/seated work/prolonged riding in canter) ....hours and ....minutes

Moderate (walk/skill work) ....hours and ....minutes

SHOW JUMP TRAINING (in a seated or forwards position in walk/trot/canter including lateral, skill, pole and jump work)

Show total amount of sessions included in training week .... sessions

Show total time of:

Vigorous Riding (canter work, jumping, work in 2 point/forwards seat) ....hours and........minutes

Moderate (rising trot/skill or pole work) ....hours and ....minutes

CROSS COUNTRY TRAINING(specific to Cross Country usually in a field or mock XC setting over more solid obstacles including walk/trot/canter and gallop work both in seated and forwards positions)

Show total amount of sessions included in training **week** .... sessions

If less than once per week please indicate total amount of sessions per **month:** ....sessions

Show total time of:

Vigorous Riding (gallop work/canter work, jumping, work in 2 point/forwards seat) ....hours and ....minutes

Moderate (rising trot/skill or pole work/walking) ....hours and ....minutes

Please include any further detail about your current equestrian training programme that you think would be useful here

....

....

....

Current Additional Training that you complete off of the horse.

These questions are all related your time spent training yourself off of a horse over the last **month.** Please answer questions related to a typical **week.** Additional training is considered as any purposeful exercise designed to get you physically fitter or stronger. For example, running, gym attendance, exercise attendance, swimming, yoga, Pilates, circuit training. You may include walking if it is specific but please do not include leisure activities such as casually walking the dog.

In the last **month**, have you completed exercise **off** of the horse to improve your general fitness?

a) yes **b**) no

If you have not spent any time training yourself off of the horse in the last **month**, why?

a) I do not believe it is beneficial for improving my ridden performance **b)** I do not have time **c)** the horses programme is more important **d)** other (please detail why not here) ....

How many additional training sessions have you completed in a typical week over the last month?

............sessions

To understand more about your current training regime, please answer the following questions aimed to understand specificity of your additional training. Examples are given but if you are unsure please ask the lead researcher. The questions relate to additional training you have completed in a typical **week** over the last *month.*

BALANCE TRAINING (for example exercises on unstable platforms such as exercise balls, BOSU balls.)

Show total time included in training week ....hours and ....minutes

List your main balance training exercises

_____________________ _____________________ _____________________

FLEXIBILITY TRAINING (for example cooling down stretches/yoga)

Show total time included in training week ....hours and ....minutes

List your main flexibility training exercises/sessions

________________ ________________ ________________

CORE TRAINING (for example abdominal exercises, pilates.)

Show total time included in training week ....hours and ....minutes

List your main core training exercises

________________ ________________ ________________

STRENGTH TRAINING (also called resistance training. For example: press up, shoulder press, bicep curl, squat, lunges)

Show total time each week at:

Vigorous (hard or exhausting workouts) ....hours and ....minutes

Moderate (moderate and easy workouts) ....hours and ....minutes

List your main strength training exercises

________________ ________________ ________________

ENDURANCE TRAINING (non-stop exercises and intervals, each lasting three minutes or more)

Show total time each week at:

Vigorous (hard or fast pace) ....hours and ....minutes

Moderate (moderate and easy pace) ....hours and ....minutes

List your main endurance training activities

________________ ________________ ________________

INTERVAL TRAINING (each interval lasting less than three minutes)

Show total time each week at:

Vigorous (hard or fast sets) ....hours and ....minutes

Moderate (moderate and easy sets) ....hours and ....minutes

List your main interval training activities

________________ ________________ ________________

Please include any further detail about your current un-mounted training programme that you think would be useful here

....

....

APPENDIX THREE

Appendix 3a

Chapter Three Ethics Documentation

APPENDIX 1

University of Worcester

INSTITUTE OF SPORT & EXERCISE SCIENCE

University of Worcester
Henwick Grove
WR2 6AJ
Telephone: +44(0)1905 855238
Email: jenni-louise.johnson@worc.ac.uk

Dear {name of participant},

Thank you for volunteering to take part in the research entitled 'Physiological and anthropometric profiles of Novice, Intermediate and Advanced Event riders. You have confirmed to participate in a laboratory exercise test battery at the University of Worcester on the {dd/mm/yy} at {time}. Please arrive at the main reception where Jenni will meet you. Included within this letter are locations and campus maps.

The Physical Test Battery

Research investigating what physical traits are required by riders to excel are absent. A test 'battery' is a common method used in other sports to gain a range of results from varied tests. Various tests will be performed in novice, intermediate and advanced event riders to compare results and see what effect levelness have upon riders performance in the selected tests.

Exercise test protocol

Upon your arrival to the University, you will be greeted and shown to the human performance laboratories. I will verbally brief you and ask you to participate in a pre-exercise screening, which will consist of you giving written consent of your participation and also monitoring your height and weight. Following this you will be fully briefed on the day's protocol. It is important that you note that as this testing is a series of tests you will be in lab for approximately three hours.

Your height and weight will be identified and then your body composition will be measured via a technique where a skinfold is taken to calculate your percentage body fat. Your balance will be measured via a test where you will be asked to stand on one leg with your eyes closed for as long as possible. This test is then repeated on the opposite side. Your reaction time will also be measured on a 'Batak' wall. This is a computer package where a series of lights will flash and you will be required to react as fast as possible and press the light that is on.

To measure muscular strength there are a series of test that will be performed. For general strength you will be asked to perform exercises such as press ups (on your knees) and a squat against a wall. To get a better measure of strength we have a machine called a dynamometer which can accurately measure the strength of your thighs. This machine will exert a force against you and you have to either push back as hard as you can, or resist it from moving.

The last exercise test that you will be participating in will be aiming to determine to key variables, your lactate threshold and also your maximal oxygen uptake. The body constantly produces lactate. At rest and in light exercise the levels of lactate are small enough that you can effectively remove it from the working muscles. With increasing intensity of exercise, lactate production reaches higher levels and can induce fatigue. By assessing your blood lactate levels at a rage of exercise intensities, a blood lactate curve can be plotted and from this curve I can determine your lactate threshold, which is important indicator when monitoring your aerobic and anaerobic fitness. In addition to this a maximal oxygen consumption test measures the volume of oxygen consumed and the volume of carbon dioxide produced by the body in a controlled setting. Those who have a higher oxygen consumption value can exercise more intensely than that that are not as well conditioned, and is a good indicator of aerobic fitness.

You will complete a ten minute warm up on the bike which will also help you to relax and familiarise yourself with the equipment. You will wear a strap around your chest which will monitor your heart rate throughout the test. Initially you will cycle for four minutes, at the end of this I will take a small sample of blood from your earlobe. The resistance on the bike will be increased slightly, and you will be asked to continue to pedal, this will be repeated (a maximum of five times) until I have determined your lactate threshold. The intensity will then be increased every minute until you reach volitional exhaustion. Once the test has been completed you will follow a progressive warm down.

It is important at this stage for me to highlight to you that your involvement in this study is entirely voluntary and you are able to stop testing at any point. As with all exercises there is a chance that you will incur delayed onset of muscular soreness 1-2 days after testing. This is the bodies normal response to exercise and is an expected outcome.

To help you prepare for the day, please read the following participant guidelines that will ensure you are physically prepared for the tests that will be measured. Please also make a note of my personal mobile number which is 07793202165 and will allow you to contact me on the day itself.

Once again, thank you for your participation in this research trial. If you have any questions or queries please contact me on the details to follow.

Yours faithfully,

.

Jenni-Louise Johnson PhD Student
Institute of Sport & Exercise Science
jenni-louise.johnson @worc.ac.uk,
01905 855238

&

Dr Derek M Peters, Director of Studies
Institute of Sport & Exercise Science
d.peters@worc.ac.uk, 01905 855352

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LABORATORY BASED EXERCISE TESTING

Participant Instructions

Dear {Name of participant},

The laboratory based physical test battery is physically strenuous that measures your strength, balance, reaction time and cardio-respiratory fitness. Please ensure that you read the following instructions thoroughly prior to your laboratory sessions and **sign the form to acknowledge your understanding of the instructions. Please note the testing will likely take ½ day (3 hours).**

Pre-Test Instructions:

Please bring to your laboratory session:

- ✓ Participant Instructions (signed)
- ✓ Comfortable activity clothing e.g. shorts and t-shirt (you may wish to bring a change of clothes)
- ✓ Water bottle
- ✓ Indoor running shoes with clean soles.

Please adhere to the following guidelines:

- ✓ Participants should refrain from ingesting food, alcohol or caffeine or using tobacco products within three hours of testing.
- ✓ Participants should be rested for the assessment, avoiding significant exertion or exercise on the day of the assessment.
- ✓ Drink ample fluids over the 24 hour period preceding the test to ensure normal hydration.

Signed: ______________________________ Date____________

Test Supervisor ____________________________ Date____________

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Research supported by

Participant Information Sheet and Informed Consent

Project Title: Physiological and anthropometric profiles of Novice, Intermediate and Advanced Event riders.

Dear Participant,

Thank you for expressing an interest in participating in the above study.

Purpose of this information sheet:

This information sheet has been written to help you better understand an upcoming research project run by the Institute of Sport and Exercise Science, University of Worcester. The information provided within this sheet is designed to inform you about your participation in the project. It really is important that you understand that taking part in this study is voluntary and if you do not want to continue you can withdraw at any time from the project.

Rationale:

Training within sport is driven towards being as specific to competitive performance as possible. There is very little information present that determines the physiological demands placed upon event riders during competition. A recent document released by the British Equestrian Federation, entitled the Long Term Rider Development Plan, indicates that riders should address core components of athleticism both on and also off of the horse. We want to assess the effectiveness of un-mounted strength and conditioning training interventions on performance related fitness in female event riders. To do this we need to determine the physical traits that are seen between levels of event riders.

- When the project is complete we intend to publish the results in a prominent journal and disseminate to the equestrian community.
- If you require further information to help you make a decision about joining this study please contact Jenni on the contact details provided at the end of this form.

Why you have been asked:

All female riders that are over 18 and competing at Novice, Intermediate or Advanced level Eventing are being invited to participate in this research. You have expressed an interest to participate in this study and have been sent this information to inform you of what participant protocol throughout the study.

What happens if you change your mind?

If you decide to join this study you can change your mind at any time. Please contact Jenni if you have made a decision not to take part in this research as it will prevent you being contacted further.

What would happen if you join the study?

Your involvement in this study consists of one session. This will be performed at the University of Worcester in the human performance laboratory. The lab testing is a physical test battery where you will undergo multiple tests to asses physical traits. Your height, weight, balance, strength, reaction time, balance, flexibility, power and cardiovascular fitness will be measured. Detailed protocol can be seen

Exercise test protocol
Upon your arrival to the University, you will be greeted and shown to the human performance laboratories. I will verbally brief you and ask you to participate in a pre-exercise screening, which will consist of you giving written consent of your participation. Following this you will be fully briefed on the day's protocol. It is important that you note that as this testing is a series of tests you will be in lab for approximately 3-4 hours.

Your height and weight will be identified and then your body composition will be measured via a technique where a skinfold is taken to calculate your percentage body fat. Your balance will be measured via a test where you will be asked to stand on one leg with your eyes closed for as long as possible. This test is then repeated on the opposite side. Your reaction time will also be measured on a 'Batak' wall. This is a computer package where a series of lights will flash and you will be required to react as fast as possible and press the light that is on.

To measure muscular strength there are a series of test that will be performed. For general strength you will be asked to perform exercises such as press ups (on your knees) and a squat against a wall. To get a better measure of strength we have a machine called a dynamometer which can accurately measure the strength of your thighs. This machine will exert a force against you and you have to either push back as hard as you can, or resist it from moving.

The last exercise test that you will be participating in will be aiming to determine to key variables, your lactate threshold and also your maximal oxygen uptake. The body constantly produces lactate. At rest and in light exercise the levels of lactate are small enough that you can effectively remove it from the working muscles. With increasing intensity of exercise, lactate production reaches higher levels and can induce fatigue. By assessing your blood lactate levels at a rage of exercise intensities, a blood lactate curve can be plotted and from this curve I can determine your lactate threshold, which is important indicator when monitoring your aerobic and anaerobic fitness. In addition to this a maximal oxygen consumption test measures the volume of oxygen consumed and the volume of carbon dioxide produced by the body in a controlled setting. Those who have a higher oxygen consumption value can exercise more intensely than that that are not as well conditioned, and is a good indicator of aerobic fitness.

You will complete a ten minute warm up on the bike which will also help you to relax and familiarise yourself with the equipment. You will wear a strap around your chest which will monitor your heart rate throughout the test. Initially you will cycle for four minutes, at the end of this I will take a small sample of blood from your earlobe. The resistance on the bike will be increased slightly, and you will be asked to continue to pedal, this will be repeated (a maximum of five times) until I have determined your lactate threshold. The intensity will then be increased every minute until you reach volitional exhaustion. Once the test has been completed you will follow a progressive warm down.

In addition to your laboratory tests you will also be asked to complete a questionnaire designed to quantify your equestrian and un-mounted training load. As with all data, your results will be kept anonymous and stored on a password protected computer with the hard documents kept in a locked file coded by participant number.

Are there any risks?
As with any aspect of exercise there is a risk of delayed onset of muscle soreness (DOMS) and a very small risk of muscular injury. The risk of such issues is decreased by thorough preparation, warm up and also including being familiarised with the protocol, and equipment being used in this study. This will be provided as part of your involvement within the study. As this study involves sampling of blood there is some risks associated with contamination. Such risks have been decreased by full training and assessment of researcher competency, and the researcher following strict blood sampling guidelines at all times. As the participant, you will be asked to fill in a blood sampling survey which will ask questions to ensure you are healthy to sample blood from. Questions will include history on any tattoos or piercings that you may have and of any blood contaminating diseases the researcher would need to be aware of. As we will be measuring expired gas, you will be required to breathe through a mouth piece and as such there is a small

risk of infection to participants. This risk is minimal and is further reduced as mouthpieces are sterilised after every test.

Ethical considerations.

The findings of this study will be submitted for publication; however your anonymity will be protected at all times. All information can be identified with each individual and will be kept confidential by the principal researcher at all times.

INFORMED CONSENT

Please read the following statements carefully. Please sign only when you have agreed with the statement and when you have had any relevant questions answered.

- I have read the information sheet for the above study and the full details of the tests have been explained to me (verbally and written). I am clear about what will be involved and I am aware of the purposes of the tests, the potential benefits and the potential risks.
- I know that I am not obliged to complete the tests. I am free to stop the test at any point and for any reason.
- I am responsible to report promptly any unusual feelings or discomfort during the exercise test.
- Tests results will only be used for the purposes of this research
- I have no injury or illness that will affect my ability to successfully complete the tests.
- I hereby give my full consent to take part in the study.

Signature of participant: ______________________ Date: ________________

Name of Test Supervisor: ______________________ Date: ________________

Appendix 3b:

Chapter Four Ethics Documentation

BRITISH EVENTING

Stoneleigh Park, Kenilworth, Warwickshire CV8 2RN
T: +44 (0)2476 698865 • F: +44 (0)2476 697235
E: info@britisheventing.com

www.britisheventing.com

Miss Jenni-Louise Johnson
Graduate Research School
Institute of Sport and Exercise Science
University of Worcester
WR3 6AJ

March 10, 2010

To whom it may concern

Mike Etherington-Smith, Chief Executive of British Eventing Ltd ('BE') is giving permission for research to be undertaken by Miss Jennie-Louise Johnson of the Institute of Sport and Exercise Science at the University of Worcester at BE Events during the 2010 season. BE has consulted its Chief Medical Advisor before granting permission.

The research involves a number of competitors to wear a heart rate monitor system which consists of two devices: a receiver (a band around the chest) which is worn under the competitor's clothing and a wrist 'watch' which is the data recorder. This is not a timing device. Additionally the research involves taking small blood samples. Miss Johnson will seek the appropriate consent with the competitors who agree to take part in the research.

Dispensation of Rule 3.21: All of the riders involved in the research are permitted to wear the wrist 'watch' during any stage of the competition but only with the face blanked out/taped off, therefore making it illegible during competition.

Furthermore, BE is allowing this research to take place under the following conditions:

1. Miss Johnson has the appropriate insurance in place to undertake this research. (public/third party liability) and a copy of the insurance schedule is lodged with BE.
2. BE Ltd, the BE Organiser and all the Event staff involved at the events where the research may take place are not liable in anyway for any accidents, incidents, loss of or damage to property or any other eventuality that results from this research.
3. British Eventing is giving permission for this research to be undertaken but Miss Johnson will undertake this research only with the full agreement and permission of the BE Event Organiser.
4. The research should in no way interfere with the running of the event or its competitors.
5. Miss Johnson will submit a list of events and riders partaking in the research to British Eventing's Sport Department (via email: debbie.marfell@britisheventing.com), at the very latest a week before the start of the event, enabling BE to notify the necessary officials in time.

Yours sincerely

Mike Etherington-Smith
Chief Executive

VAT No 670 971 805 Limited Liability Registered in England No. 3218925

INSTITUTE OF SPORT & EXERCISE SCIENCE

University of Worcester
Henwick Grove
WR2 6AJ
Telephone: +44(0)1905 855238
Email: jenni-louise.johnson@worc.ac.uk

Participant Information Sheet

Dear Participant,

Thank you for expressing an interest in participating in the above study.

Purpose of this information sheet:

This information sheet has been written to help you better understand an upcoming research project run by the Institute of Sport and Exercise Science, University of Worcester. The information provided within this sheet is designed to inform you about your participation in the project. It really is important that you understand that taking part in this study is voluntary and if you do not want to continue you can withdraw at any time from the project.

Rationale:

Training within sport is driven towards being as specific to competitive performance as possible. There is very little information present that determines the physiological demands placed upon event riders during competition. A recent document released by the British Equestrian Federation, entitled the Long Term Rider Development Plan, indicates that riders should address core components of athleticism both on and also off of the horse. We want to asses the effectiveness of un-mounted strength and conditioning training interventions on performance related fitness in female event riders. To do this firstly we need to determine the physiological demands of eventing in a competition based environment.

- When the project is complete we intend to publish the results in a prominent journal and disseminate to the equestrian community.
- If you require further information to help you make a decision about joining this study please contact Jenni on the contact details provided at the end of this form.

Why you have been asked:

All female riders that are over 18 and competing at BE80, BE90, BE100 or Novice level Eventing are being invited to participate in this research. You have expressed an interest to participate in this study and have been sent this information to inform you of what participant protocol throughout the study.

What happens if you change your mind?

If you decide to join this study you can change your mind at any time. Please contact Jenni if you have made a decision not to take part in this research as it will prevent you being contacted further.

What would happen if you join the study?

Your involvement in this study consists of two sessions. The first consists of a competition that you have agreed for Jenni to attend. Jenni will meet you at your event and verbally brief you of the days protocol. You will be asked to wear a strap around your chest for the entirety of the event. In addition to this a small sample of blood from your earlobe will be taken prior to initial mounting, six minutes following each warm up, and six minutes following the dressage, cross country and show-jump phase. The second session will require you to visit the University of Worcester for exercise testing. Jenni will meet you and again verbally brief you of the days protocol. Your height and weight will be measured and following this you will then undergo a bicycle test where your cardio-respiratory fitness will be measured. During this bicycle test Jenni will ask you to breathe into and out of a mouth piece and also take a sample of blood from your earlobe every four minutes (for a maximum of 5 times). **This test is a maximal exercise test and the length is determined by your personal fitness but it is anticipated to last no longer than 30 minutes. As you will be required to complete a warm up and warm down you will likely be in the laboratory for 1 hour. Opportunity to discuss your results can be done post the test or via telephone conversation dependent on your individual preferences. Should you wish to discuss results after your test it is anticipated that this will take an additional 30 minutes.**

Are there any risks?

As with any aspect of exercise there is a risk of delayed onset of muscle soreness (DOMS) and a very small risk of muscular injury. The risk of such issues is decreased by thorough preparation, warm up and also including being familiarised with the protocol, and equipment being used in this study. This will be provided as part of your involvement within the study. **As this study involves sampling of blood there is some risks associated with contamination. Such risks have been decreased by full training and assessment of researcher competency, and the researcher following strict blood sampling guidelines at all times. As the participant, you will be asked to fill in a blood sampling survey which will ask questions to ensure you are healthy to sample blood from. Questions will include history on any tattoos or piercings that you may have and of any blood contaminating diseases the researcher would need to be aware of. As we will be measuring expired gas, you will be required to breathe through a mouth piece and as such there is a small risk of infection to participants. This risk is minimal and is further reduced as mouthpieces are sterilised after every test.**

Ethical considerations:

The findings of this study will be submitted for publication; however your anonymity will be protected at all times. All information can be identified with each individual and will be kept confidential by the principal researcher at all times.

I hope that you find the information provided in this sheet useful. Jenni will contact you nearer the event to confirm a mutually convenient meeting time and place at your chosen competition venue. You will then be sent a confirmation letter and participant instructions for the day.

Once again, we would like to thank you for your involvement with this study, and look forwards to communicating with you soon.

Yours faithfully,

Jenni-Louise Johnson PhD Student &
Institute of Sport & Exercise Science
jenni-louise.johnson @worc.ac.uk,
01905 855238

Dr Derek M Peters, Director of Studies
Institute of Sport & Exercise Science
d.peters@worc.ac.uk, 01905 855352

INSTITUTE OF SPORT & EXERCISE SCIENCE

University of Worcester
Henwick Grove
WR2 6AJ
Telephone: +44(0)1905 855238
Email: jenni-louise.johnson@worc.ac.uk

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Purpose of this information sheet:

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Rationale:

Training within sport is driven towards being as specific to competitive performance as possible. There is very little information present that determines the physiological demands placed upon event riders during competition. A recent document released by the British Equestrian Federation, entitled the Long Term Rider Development Plan, indicates that riders should address core components of athleticism both on and also off of the horse. We want to asses the effectiveness of un-mounted strength and conditioning training interventions on performance related fitness in female event riders. To do this firstly we need to determine the physiological demands of eventing in a competition based environment.

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If you decide to join this study you can change your mind at any time. Please contact Jenni if you have made a decision not to take part in this research as it will prevent you being contacted further.

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Your involvement in this study consists of two sessions. The first consists of a competition that you have agreed for Jenni to attend. Jenni will meet you at your event and verbally brief you of the days protocol. You will be asked to wear a strap around your chest for the entirety of the event. In addition to this a small sample of blood from your earlobe will be taken prior to initial mounting, six minutes following each warm up, and six minutes following the dressage, cross country and show-jump phase. The second session will require you to visit the University of Worcester for exercise testing. Jenni will meet you and again verbally brief you of the days protocol. Your height and weight will be measured and following this you will then undergo a bicycle test where your cardio-respiratory fitness will be measured. During this bicycle test Jenni will ask you to breathe into and out of a mouth piece and also take a sample of blood from your earlobe every four minutes (for a maximum of 5 times). **This test is a maximal exercise test and the length is determined by your personal fitness but it is anticipated to last no longer than 30 minutes. As you will be required to complete a warm up and warm down you will likely be in the laboratory for 1 hour. Opportunity to discuss your results can be done post the test or via telephone conversation dependent on your individual preferences. Should you wish to discuss results after your test it is anticipated that this will take an additional 30 minutes.**

Are there any risks?

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Ethical considerations:

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I hope that you find the information provided in this sheet useful. Jenni will contact you nearer the event to confirm a mutually convenient meeting time and place at your chosen competition venue. You will then be sent a confirmation letter and participant instructions for the day.

Once again, we would like to thank you for your involvement with this study, and look forwards to communicating with you soon.

Yours faithfully,

Jenni-Louise Johnson PhD Student
Institute of Sport & Exercise Science
jenni-louise.johnson @worc.ac.uk,
01905 855238

&

Dr Derek M Peters, Director of Studies
Institute of Sport & Exercise Science
d.peters@worc.ac.uk, 01905 855352

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Henwick Grove
WR2 6AJ
Telephone: +44(0)1905 855238
Email: jenni-louise.johnson@worc.ac.uk

Dear Sir or Madame,

Invitation for you to participate in equestrian research.

My name is Jenni-Louise Johnson and I am a postgraduate PhD student in the Institute of Sport and Exercise Science at the University of Worcester. Over the next three years my research will investigate the effectiveness of sport specific strength & conditioning training interventions for the enhancement of rider fitness and performance in event riders. In order to achieve this, I first need to undertake a number of studies essentially to understand physiological and biomechanical demands placed upon the rider. I am looking to recruit female riders who are 18 and above competing at novice level or below. I would therefore like to invite you (if you meet our desired criteria), or athletes that you are currently coaching to participate in the first of these studies.

The first study will investigate the physiological demands of eventing in adult female riders competing at BE80, BE90, BE100 or novice level eventing. If you or your athletes agree to take part I would come to a one day competition and the competitor would wear a heart rate monitor over the entire competition. I have sought and been granted permissions from the chief executive of British Eventing for riders at novice level and below to wear a wrist watch which acts as the heart rate monitor. The cross country stewards will be given details of all competitors involved in the study. In addition to this at various stages a very small blood sample will be collected from your earlobe, to allow the team to determine how the body copes physiologically during each phase of competition. Finally, you would be required to come to the University of Worcester to undertake an aerobic fitness assessment on an exercise bike. All data collected will be confidential and participants will receive their fitness assessment results and be offered a free personalised fitness training programme.

The findings from this research will significantly enhance our understanding of the demands placed on the female riders during eventing. As such, the research will enable the more appropriate planning of event specific strength and conditioning programmes in order to improve rider performance. Indeed, the creation and evaluation of such training programmes will be the next stage of my research!

If you are interested in participating in this important study, (or even if you are NOT) please complete the attached form and **return it to me in the envelope provided or via e mail.** If you are a coach and currently training riders at novice level and below I would be grateful if you could extend the invitation to them or ask them to contact me on the details to follow. If you have any questions that need to be answered in the interim please do not hesitate to contact me. If you express an interest to participate I will contact you to discuss your involvement and progression of the study.

Yours sincerely,

Jenni-Louise Johnson PhD Student
Institute of Sport & Exercise Science
jenni-louise.johnson @worc.ac.uk,
01905 855238

&

Dr Derek M Peters, Director of Studies
Institute of Sport & Exercise Science
d.peters@worc.ac.uk, 01905 855352

Please complete and return the following form

Expression of interest to participate in the research study entitled 'The effectiveness of sport specific strength & conditioning interventions on performance related fitness in female novice equestrian event riders'.

I:……………………………………………………………………………………………. *{name}*,

***do / do not** *{*delete one}* wish to express an interest to volunteer to participate in the research study entitled **The effectiveness of sport specific strength & conditioning interventions on performance related fitness in female novice equestrian event riders** being undertaken by Jenni-Louise Johnson & Dr Derek M Peters in the Institute of Sport & Exercise Science at the University of Worcester.

If you have expressed an interest to participate, please provide the following details:

Name………

Age (must be over 18)……………………………………………………………………………………………

Highest Level of Competition (must be no higher than novice level)……………………………………

Please list the One Day Events that you would be interested in Jenni attending (must be the highest level you are competing at, and in the midlands region)

The best way to contact me further is by:

* Email: ……………………………@ ……………………………………

or

* Telephone: (……………) ……………………………………………………………

or

*Address:

……
……
………

PRINT NAME: ……………………………………………………………………………………

Sign: ……………………………………………………………………………………

Date: ………….. / …………….. **/ 2010**

Over the next three years I will be conducting two more studies; one relating to sports specific fitness test performance between levels of athletes, the other, on the effectiveness of training interventions on rider performance. If you **DO NOT** want to be invited to participate in these studies, please tick this box ☐

INSTITUTE OF SPORT & EXERCISE SCIENCE

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WR2 6AJ
Telephone: +44(0)1905 855238
Email: jenni-louise.johnson@worc.ac.uk

University of Worcester

Dear Sir or Madame,

Invitation for you to participate in equestrian research.

My name is Jenni-Louise Johnson and I am a postgraduate PhD student in the Institute of Sport and Exercise Science at the University of Worcester. Over the next three years my research will investigate the effectiveness of sport specific strength & conditioning training interventions for the enhancement of rider fitness and performance in event riders. In order to achieve this, I first need to undertake a number of studies essentially to understand physiological and biomechanical demands placed upon the rider. I am looking to recruit female riders who are 18 and above competing at novice level or below. I would therefore like to invite you (if you meet our desired criteria), or athletes that you are currently coaching to participate in the first of these studies.

The first study will investigate the physiological demands of eventing in adult female riders competing at BE80, BE90, BE100 or novice level eventing. If you or your athletes agree to take part I would come to a one day competition and the competitor would wear a heart rate monitor over the entire competition. I have sought and been granted permissions from the chief executive of British Eventing for riders at novice level and below to wear a wrist watch which acts as the heart rate monitor. The cross country stewards will be given details of all competitors involved in the study. In addition to this at various stages a very small blood sample will be collected from your earlobe, to allow the team to determine how the body copes physiologically during each phase of competition. Finally, you would be required to come to the University of Worcester to undertake an aerobic fitness assessment on an exercise bike. All data collected will be confidential and participants will receive their fitness assessment results and be offered a free personalised fitness training programme.

The findings from this research will significantly enhance our understanding of the demands placed on the female riders during eventing. As such, the research will enable the more appropriate planning of event specific strength and conditioning programmes in order to improve rider performance. Indeed, the creation and evaluation of such training programmes will be the next stage of my research!

If you are interested in participating in this important study, (or even if you are NOT) please complete the attached form and **return it to me in the envelope provided or via e mail.** If you are a coach and currently training riders at novice level and below I would be grateful if you could extend the invitation to them or ask them to contact me on the details to follow. If you have any questions that need to be answered in the interim please do not hesitate to contact me. If you express an interest to participate I will contact you to discuss your involvement and progression of the study.

Yours sincerely,

Jenni-Louise Johnson PhD Student
Institute of Sport & Exercise Science
jenni-louise.johnson @worc.ac.uk,
01905 855238

&

Dr Derek M Peters, Director of Studies
Institute of Sport & Exercise Science
d.peters@worc.ac.uk, 01905 855352

Please complete and return the following form

Expression of interest to participate in the research study entitled 'The effectiveness of sport specific strength & conditioning interventions on performance related fitness in female novice equestrian event riders'.

I:.. *{name}*,

***do / do not** *{*delete one}* wish to express an interest to volunteer to participate in the research study entitled **The effectiveness of sport specific strength & conditioning interventions on performance related fitness in female novice equestrian event riders** being undertaken by Jenni-Louise Johnson & Dr Derek M Peters in the Institute of Sport & Exercise Science at the University of Worcester.

If you have expressed an interest to participate, please provide the following details:

Name...

Age (must be over 18)..

Highest Level of Competition (must be no higher than novice level)...

Please list the One Day Events that you would be interested in Jenni attending (must be the highest level you are competing at, and in the midlands region)

The best way to contact me further is by:

* Email: ....@ ....

or

* Telephone: (...............) ....

or

*Address:

....

....

....

PRINT NAME: ....

Sign: ....

Date: .... / .... **/ 2010**

Over the next three years I will be conducting two more studies; one relating to sports specific fitness test performance between levels of athletes, the other, on the effectiveness of training interventions on rider performance. If you **DO NOT** want to be invited to participate in these studies, please tick this box ☐

INSTITUTE OF SPORT & EXERCISE SCIENCE

University of Worcester
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Telephone: +44(0)1905 855238
Email: jenni-louise.johnson@worc.ac.uk

Dear {name of participant},

Thank you for volunteering to take part in the research entitled 'The effectiveness of sport specific strength & conditioning interventions on performance related fitness in female novice equestrian event riders'. I would like to confirm that I will be attending the competition event {name of event} on the {dd/mm/yy}.

What will happen during the day?

Prior to your competition I will contact you to confirm a mutually convenient meeting time and place on the day of the event. Prior to you mounting a strap will be placed around your chest to monitor your heart rate throughout the competition. You will not need to worry about the chest strap and it will not interfere with you throughout the day.

During the day I will also be taking samples of blood from your earlobe. I will take the first prior to you initially mounting your horse and then six minutes after each warm up and also six minutes after you have finished the dressage, show jump and cross country phases. It is therefore important that we communicate a meeting point for when you exit the arena or course!

To help you prepare for the day, please read the following participant guidelines that will ensure you are physically prepared for the tests that will be measured. Please also make a note of my personal mobile number which is 07793202165 and will allow you to contact me on the day of the event itself.

Once again, thank you for your participation in this research trial. I will contact you nearer to your competition to arrange a meeting place. If you have any questions or queries or in the event your competition has been cancelled please contact me on the details to follow.

Yours faithfully,

Jenni-Louise Johnson PhD Student
Institute of Sport & Exercise Science
jenni-louise.johnson @worc.ac.uk,
01905 855238

&

Dr Derek M Peters, Director of Studies
Institute of Sport & Exercise Science
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Email: jenni-louise.johnson@worc.ac.uk

FIELD BASED EXERCISE TESTING

Participant Instructions

Dear {participant name},

The competition field based testing will collect data to determine the physiological demands of eventing. Please ensure that you read the following instructions thoroughly prior to your laboratory sessions and **sign the form to acknowledge your understanding of the instructions.**

Pre-Test Instructions:

Please bring to your competition:

- ✓ Participant Instructions (signed)
- ✓ Water bottle
- ✓ Jenni's contact details for the day of the event

Please adhere to the following guidelines:

- ✓ Participants should refrain from ingesting food, alcohol or caffeine or using tobacco products within three hours of testing.
- ✓ Drink ample fluids over the 24 hour period preceding the test to ensure normal hydration.

Signed: ____________________________ Date____________

Test Supervisor ___________________________ Date____________

Appendix 3c:

Chapter Five Ethics Documentation

APPENDIX 1

University of Worcester

INSTITUTE OF SPORT & EXERCISE SCIENCE

University of Worcester
Henwick Grove
WR2 6AJ
Telephone: 01452 702100 ex 2267
Email: jenni-louise.douglas@worc.ac.uk

Dear Sir or Madame,

Invitation for you to participate in equestrian research.

My name is Jenni-Louise Johnson and I am a postgraduate PhD student in the Institute of Sport and Exercise Science at the University of Worcester and am now completing my final research trial. Over the next few months my research will investigate cardio-respiratory and neuromuscular demands of horse-riding. In order to achieve this I am looking to recruit female riders who are 18years or above that have access to a horse that is capable of jumping a 80cm oxer based at, or who are willing to travel to Hartpury College, where the testing will take place. I would therefore like to invite you (if you meet our desired criteria) to participate in this study.

This final study will build on research investigating the physiological demands of eventing in adult female riders. If you agree to take part you would come to Hartpury College and would ride in the 80m x 60m Parkway equestrian arena. There would be a few pieces of equipment that you would be required to wear (nothing for your horse). You would wear a heart rate monitor over the entire data collection, this is a strap around your chest, a strap round your upper arm (to measure speed and distance) and a watch on your wrist. You will also be required to wear small electrodes that measure muscle activity on your thighs, abdomen, forearms, upper-back and lower- back. These are fixed with sticky tape and secured with bandages. Lastly, to measure oxygen uptake you would wear a small backpack with a facemask whilst you ride. These will be fitted before you mount your horse, you will then be required to perform a 15 minute warm up on your horse including walk (3 min), trot (3min), canter (3min) and six minutes preparation for jumping including a 'cross-pole' up to 80cm, a vertical up to 80cm and an oxer at 80cm.

The test itself will last ~22 minutes and will require you and your horse to complete the following around the perimeter of the arena in a clockwise direction; walk (3 minutes), trot rising (3 minutes), trot sitting (3minutes), canter (3minutes), and 2-point canter (3minutes). You will then be asked to rest in walk (2minutes), then gallop (3minutes) and again rest in walk (2 minutes). The last stage is to canter in a 2-point seat jumping a 80cm oxer at a comfortable 'cross-country speed' (3minutes). Prior to mounting, post warm up and at the end of each 3 minute stage you will be asked to return to the researcher to have blood lactate sampled – this will be fully explained to you in detail if you are interested in participating in this research. It will involve sampling via your right earlobe. Throughout testing in the arena a video camera will be placed so that your test can be captured. This is to ensure timings of all devices are accurate and to allow me to work out your speed, should the GPS of the watches fail.

Finally, you are invited to come to the Human Performance Laboratory at Hartpury College to undertake an aerobic fitness assessment on a treadmill. All data collected will be confidential and participants will receive their fitness assessment results and be offered a free personalised fitness training programme.

The findings from this research will significantly enhance our understanding of the demands placed on the female riders during riding. As such, the research will enable the more appropriate planning of specific strength and conditioning programmes in order to improve rider performance.

If you are interested in participating in this important study, (or even if you are NOT) please complete the attached form and **return it to me in the envelope provided or via e mail.** If you have any questions that need to be answered in the interim please do not hesitate to contact me. If you express an interest to participate I will contact you to discuss your involvement and progression of the study.

Yours sincerely,

Jenni-Louise Johnson PhD Student
Institute of Sport & Exercise Science
jenni-louise.johnson @worc.ac.uk,
01905 855238

&

Prof. Derek M Peters, Director of Studies
Institute of Sport & Exercise Science
d.peters@worc.ac.uk, 01905 855352

Please complete and return the following form

Expression of interest to participate in the research study entitled 'The cardiovascular and neuromuscular demands of horse-riding'

I:.. *{name}*.

***do / do not** *{*delete one}* wish to express an interest to volunteer to participate in the research study entitled 'The cardio-respiratory and neuromuscular demands of horse-riding' being undertaken by Jenni-Louise Douglas & Prof. Derek M Peters in the Institute of Sport & Exercise Science at the University of Worcester.

If you have expressed an interest to participate, please provide the following details:

Name..

Age (must be over 18)..

The best way to contact me further is by:

* Email: ....@ ....

or

* Telephone: (...............) ....

or

*Address:

....
....
....

PRINT NAME: ....

Sign: ....

Date: .... / .... **/ 2015**

Thank you for your time & I hope to undertake research with you soon!

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Email: jenni-louise.douglas@worc.ac.uk

Participant Information Sheet and Informed Consent

The cardio-respiratory and neuromuscular demands of horse-riding'

Dear Participant,

Thank you for expressing an interest in participating in the above study.

Purpose of this information sheet:

This information sheet has been written to help you better understand an upcoming research project run by the Institute of Sport and Exercise Science, University of Worcester. The information provided within this sheet is designed to inform you about your participation in the project. It really is important that you understand that taking part in this study is voluntary and if you do not want to continue you can withdraw at any time from the project.

Rationale:

Training within sport is driven towards being as specific to competitive performance as possible. There is very little information present that determines the physiological demands placed upon horse-riders but what has indicates that horse-riding, particularly jumping requires considerable cardio-respiratory efforts. This study seeks to further understand cardiorespiratory responses in horse riders by additionally measuring muscular responses.

- When the project is complete we intend to publish the results in a prominent journal and disseminate to the equestrian community.
- If you require further information to help you make a decision about joining this study please contact Jenni on the contact details provided at the end of this form.

Why you have been asked?:

All female riders that are over 18 and regularly riding (e.g. 3 x per week minimum) are being invited to participate in this research. You have expressed an interest to participate in this study and have been sent this information to inform you of what participant protocol is throughout the study.

What happens if you change your mind?

If you decide to join this study you can change your mind at any time. Please contact Jenni if you have made a decision not to take part in this research as it will prevent you being contacted further.

Details of the study:

The study aims to explore the physiological responses of riders to jumping to determine the relationship between oxygen uptake and heart rate. You have been invited to participate which will involve two tests, one ridden and one in a human performance laboratory.

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What will happen if I join the study?

Your involvement in this study consists of two sessions. The first consists of field based testing at Hartpury College. Jenni will meet you at Parkway Equestrian Arena and verbally brief you of the days protocol. There would be a few pieces of equipment that you would be required to wear (nothing for your horse). You would wear a heart rate monitor over the entire data collection, this is a strap around your chest, a strap round your upper arm (to measure speed and distance) and a watch on your wrist. You will also be required to wear small electrodes that measure muscle activity on your thighs, abdomen, forearms, upper-back and lower- back. These are fixed with sticky tape and secured with bandages. Lastly, to measure oxygen uptake you would wear a small backpack with a facemask whilst you ride. These will be fitted before you mount your horse, you will then be required to perform a 15 minute warm up on your horse including walk (3 min), trot (3min), canter (3min) and six minutes preparation for jumping including a 'cross-pole' up to 80cm, a vertical up to 80cm and an oxer at 80cm.

The test itself will last ~22 minutes and will require you and your horse to complete the following around the perimeter of the arena in a clockwise direction; walk (3 minutes), trot rising (3 minutes), trot sitting (3minutes), canter (3minutes), and 2-point canter (3minutes). You will then be asked to rest in walk (2minutes), then gallop (3minutes) and again rest in walk (2 minutes). The last stage is to canter in a 2-point seat jumping a 80cm oxer at a comfortable 'cross-country speed' (3minutes). Prior to mounting, post warm up and at the end of each 3 minute stage you will be asked to return to the researcher to have blood lactate sampled – this will be fully explained to you in detail if you are interested in participating in this research. It will involve sampling via your right earlobe. Throughout testing in the arena a video camera will be placed so that your test can be captured. This is to ensure timings of all devices are accurate and to allow me to work out your speed, should the GPS of the watches fail.

The second session will require you to visit Hartpury College's Human Performance Centre for exercise testing. Jenni will meet you and again verbally brief you of the protocol. Your height and weight will be measured and following this you will then undergo a treadmill test where your cardio-respiratory fitness will be measured. During this treadmill test Jenni will ask you to breathe into and out of a mouth piece and also take a sample of blood from your earlobe every four minutes. **This test is a maximal exercise test and the length is determined by your personal fitness but it is anticipated to last no longer than 30 minutes. As you will be required to complete a warm up and warm down you will likely be in the laboratory for 1 hour. Opportunity to discuss your results can be done post the test or via telephone conversation dependent on your individual preferences. Should you wish to discuss results after your test it is anticipated that this will take an additional 30 minutes.**

What happens if you change your mind?

If you decide to join this study you can change your mind at any time. Please contact us if you have made a decision not to take part in this research as it will prevent you being contacted further.

Are there any risks?

As with any aspect of exercise there is a risk of delayed onset of muscle soreness (DOMS) and a very small risk of muscular injury. The risk of such issues is decreased by thorough preparation, warm up and also including being familiarised with the protocol, and equipment being used in this study. This will be provided as part of your involvement within the study. **As this study involves sampling of blood there is**

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some risks associated with contamination. Such risks have been decreased by full training and assessment of researcher competency, and the researcher following strict blood sampling guidelines at all times. As the participant, you will be asked to fill in a blood sampling survey which will ask questions to ensure you are healthy to sample blood from. Questions will include history on any tattoos or piercings that you may have and of any blood contaminating diseases the researcher would need to be aware of. As we will be measuring expired gas, you will be required to breathe through a mouth piece and as such there is a small risk of infection to participants. This risk is minimal and is further reduced as mouthpieces are sterilised after every test.

There is no additional risk of you falling off your horse by wearing any of this equipment, however, if at any point you do not feel comfortable riding in the equipment and certainly if you feel un-safe it is recommended that you stop immediately.

Ethical considerations:

The findings of this study will be submitted for publication; however your anonymity will be protected at all times. All information can be identified with each individual and will be kept confidential by the principal researcher at all times.

I hope that you find the information provided in this sheet useful. Thank you for your interest in this project.

Yours faithfully,

Jenni-Louise Johnson PhD Student
Institute of Sport & Exercise Science
jenni-louise.johnson @worc.ac.uk.
01905 855238

&

Prof. Derek M Peters, Director of Studies
Institute of Sport & Exercise Science
d.peters@worc.ac.uk, 01905 855352

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What will happen if I join the study?

Your involvement in this study consists of two sessions. The first consists of field based testing at Hartpury College. Jenni will meet you at Parkway Equestrian Arena and verbally brief you of the days protocol. There would be a few pieces of equipment that you would be required to wear (nothing for your horse). You would wear a heart rate monitor over the entire data collection, this is a strap around your chest, a strap round your upper arm (to measure speed and distance) and a watch on your wrist. You will also be required to wear small electrodes that measure muscle activity on your thighs, abdomen, forearms, upper-back and lower- back. These are fixed with sticky tape and secured with bandages. Lastly, to measure oxygen uptake you would wear a small backpack with a facemask whilst you ride. These will be fitted before you mount your horse, you will then be required to perform a 15 minute warm up on your horse including walk (3 min), trot (3min), canter (3min) and six minutes preparation for jumping including a 'cross-pole' up to 80cm, a vertical up to 80cm and an oxer at 80cm.

The test itself will last ~22 minutes and will require you and your horse to complete the following around the perimeter of the arena in a clockwise direction; walk (3 minutes), trot rising (3 minutes), trot sitting (3minutes), canter (3minutes), and 2-point canter (3minutes). You will then be asked to rest in walk (2minutes), then gallop (3minutes) and again rest in walk (2 minutes). The last stage is to canter in a 2-point seat jumping a 80cm oxer at a comfortable 'cross-country speed' (3minutes). Prior to mounting, post warm up and at the end of each 3 minute stage you will be asked to return to the researcher to have blood lactate sampled – this will be fully explained to you in detail if you are interested in participating in this research. It will involve sampling via your right earlobe. Throughout testing in the arena a video camera will be placed so that your test can be captured. This is to ensure timings of all devices are accurate and to allow me to work out your speed, should the GPS of the watches fail.

The second session will require you to visit Hartpury College's Human Performance Centre for exercise testing. Jenni will meet you and again verbally brief you of the protocol. Your height and weight will be measured and following this you will then undergo a treadmill test where your cardio-respiratory fitness will be measured. During this treadmill test Jenni will ask you to breathe into and out of a mouth piece and also take a sample of blood from your earlobe every four minutes. **This test is a maximal exercise test and the length is determined by your personal fitness but it is anticipated to last no longer than 30 minutes. As you will be required to complete a warm up and warm down you will likely be in the laboratory for 1 hour. Opportunity to discuss your results can be done post the test or via telephone conversation dependent on your individual preferences. Should you wish to discuss results after your test it is anticipated that this will take an additional 30 minutes.**

What happens if you change your mind?

If you decide to join this study you can change your mind at any time. Please contact us if you have made a decision not to take part in this research as it will prevent you being contacted further.

Are there any risks?

As with any aspect of exercise there is a risk of delayed onset of muscle soreness (DOMS) and a very small risk of muscular injury. The risk of such issues is decreased by thorough preparation, warm up and also including being familiarised with the protocol, and equipment being used in this study. This will be provided as part of your involvement within the study. **As this study involves sampling of blood there is**

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INFORMED CONSENT

Please read the following statements carefully. Please sign only when you have agreed with the statement and when you have had any relevant questions answered.

- I have read the information sheet for the above study and the full details of the tests have been explained to me (verbally and written). I am clear about what will be involved for myself and my horse and I am aware of the purposes of the investigation, the potential benefits and the potential risks.
- I know that I nor my horse are obliged to complete the tests. I am free to stop the testing at any point and for any reason.
- I am responsible to report promptly any unusual behaviors of my horse that may pose a risk to researchers during data collection.
- Tests results will only be used for the purposes of this research
- I declare that I am 18 years of age or over
- I hereby give my full consent to participate within this research

Signature of participant (or owner): ____________________ Date: ________________

Name of lead researcher (s): ____________________ Date: ________________

Appendix 3d:

Appendix 1 Ethics Documentation

University of Worcester

Institute of Sport and Exercise Science

Centre for Performance in Equestrian Sports

Participant Information Sheet and Informed Consent Form

Project Title: Comparison of three exercise modes in assessing peak oxygen uptake in equestrian athletes

Thank you for expressing an interest in participating in the above study.

Purpose of this information sheet:

This information sheet has been written to help you better understand an upcoming research project run by the Institute of Sport and Exercise Science, University of Worcester and Centre for Performance in Equestrian Sports at UWE Hartpury. The information provided within this sheet is designed to inform you about your participation in the project. It really is important that you understand that taking part in this study is voluntary and if you do not want to continue you can withdraw at any time from the project.

Rationale:

A maximal oxygen consumption test (VO_{2max}) measures the volume of oxygen consumed and the volume of carbon dioxide produced by the body in a controlled setting. Those who have a higher oxygen consumption value can exercise more intensely than that that are not as well conditioned, and is a good indicator of aerobic fitness.

Findings from both my research and that of Westerling (1983) have reported higher VO_{2max} data attained via cycling than reported by Meyers and Stirling (2000) and Meyers (2006) who adopted a treadmill protocol in comparable populations. This indicates that cycling may relate to local muscle stress in equestrians more effectively than the treadmill but warrants investigation in a single sample. Research considering the most suitable mode of testing maximal oxygen consumption in equestrians is lacking and warrants further investigation to validate future protocols in this population of athletes. Additionally there is no sports specific mode for testing peak oxygen consumption so this trial will compare the use of a mechanical horse compared to more traditional testing methods.

- When the project is complete we intend to publish the results in a prominent journal and disseminate to the equestrian community.
- If you require further information to help you make a decision about joining this study please contact Jenni on the contact details provided at the end of this form.

Benefits of this research:

Currently, the most appropriate method for assessing aerobic fitness is unknown and therefore different approaches are used within scientific literature (commonly a bike or a treadmill). This research will identify which method (Bike, Treadmill or mechanical horse) is most effective in identifying aerobic fitness for an equestrian population so that a more cohesive and sports specific test protocol can be employed for future research.

BRITISH EVENTING

POLAR LISTEN TO YOUR BODY

University of Worcester

Institute of Sport and Exercise Science

Centre for Performance in Equestrian Sports

Why you have been asked:

All female riders that are over 18 and competing in equestrian sports are being invited to participate in this research. This document serves to help you to understand what if required of you should you decide to participate in this research trial.

What happens if you change your mind?

If you decide to join this study you can change your mind at any time. Please contact Jenni if you have made a decision not to take part in this research as it will prevent you being contacted further.

What would happen if you join the study?

Your involvement in this study consists of three sessions one on a bike, one on a treadmill and one on a simulated horse. Jenni will meet you and verbally brief you of the protocol at a pre agreed time and place. Your height and weight will be measured and following this you will then undergo a fitness test where your cardio-respiratory fitness will be measured. During all tests Jenni will ask you to wear a face mask and a small back pack. She will additionally take a sample of blood from your earlobe post testing. This test is a maximal exercise test and the length is determined by your personal fitness but it is anticipated to last no longer than 20 minutes. As you will be required to complete a warm up and warm down you will likely be in the laboratory for a maximum of 1 hour (each test session). The tests will require you to attend testing on three separate occasions, with a weeks interim between tests. Opportunity to discuss your results can be done post the test or via telephone conversation dependent on your individual preferences.

Are there any risks?

As with any aspect of exercise there is a risk of delayed onset of muscle soreness (DOMS) and a very small risk of muscular injury. The risk of such issues is decreased by thorough preparation, warm up and also including being familiarised with the protocol, and equipment being used in this study. This will be provided as part of your involvement within the study. As this study involves sampling of blood there are some risks associated with contamination. Such risks have been decreased by full training and assessment of researcher competency, and the researcher following strict blood sampling guidelines at all times. As the participant, you will be asked to fill in a blood sampling survey which will ask questions to ensure you are healthy to sample blood from. Questions will include history on any tattoos or piercings that you may have and of any blood contaminating diseases the researcher would need to be aware of. As we will be measuring expired gas, you will be required to breathe through a mask and as such there is a small risk of infection to participants. This risk is minimal and is further reduced as mouthpieces are sterilised after every test.

BRITISH EVENTING

POLAR
LISTEN TO YOUR BODY

Institute of Sport and Exercise Science

Centre for Performance in Equestrian Sports

Ethical considerations:

The findings of this study will be submitted for publication; however your anonymity will be protected at all times. From the information published you will be unable to be identified individually.

I hope that you find the information provided in this sheet useful. Should you have any concerns about this project you can contact Dr. John-Paul Wilson on the following contact details: j.wilson@worc.ac.uk; 01905 542196.

Once again, I would like to thank you for your involvement with this study.

Jenni Douglas.

INFORMED CONSENT

Please read the following statements carefully. Please sign only when you have agreed with the statement and when you have had any relevant questions answered.

- I have read the information sheet for the above study and the full details of the tests have been explained to me (verbally and written). I am clear about what will be involved and I am aware of the purposes of the tests, the potential benefits and the potential risks.
- I know that I am not obliged to complete the tests. I am free to stop the test at any point and for any reason.
- I am responsible to report promptly any unusual feelings or discomfort during the exercise test.
- Tests results will only be used for the purposes of this research
- I have no injury or illness that will affect my ability to successfully complete the tests.
- I hereby give my full consent to take part in the study.

Signature of participant: ________________________ Date: _________________

Name of Test Supervisor: ________________________ Date: __________________

Appendix 3e:

Generic Exercise Screening Questionnaire

University of Worcester

PRE-TEST QUESTIONNAIRE AND INFORMED CONSENT

Name:____________________________ Age:_________ D.O.B.: __________

As you are to be a participant in this field trial would you please complete the following questionnaire truthfully and completely. The purpose of this questionnaire is to ensure that you are in a fit and healthy state to participate in this research.

*Please delete as appropriate

1. **How would you describe your present level of activity?**

   sedentary/moderately active/highly active*

2. **How would you describe your current level of fitness?**

   very unfit/moderately fit/trained/highly trained*

3. **How would you consider your present weight?**

   underweight/ideal weight/slightly overweight/very overweight*

4. **Smoking Habits**

Currently non-smoker	yes/no*	
A previous smoker	yes/no*	of..........per day
If previous smoker, how long since stopping?		..........years
A regular smoker	yes/no*	of..........per day
An occasional smoker	yes/no*	of..........per day

5. **Consumption of alcohol**

Do you drink alcoholic drinks?	yes/no*
If yes, then do you:	
Have the occasional drink?	yes/no*
Have a drink everyday?	yes/no*
Have more than one drink a day?	yes/no*

6. **Have you had to consult your doctor within the last 6 months?**

   yes/no*
   If yes please give brief details.

7. **Are you presently taking any form of medication?**

   yes/no*
   If yes please give details.

8. **Have you suffered from a bacterial or viral infection in the last 2 weeks?**

   yes/no*

9. Do you suffer, or have ever suffered, from

Asthma?	yes/no*
Diabetes?	yes/no*
Bronchitis?	yes/no*
Epilepsy?	yes/no*
High blood pressure?	yes/no*

10. Do you suffer, or have ever suffered from, any form of heart complaint?

yes/no*

11. Is there a history of heart disease in your family?

yes/no*

12. Do you currently have any form of muscle or joint injury?

yes/no*. *If yes please give brief details.*

13. Have you had to suspend training in the last two weeks for a physical reason?

yes/no*. *If yes please give brief details.*

14. Is there anything to your knowledge that may prevent you from successfully completing the tests that have been outlined to you?

yes/no*

INFORMED CONSENT

Please read the following statements carefully. Please sign only when you have agreed with the statement and when you have had any relevant questions answered.

- I have read the information sheet for the above study and the full details of the tests have been explained to me (verbally and written). I am clear about what will be involved and I am aware of the purposes of the tests, the potential benefits and the potential risks.
- I know that I am not obliged to complete the tests. I am free to stop the test at any point and for any reason.
- I am responsible to report promptly any unusual feelings or discomfort during the exercise test.
- Tests results will only be used for the purposes of this research
- I have no injury or illness that will affect my ability to successfully complete the tests.
- I hereby give my full consent to take part in the study.

Signature of participant: ______________________ Date: ________________

Name of Test Supervisor: ______________________ Date: ________________

QUESTIONNAIRE FOR PARTICIPANTS IN PROJECTS INVOLVING BLOOD ANALYSIS

Name:___________________________ Age:_________ D.O.B.: ____

STRICTLY CONFIDENTIAL: All information given will be protected under the Data Protection Act 1998. Answer all questions by 'ticking' the appropriate box. The purpose of this questionnaire is to ensure that you are in a fit and healthy state for blood analysis.

		Yes	No
1.	Are you receiving any medicines, dental treatment, have had recent illness or attending hospital outpatients?	☐	☐
2.	Have you had ears pierced, acupuncture or have been tattooed in the last 6 months?	☐	☐
3.	Have you ever been advised by a doctor not to give blood?	☐	☐
4.	Are you or have you ever suffered from any of the following?		
	Allergy from latex	☐	☐
	Diabetes	☐	☐
	Epilepsy (fits)	☐	☐
	Hepatitis (jaundice) or been in contact with a case in the last 6 months	☐	☐
	Tropical disease especially malaria	☐	☐
	Sexually Transmitted Infections	☐	☐

Please advise the test supervisor if you have travelled outside Europe within the last 6 months and/or received travel vaccinations.

DECLARATION

I have had explained to me, and fully understand, the reasons for blood analysis during exercise testing.

I have not answered 'Yes' to any of the questions listed and to the best of my knowledge am fully eligible to undertake blood testing and do so of my own free will.

Signed _________________________ Date___________

Test Supervisor _________________________ Date___________