Comparative Exercise Physiology, 2012; 8 (1): 53-62

Wageningen Academic Publishers

A systematic review of physical fitness, physiological demands and biomechanical performance in equestrian athletes

J.-L. Douglas[1], M. Price[2] and D.M. Peters[1,3]

[1]University of Worcester, Institute of Sport and Exercise Science, Henwick Grove, WR2 6AJ Worcester, United Kingdom; [2]Coventry University, Department of Biomolecular and Sport Sciences, Priory Street, CV1 5FB Coventry, United Kingdom; [3]University of Agder, Faculty of Health and Sport Sciences, P.O. Box 422, 4604 Kristiansand, Norway; jenni-louise.douglas@worc.ac.uk

Received: 29 September 2011 / Accepted: 12 March 2012

REVIEW PAPER

Abstract

This article presents a systematic review of the literature investigating physical fitness, physiological demands and biomechanical performance in equestrian athletes. Three databases (SportsDiscus, CAB abstracts and PubMed) were searched to identify the literature. The main search term of 'horse-riding' was combined with eleven specific keywords ('fitness', 'physiology', 'biomechanics', 'equestrian', 'athlete', 'co-ordination', 'heart rate', 'oxygen consumption' 'kinematic' 'EMG' and 'skill'). Exclusion criteria were: conference proceedings, abstracts, theses, and non-peer reviewed articles. Subsequently, 15 peer-reviewed papers were identified and included within this review. The main research findings are that as a horse progresses through the gaits (walk, trot and canter), the rider's heart rate and oxygen consumption increase. The causal physiological factor at present is thought to be higher levels of tonic muscular contraction particularly of the trunk, which in elite equestrians achieves a more controlled upright trunk position, compared to their novice counterparts. It is the faster gaits, and jumping that require the rider to adopt a 'forwards' riding position that necessitates weight bearing to be through the rider's legs, as opposed to a seated position, where weight bearing is predominantly through the pelvis. It is apparent that these 'forward position' modes of riding significantly increase metabolic cost and result in elevated levels of blood lactate, thus implying that they incorporate some anaerobic demand. Due to the paucity of literature available for review and particularly that which incorporates data obtained from 'competitive' performances, future research should attempt to prioritise investigations in competitive in addition to simulated riding environments. Only when further physiological and biomechanical data are available from a greater range of equestrian disciplines and from a range of level of athletes, will the demands of these sports be more clearly understood. Until such time, the development of evidence-based sport specific and potentially performance enhancing rider strength and conditioning programmes cannot be realised.

Keywords: horse-rider, aerobic power, heart rate, muscular strength, position

1. Introduction

Equestrian sports have proliferated from the ancient Olympics and today are governed by national and international organisations. The Fédération Equestre Internationale (FEI) governs seven international equestrian sports including show jumping, dressage (including para-equestrian dressage), eventing, endurance, equestrian vaulting, reining and horse driving trials (including para-equestrian driving). Horse racing is the only professional equestrian sport, represented by the International Federation of Horse Racing Authorities. Today, equestrianism is represented in the Olympics with the disciplines of show jumping, dressage and eventing. The equestrian industry in the UK is vast, turning over more than £4 billion per annum and it is estimated that over 4.3 million people ride or drive horses in the UK alone (BETA, 2010). Despite this level of financial commitment and extensive level of rider participation, the investigation of human physical, biomechanical and fitness related factors that might enhance rider performance is limited.

Whilst athlete specific performance variables have been investigated in many individual and team sports, the unique nature of the horse-rider partnership in equestrian sports complicates the interpretation of such human-focused data. Riding requires both the horse and human to perform at the same time to achieve optimal performance. Complexities and logistics of in-field data collection of this partnership are a likely cause for the limited research investigating competitive performance in equestrian sports. Despite the origins of equestrianism dating back many centuries, relative to mainstream sports such as football, equine sport has only recently received increased exposure in the mass media. As a consequence, the concept of the equestrian (horse-rider) as an athlete is an emerging concept in both popular and academic press. In 2007 the British Equestrian Federation launched a long term athlete development (LATD) model entitled 'Long Term Rider Development'. The document explicitly discusses the concept of addressing the core components of athleticism whilst riding, and also via an un-mounted additional training programme. Despite the LTAD's suggestion for the inclusion of additional un-mounted training, neither the physical, physiological, nor biomechanical traits required by riders, nor the most beneficial type of training for this population of athletes have been investigated.

Equestrianism has been identified as a sport that requires perfecting the conduct of different means of travel and has been compared to other travel sports such as motor sports and water events (e.g. sailing, yachting) (Bompa and Haff, 2009). In the extant literature there is scant research investigating performance traits and the physiological and morphological requirements of equestrians. It has been elucidated that these 'travel sports' require the development of complex skills that require many hours of training, and as athletes will have to make quick decisions, they require quick proprioceptive processing. Bompa and Haff (2009) suggest that the dominant motor abilities athletes should possess in these sports are strength, reaction time, balance and endurance. There is, however, distinctiveness about equestrian sport as the horse has its own free mind. This combined horse-human partnership adds further complexity and variability to the control of extraneous variables and events in scientific investigations.

2. Literature

This review evaluates, draws conclusions and makes recommendations from a critical evaluation of the limited number of studies published that have investigated from the rider's perspective, the physiological, metabolic and biomechanical characteristics and demands of equestrianism. Systematic review methodology was adopted to formalise literature searching. Whilst systematic reviews have been well documented in the field of medical science, there is a small but growing body of research outside of medicine which is beginning to utilise the more formal systematic review. Three methodological stages of a systematic literature review as guided by Tranfield *et al.* (2003): planning the review, conducting the review and finally reporting and dissemination, were used in the current study.

The following databases were used for this review: SportsDiscus, CAB abstracts and PubMed (http://www.ncbi.nlm.nih.gov/sites/entrez). These databases were searched with 'horse-riding' as the main keyword combined with each of the following: 'fitness', 'physiology', 'biomechanics', 'equestrian', 'athlete', 'coordination', 'heart rate', 'oxygen consumption', 'kinematic', 'EMG' (electromyography) and 'skill'. Peer-reviewed articles in scientific publications until September 2011 were included in this review. The following types of references were excluded: papers in conference proceedings, abstracts, theses, and non-peer reviewed articles. Based on these criteria 15 peer-reviewed articles, all focussed on equestrianism (horse-riding) and on either physical fitness, physiological demands or biomechanical performance parameters were included in this review (Table 1).

3. Physical characteristics of equestrians

Body mass and height

Body mass and height has been recorded in equestrians over the last three decades with the majority of participants being female. Westerling (1983), Alfredson *et al.* (1998), Meyers and Sterling (2000), Devienne and Guezennec (2000) and Meyers (2006) reported findings for body mass and height throughout their research. Westerling (1983) reported mean body mass and height in 13 female experienced riders with a mean age of 21 (no standard deviation reported) years (range 16-28) as 61.5 kg (range 49-74 kg). Similarly Alfredson *et al.* (1998) reported body mass and height in 20 female collegiate riders with a mean age of 17.9±0.6 years (mixture of dressage and show jump riders) as 61.8±7.0 kg (no range reported) and 165.1±4.5 cm (no range reported). Meyers and Sterling (2000) investigated body mass and height in 24 female collegiate riders with a mean age of 23.5±6.4 years (range 18-35 years) with findings of 64.9±9.3 kg (range 56-83 kg) and 161.8±5 cm (range 157-175 cm), and Devienne and Guezennec (2000) reported body mass and height in five experienced show jump riders (3 female, 2 male) mean age, 26±6.16 years (range 19-35 years), as mean height, 172±0.08 cm, and mean body mass, 58.2±11.1 kg. More recently Roberts *et*

Table 1. Main results of research used in this review article.

Reference	Discipline[1]	Participants (number, sex)	Main results
Physiological references			
Westerling (1983)	Dr/SJ	n=13 female	riders use >60% aerobic power
Gutirrez Rincon *et al.* (1992)	SJ	n=3 non-specified sex	riders use >90% heart rate maximum (HR_{max}); mean blood lactate (BLa) ranged from 4-9 mmol/1
Trowbridge *et al.* (1995)	NH	n=7 male	mean HR 137-178 bpm-1; mean BLa ranged from 3.5-15 mmol/1
Meyers (2006)	-	n=15 female in equitation group; n=10 female in control group	a 14 week equitation programme (40 minutes of walk, trot, canter daily) does not provoke any cardiovascular or strength stimulus
Alfredson *et al.* (1998)	-	n=20 female	impact forces during horse riding are not enough to create osteogenic strains on the skeleton, and riders have high thigh strength, but low bone mass
Devienne and Guzennec (2000)	Dr/SJ	n=3 female n=2 male	>75% VO_{2max}; there is variability on metabolic cost dependent on the nature of the horse being ridden
Meyers and Stirling (2000)		n=24 female	
Wright and Peters (2008)	Polo	n=7 male	67% of total playing time was spent in hard heart rate zones (70-89 HR_{max})
Roberts *et al.* (2010)	Ev	n=16 female	Dr = mean O_2 consumption 20.4 ml/kg/min; mean HR 157 bpm; SJ = mean O_2 consumption 28 4 ml/kg/min, mean HR 180 bpm; XC = mean O_2 31.2 4 ml/kg/min, mean HR 184 bpm
Biomechanical references			
Terada (2000)	Dr	n=3 novice unspecified sex; n=3 advanced unspecified sex	advanced riders displayed higher frequency bandings in EMG recordings which suggests they had more active control of their posture; novice riders had a greater dispersion at their head; novice riders could not gauge movements accurately
Lovett *et al.* (2004)	Dr	n=5 female	throughout rising trot the trunk is tilted further forwards, more active movement required from thigh muscles
Terada *et al.* (2004)	Dr	n=6 female	EMG recording found muscle activity of riders on the flat were more responsible for postural control than power production; tonic arm contraction responsible for the control of the bit
Terada *et al.* (2006)	Dr	n=6 unspecified sex	when rider's hip moves forwards the trunk moves backwards, the rider extends the shoulder and elbow to keep a constant contact on the bit; the movement is reversed and repeated
Bystrom *et al.* (2009)	Dr	n=3 male; n=4 female	in trot, at deceleration, rider is pressed into saddle lumbar spine hollows, leg joints flex and feet move forwards; at propulsion, rider pushed out of saddle, lumbar spine straightens, legs extend, head and feet move backward; all riders had some asymmetry in movement
Symes and Ellis (2009)	Dr	n=17 female	in walk trot and canter, shoulder displacement was greater for the right shoulder and the riders thoracic girdle rotated left; 100% of riders had some asymmetry

[1] Disciplines: Dr = dressage, SJ = show jumping, Ev = eventing, NH = national hunt. Dressage is considered to be any ridden activity that does not incorporate any galloping or jumping effort.

al. (2009) reported the mean body mass of female novice event riders to be 60.3±5.8 kg (range 49.2-76.6 kg) and height as 166.6±3.8 cm (range 161.5-175.6 cm) in 16 female participants with a mean age of 24.5 years (range 17-44). Meyers (2006) reported mean body mass and height of 15 amateur collegiate riders (mean age 24.8±2.0 years) pre and post a 14-week equitation training intervention. Baseline values prior to intervention were reported as 63.5±2.6 kg, 164.3±1.3 cm. Post intervention a non significant increase in mean weight was observed (64.0±2.4 kg).

Percentage body fat

Female collegiate riders have been shown to have mean body fat levels of 28.6±6.5% (Alfredson *et al.*, 1998) and 24.5±6.0% (Meyers and Sterling, 2000). Meyers (2006) reported percentage body fat in n=15 collegiate riders pre and post a 14 week equitation training programme. Non-significant changes in percentage body fat were reported at baseline (25.1±1.1%) and post intervention (23.5±0.9%). In novice female event riders body fat was slightly lower, with mean values of 23.4±5.3% (Roberts *et al.*, 2009) comparable to work by Meyers (2006). Roberts *et al.* (2009) noted that the high body fat percentages reported in equestrian athletes reflect a lack of physical conditioning when compared to other groups of athletes. There is range in mean body fat percentage of 23.4-28.6% in equestrians within the currently available literature. It is appropriate to consider these reported findings with caution due to the validity of different methods of collecting body composition. Body composition in equestrians has been investigated via dual X-ray absorptiometry (Alfredson *et al.*, 1998), hydrodensitometry (Meyers and Sterling, 2000) and skin fold techniques (Roberts *et al.*, 2009).

4. The physical fitness of equestrians

Scientific research investigating the physiological capacities of riders is limited, despite an apparent consensus from current literature that equestrianism requires physical fitness for the maintenance of rider balance and general effectiveness (Alfredson *et al.*, 1998; Meyers, 2006; Meyers and Sterling, 2000; Roberts *et al.*, 2009; Westerling, 1983).

There is limited available research that has investigated physiological responses during actual competition in individual equestrian sports (dressage, show jumping and eventing), with the majority instead having used simulated competition scenarios or laboratory based experimental situations.

Maximal oxygen consumption

The mode of exercise testing for collecting maximal oxygen consumption in equestrians has included cycle ergometers and treadmills. As a predominantly 'seated' sport, Westerling (1983) and Devienne and Guezennec (2000) used a cycle ergometer protocol to induce fatigue in riders (Table 2). Conversely, a treadmill protocol was used by Meyers and Sterling (2000) and Meyers (2006) which 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. No consensus has been gained as to the most appropriate outcome measures, and further differing study protocols preclude direct comparison between studies. It is also important to note that the available literature has largely been based on amateur riders (Devienne and Guezennec, 2000; Meyers and Sterling, 2000) and where an experienced population has been used (Westerling, 1983) the riders are only from dressage and show jumping disciplines.

The importance of a high VO_{2max} for equestrian athletes is uncertain, although high aerobic cost in eventing (Roberts *et al.*, 2009), show jumping (Guittérrez Rincón *et al.*, 1992), racing (Trowbridge *et al.*, 1995), and polo (Wright and Peters, 2008) suggests that the aerobic demands of equestrian disciplines requiring galloping and jumping efforts are higher. Meyers and Sterling (2000) observed mean VO_{2max} values of female equestrians (age range 18-24 years) to be 33.9±9 ml/kg/min. In contrast Westerling (1983) reported mean VO_{2max} of 43.8±4.0 ml/kg/min. Differences in reported findings may in part be explained by exercise modality. Westerling (1983) used a bicycle ergometer to induce maximal effort in equestrians compared to Meyers and Stirling (2000) who used a treadmill protocol. Where a bicycle ergometer was used VO_{2max} values were reported higher in comparison to where the treadmill was adopted. This is an interesting finding as bicycle ergometry has been demonstrated by several authors to underpredict maximal oxygen uptake and lactate threshold (Mazzeo and Marshall, 1989; Withers *et al.*, 1981).

Meyers (2006) investigated the effect of a 14-week equitation programme of n=15 female collegiate riders and reported VO_{2max} as 33.4±1.2 ml/kg/min at baseline and 35.3±1.1 ml/kg/min post intervention. These changes were non-significant and reflected minimal improvement in aerobic capacity in this group post equitation intervention.

Table 2. Comparison of oxygen consumption (l/min) and pulmonary ventilation (l/min) between Westerling (1983) and Devienne and Guzennec (2000).

	Measurement	Walk	Trot (rising)	Trot (sitting)	Canter	Jumping
Westerling (1983)	oxygen consumption	0.59	1.68	1.70	1.86	-
	pulmonary ventilation	21.2	44.3	49.4	55.4	-
Devienne and Guzennec (2000)	oxygen consumption	0.7	-	1.47	2.17	2.25
	pulmonary ventilation	19.39	29.57	-	47.45	59.11

The difference in reported VO_{2max} data between Westerling (1983) and that of Meyers and Sterling (2000) and Meyers (2006) may also be explained by the experience of the riders. Westerling (1983) used experienced riders in comparison to Meyers and Sterling (2000) and Meyers (2006) who used amateur populations. A high aerobic cost of riding, particularly in the faster equine gaits or equestrian sports that involve jumping efforts (Guittérrez Rincón *et al.*, 1992; Trowbridge *et al.*, 1995; Wright and Peters, 2008) potentially indicate that experienced riders spending prolonged durations in these activities may have an increased aerobic fitness compared to their amateur equivalents.

Data from Devienne and Guezennec (2000), Meyers and Sterling (2000) and Meyers (2006) indicate that aerobic capacity is low in female equestrians, particularly when compared to other female athletes such as long distance runners, where normative maximal oxygen consumption values for female populations have been reported as 58.2 ml/kg/min (Davies and Thompson, 1979). It is established that riding in a forwards, or un-seated position can provoke a high aerobic response in riders (Guittérrez Rincón *et al.*, 1992; Roberts *et al.*, 2009; Trowbridge *et al.*, 1995; Wright and Peters, 2008), however, maximal aerobic capacity is reported as low (Devienne and Guezennec, 2000; Meyers and Sterling, 2000).

Anaerobic performance

Research on anaerobic characteristics has focussed on cycle ergometry. Meyers and Sterling (2000) reported peak power of 5.3±0.9 W/kg in 24 female equestrians and ranges in peak power of 3.7 to 6.9 W/kg. Meyers (2006) reported peak and mean power output pre and post a 14 week equitation intervention in n=15 collegiate females. Participants exhibited a +13.3% improvement in mean power (baseline = 5.2±0.2 W/kg; post intervention = 6.0±0.2 W/kg), but no improvement (-10.5%) in peak power (baseline = 10.1±0.6 W/kg; post intervention = 8.7±0.4 W/kg). These data suggest that post equitation intervention, riders were capable of maintaining a consistent power output, which indicates improved strength endurance, but with no improvement in peak power.

Although limited information exists in relation to anaerobic performance and power in equestrians, Meyers and Sterling (2000) concluded that their rider sample did not display any indication of substantial anaerobic power, and that horse-riders demonstrated anaerobic power ranges lower than normal ranges in non-athletes.

Muscular strength and endurance

The requirement for strength in equestrianism in uncertain, however EMG studies imply the need for muscular endurance due to long periods spent with muscles in tonic contraction to maintain posture (Terada *et al.*, 2004).

Westerling (1983) measured static muscular strength in equestrians as a maximal voluntary isometric contraction during knee extension (147 Nm), hip adduction (140 Nm), elbow flexion (52 Nm) and hand grip (403 N), and compared these to a control sample where results were reported as 144 Nm, 116 Nm, 49 Nm, and 411 N respectively. This study therefore reported no significant differences in strength between equestrians and the control group.

Alfredson *et al.* (1998) investigated isokinetic concentric and eccentric thigh strength in equestrians using an isokinetic dynamometer (90°/s eccentrically and concentrically, 225°/s concentrically). Equestrians were observed to have significantly greater strength than their control counterparts. The authors theorised this was due to the thigh muscle activity particularly in the 'rising trot'.

Meyers and Sterling (2000) used a curl up test, reverse sit ups, and push ups performed as the number of repetitions per minute to assess muscular strength of the abdominals, back and arms, respectively. The authors reported mean values for the curl up of 56.5±15.8/min (range 23-88/min), reverse sit up, 36.6±13.2/min (range 8-58/min), push up 32.1±10.6/min (range 12-50/min) and hand grip right 28.9±6.7 kg (range 17-44.5 kg) and hand grip left 26.7±6.3 kg (range 18-42.5 kg).

As per Meyers and Sterling (2000), Meyers (2006) used a curl up test, reverse sit ups or back extensions, and push ups to assess muscular endurance. At baseline, reported mean values for the curl up were 58.9±4.2/min, reverse sit up 40.1±2.6/min, push up 29.7±2/min. Post a 14 week equitation intervention no significant improvements were seen in muscular strength apart from in the abdominals where an 11.4% increase was observed (curl up post intervention 66.5±3.3/min). Evidence for the requirement of high levels of muscular strength and endurance in equestrians therefore appears inconclusive and this review highlights the lack of consistency between approaches to measuring strength in equestrian athletes.

Summary

There is limited information that exists on the physical fitness of equestrian athletes. It is clear that available research has focussed on sub-elite populations from a range of disciplines in female athletes. Westerling (1983) noted that both men and women compete on equal terms and that it is therefore unlikely that oxygen uptake and muscle strength is a limiting factor in equestrians. It appears that recreational equitation (walk, trot and canter) as a sole form of exercise is not sufficient to significantly improve aerobic fitness, muscular strength or body composition. Investigation of the effects of elite level riders' equitation programmes on physical fitness is warranted to understand if higher aerobic power seen in experienced riders (Westerling, 1983) is an effect of their riding commitments.

5. The physiological demands of equestrianism

Previous researchers have used measurements of heart rate (Devienne and Guezennec, 2000; Guittérrez Rincón *et al.*, 1992; Roberts *et al.*, 2009; Trowbridge *et al.*, 1995; Westerling, 1983; Wright and Peters, 2008), concentration of blood lactate (Guittérrez Rincón *et al.*, 1992; Roberts *et al.*, 2009; Trowbridge *et al.*, 1995) oxygen uptake and pulmonary ventilation (Devienne and Guezennec, 2000; Roberts *et al.*, 2009; Westerling, 1983) to establish the physiological responses to horse-riding. Quantifying the metabolic demands of equestrianism has been problematic given the inherent variability in physiologic responses dependent on the discipline being investigated. There are clear differences in event characteristics between disciplines in equestrianism. Dressage riders perform a test which lasts approximately 5-8 minutes with limited movement and with high proportion of tonic contractions (Terada *et al.*, 2004). Disciplines that require faster gaits, such as gallop or those that include jumping efforts (e.g. racing, polo, show jumping and some components of eventing) necessitate the rider to adopt a different, mostly 'forward' position which has been purported to require strength in the legs, lower back and arms (Roberts *et al.*, 2009).

To add further complexity when reviewing the available literature, it is important to note that due to governing body restrictions, logistics and safety reasons, the majority of research has considered only rider responses in simulated competition environments and the demands of actual competition has not been explored.

Heart rate analysis

Although there are limitations in using heart rate to assess activity, heart rate analysis can be used to estimate average work intensity (Jeukendrup and Van Diemen, 1998). Westerling (1983) reported that during riding, heart rate differed dependent on the gait of the horse. Equestrians' mean heart rate was reported as 108±13 bpm during walk, 163±19 bpm for trot rising, 170±15 bpm for trot sitting and 172±18 bpm for canter. Riders for this study were considered experienced females who spent 3-14 hours per week in show jumping and dressage.

Guitérrez Rincón *et al.* (1992) investigated heart rate responses to show jump competition in three riders. The show jump course consisted of 13 jumping efforts where each jump was 1.20 metres 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.

The heart rate response to national hunt riding has been reported with peak values ranging from 162-198 bpm and mean values of 136-178 bpm in seven male jockeys. These values suggest 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).

Devienne and Guezennec (2000) investigated the heart rate responses of equestrians (female n=3 and male n=2 participants), who were considered experienced and rode for an average of 7 hours per week. Reported findings for walk, trot and canter were 106±15 bpm, 131±20 bpm, 159±26 bpm, respectively. Devienne and Guezennec (2000) show similar trends to Westerling (1983) where mean heart rate increased with the horse's gait. These authors reported mean heart rate for jumping a show jumping course as 176±24 bpm, which is comparable to Trowbridge *et al.* (1995).

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 bpm, with heart rate ranging from 99-182 bpm (Wright and Peters, 2008). Polo is an intermittent mounted team sport and as riders would adopt both forward and seated riding positions throughout the match, variability in heart rate recorded is expected. More recently Roberts *et al.* (2009) reported heart rate values throughout a simulated competition in novice female one day event riders. The cross country phase produced the highest mean heart rate (184±11 bpm) followed by show jump (180±11 bpm) and then dressage (172±15 bpm) phases.

Lactate accumulation

Guitérrez Rincón *et al.* (1992) found that in a show jump round mean blood lactate concentration ranged from 4.0-6.3 mmol/l in equestrians which implies the involvement of anaerobic energy systems. Similarly in national hunt racing Trowbridge *et al.* (1995) observed mean blood lactate values of 7.1 mmol/l. More recently Roberts *et al.* (2009) investigated lactate responses during a simulated novice one day event and observed lactate concentration to increase progressively during the three phases (dressage, show jumping, cross-country) reaching an overall mean of 9.5 mmol/l.

Oxygen consumption and pulmonary ventilation

Westerling (1983) measured oxygen uptake and pulmonary ventilation during riding in walk, trot rising and sitting, and canter (see Table 2). These results are comparable to those of Devienne and Guezennec (2000) who also included data for one minute of show jumping. Data in Table 2 show that as the horse and thus the rider progress through the horse's gaits (walk, trot and canter) the metabolic cost of horse riding increases. Devienne and Guezennec (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 protocols. 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 individual rider responses, a general subjective behaviour score may need to be noted for comparison in data sets presented. In simulated environments, as opposed to competitive environments, using a single horse for the investigation of rider's responses may be more appropriate.

More recently, Roberts *et al.* (2009) measured oxygen uptake in female novice one day event riders, which indicated that oxygen consumption increased progressively with each phase; dressage (mean 20.4±4.0 ml/kg/min, peak 28.6±6.2 ml/kg/min), show jump (mean 28.1±4.2 ml/kg/min, peak 34.7±6.6 ml/kg/min) and cross country (mean 31.2±6.6 ml/kg/min, peak 37.9±7.4 ml/kg/min). Although maximal oxygen consumption was not measured, estimated values suggest that the cross country phase requires >90% estimated maximal oxygen uptake. The oxygen consumption values reported particularly in the cross country phase, are considered high compared to the reported VO_{2max} data reported in other equestrian populations. These results indicate event riders require a higher aerobic fitness than previously reported equestrian groups, and also further highlight the need for aerobic conditioning in equestrian athletes.

Summary

A plausible cause for the demonstrated increases in heart rate and oxygen consumption as a rider progresses through the horses gaits, and jumping, is that faster gaits and those that require adopting a forward seat, may recruit greater use of leg musculature, and necessitate greater trunk control. For the majority of equestrians, the primary method of training for the sport is through riding itself (Roberts *et al.*, 2009). This approach is not recommended in other sports due to the potential for overtraining, particularly in highly competitive sporting environments (Meyers and Sterling, 2000). Extant literature investigating physiological responses in equestrians has alleged that additional un-mounted training may benefit ridden performance (Meyers, 2006; Meyers and Sterling, 2000; Roberts *et al.*, 2009; Trowbridge *et al.*, 1995; Wright and Peters, 2008). This is not corroborated, however, by any evidence based interventions in an equestrian population.

6. Biomechanical demands of performance

There have been few studies published investigating the biomechanical demands placed upon the rider. Those studies that have analysed biomechanical variables in the rider have to date only considered dressage (walk, trot and canter).

Kinematic and electromyographic analysis

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

Lovett *et al.* (2005) investigated the angles of the rider's 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 co-ordinating their centre of balance with that of the horse. The range of movement seen at the trunk in canter was comparable to the walk. Since equine ground reaction forces are greater in canter than they are in 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 are higher in canter, than in walk and trot.

Terada *et al.* (2004) analysed EMG activity of twelve muscles of the rider (*rectus abdominus*, upper, mid and lower *trapezius*, *serratus anterior*, *teres major*, *flexor carpi radialis*, *extensor carpi ulnaris, biceps brachii, triceps brachii*, *mid deltoid* and *pectoralis major*) at trot. The authors concluded that the predominant role of muscle action was for co-ordination and postural stabilisation, rather than for the production of power.

Terada *et al.* (2006) used elite dressage riders to investigate relative stillness of the wrist relative to the bit, in gaits with aerial phases (where no limbs are in contact with the ground) such as the trot. A 'still hand' is a characteristic of an independent seat, which in an equitation example is considered a skill where the rider can move their limbs independently to apply an aid without it significantly affecting their seated position, and thus the communication to the horse. Terada *et al.* (2006) reported that equestrians have an almost vertical trunk orientation (4°), supporting the work by Schils *et al.* (1993) that trunk angulations may be an indicator of the rider's skill level. In novice riders the tendency is to throw the trunk backwards and forwards due to unexpected translational forces (Terada *et al.*, 2004). Adapting and learning predictive movements of the horse can lead to a more co-ordinated movement of the rider, facilitated by synchronised contractions of the abdominal and erector spinae muscles (Terada, 2000). It was found that throughout the stride cycle the rider's pelvis and shoulders moved in opposite directions. While the rider's pelvis moved towards the horse's head during the beginning of the stance phase, the rider's shoulders moved backwards. Simultaneously, the rider extended the shoulder and elbow joints thus keeping contact to the bit, which was reversed during the end of stance. These findings are comparable and support Terada *et al.* (2004) that contact to the bit is maintained by the *biceps brachii* and the *triceps brachii* which open and close the elbow joint. Whether this is as a result of skilled ability or muscular endurance has yet to be explored.

Asymmetry and movement patterns

Axial rotation is linked to asymmetry in muscle activation of the back and can induce spinal instability leading to injury (Kraft *et al.*, 2007). It has been suggested that reductions of asymmetric movements would have a positive effect on rider's health. Recently, Symes and Ellis (2009) investigated asymmetry in rider position. Median values and range of shoulder displacement were greater for the right shoulder in all gaits showing asymmetry in rider position. The rider sits with the thoracic girdle unevenly positioned with the thoracic girdle rotated to the left. In the right canter however, a chaotic pattern has been reported. Reduced movement is seen in both shoulders in the right canter, and the left shoulder has more movement. In the left canter shoulders move reasonably synchronously with greater displacement of the right shoulder. The right canter does not display this synchronous pattern, riders preferred left rotation which blocks movement to the right (Symes and Ellis, 2009). This asymmetry in axial rotation and velocity of rotation in right canter as theorised by Symes and Ellis (2009) increases muscle activity stress, which could contribute to injury. Symes and Ellis (2009) stipulate that cross training (functional non-sport specific training) is not a concept normally found within rider training and competition preparation. The authors suggest that building core stability and flexibility through an exercise programme may reduce movement asymmetry.

Byström *et al.* (2009) researched basic kinematics of the saddle and rider in high-level dressage horses trotting on a treadmill. Byström *et al.* (2009) concluded that the movements of the rider at trot can be largely explained from the vertical and horizontal deceleration and acceleration of the horse's trunk, that take place during each diagonal stance. At the moment of deceleration the rider is pressed against the saddle and the stirrups, the rider's lumbar back hollows, leg joints flex and the head and feet move forwards. Throughout propulsion the rider is pushed out of the saddle, the lumbar spine straightens the legs extend and the head and feet move backwards, a presumed effect of the horses push-off, transmitted through to the rider. Experienced riders are more consistent and less phase-shifted compared to novice riders thus indicating that the rider must have some active control, and that the movements of the horse clearly dictate the rider's movements but that exact phasing and amplitude are likely to be due to the rider's functional control and skill level.

Yaw (turning about the vertical axis) and roll movements showed most obvious rider asymmetries, despite the riders having a high education of riding. Byström *et al.*, (2009) conclude that asymmetric rider movements could cause asymmetric loading of the horse and the rider and that further research is warranted in the understanding and correction of asymmetric movements in a horse-riding population (Byström *et al.*, 2009; Symes and Ellis, 2009). The results from Byström *et al.* (2009) must be interpreted with care, however, before assumption that this pattern occurs throughout the general riding population. This experiment was carried out on a treadmill and it has been determined that horses have different movement patterns on a treadmill to over-ground motion, however the authors concluded that although the treadmill may induce some minor kinematic changes to the rider, it is unlikely to change the rider's basic pattern (Byström *et al.*, 2009). The results from Byström *et al.* (2009) are, however, in agreement with those of Symes and Ellis (2009) supporting that riders do not perform symmetric movements whilst riding a horse through the gaits.

Summary

The investigation of the biomechanical demands of horse riding is relatively unexplored. It is clear that a horse's 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. A common trend is that the trunk orientation of advanced riders is more vertical than lower level riders possibly due to greater trunk control exhibited by the abdominal musculature.

The upright seated position adopted by experienced riders may also be explained by this position facilitating better balance due to the rider's centre of mass being above and not in front of the base of support (seat). This position is also likely to further contribute to increased control and efficiency of the abdominal musculature due to the muscles of the trunk counter acting as a reduced movement arm when upright as opposed to the forwards position seen in novice riders.

7. Conclusions and future research directions

The main research findings appear to be that as a rider progresses through the gaits (walk, trot and canter), heart rate and oxygen consumption increase. In walk and trot rising, values are low, however in sitting trot and in canter values raise markedly. The causal factor at present is considered to be higher levels of tonic contraction particularly of the trunk. It is the faster gaits, and jumping that require the rider to adopt a 'forwards' position causing weight bearing to be through the rider's legs, as opposed to the pelvis. It is apparent that these modes of forwards seat riding significantly increase metabolic cost and blood lactate production in equestrians suggesting that the body is working in a state of anaerobiosis.

Time motion analysis of the duration riders spend in the forward seat and seated positions in training and competition has not been explored. A greater understanding of the rider's position between training and competition, between equestrian disciplines and between levels of performer may elucidate the extant literature.

The available research is mostly conducted on female riders who are not at a competitive level, or where simulations have been used instead of a competitive environment. Research using male equestrians would be beneficial to present a clearer picture of a competitive equestrian population. Research in competitive equestrian settings would be advantageous to determine the true competitive demands placed upon the rider.

The current understanding of the physiological and biomechanical demands in equestrianism has been drawn from research with relatively small samples with a range of equestrian disciplines represented. Differences in physiological and biomechanical demand between seated and forwards seat riding suggests that further research should consider discipline specific population groups (such as show jump and dressage). These may then be later subdivided into level of performer to investigate competitive demand between amateur and elite equestrians.

Acknowledgements

Jenni-Louise Douglas is in receipt of a full-time PhD studentship bursary funded jointly by the University of Worcester and the University of Coventry and further support for the empirical studies in her ensuing PhD is being provided by British Eventing and Polar Electro Europe BV, Fleurier Branch.

References

Alfredson, H., Hedburg, G., Bergström, E., Nordström, P. and Lorentzon, R., 1998. High thigh strength but not bone mass in young horseback riding females. Calcified Tissue International 62: 497-501.

Back, W. and Clayton, H., 2001. Equine locomotion. W.B. Saunders, London, UK.

Bompa, T. and Haff, G., 2009. Periodisation: theory and methodology of training. Human Kinetics, Champaigne, IL, USA.

British Equestrian Trade Association (BETA), 2010. The national equestrian survey 2005/2006. Available at: http://www.beta-uk.org/media/trade/download/Riders-publicationsandinformation-nationalequestriansurvey.pdf.

Byström, A., Rhodin, M., Von Peinen, M., Weishaupt, A. and Roepstorff, L., 2009. Basic kinematics of the saddle and rider in high-level dressage horses trotting on a treadmill. Equine Veterinary Journal 41: 280-284.

Davies, C. and Thompson, M., 1979. Aerobic performance of female marathon of female marathon and male ultramarathon athletes. European Journal of Applied Physiology 41: 233-245.

Devienne, M. and Guezennec, C., 2000. Energy expenditure of horse riding. Journal of Applied Physiology 82: 499-503.

Guitérrez Rincón, J.A., Vives Turco, J., Martinez, M. and Vaque, C., 1992. A comparative study of the metabolic effort expended by horse riders during a jumping competition. British Journal of Sports Medicine 26: 33-35.

Jeukendrup, A. and Van Diemen, A., 1998. Heart rate monitoring during training and competition in cyclists. Journal of Sports Sciences 16: 91-99.

Kraft, C., Urban, N., Ilg, A., Wallny, T.M., Scharfstädt, M., Jäger, M. and Pennekamp, P., 2007. Influence of the riding discipline and riding intensity on the incidence of back pain in competitive horseback riders. Sportverletzung Sportschaden 21: 29-33.

Lovett, T., Hodson-Tole, E. and Nankervis, K., 2005. A preliminary investigation of rider position during walk, trot and canter. Equine and Comparative Exercise Physiology 2: 71-76.

Mazzeo, R.S. and Marshall, P., 1989. Influence of plasma catecholamines on the lactate threshold during graded exercise. Journal of Applied Physiology 67: 1319-1322.

Meyers, M. and Sterling, J., 2000. Physical, hematological, and exercise response of collegiate female equestrian athletes. Journal of Sports Medicine and Physical Fitness 40: 131-138.

Meyers, M., 2006. Effect of equitation training on health and physical fitness of college females. European Journal of Applied Physiology 98: 177-184.

Roberts, M., Shearman, J. and Marlin, D., 2009. A comparison of the metabolic cost of the three phases of the one-day event in female collegiate riders. Comparative Exercise Physiology 6: 129-135.

Schils, S.J., Greer, N.L., Stoner, L.J. and Kobluk, C.N., 1993. Kinematic analysis of the equestrian – walk, posting trot and sitting trot. Human Movement Science 12: 693-712.

Symes, D. and Ellis, R., 2009. A preliminary study into rider asymmetry within equitation. The Veterinary Journal 181: 34-37.

Terada, K., 2000. Comparison of head movement and EMG activity of muscles between advanced and novice horseback riders at different gaits. Journal of Equine Science 11: 83-90.

Terada, K., Clayton, H. and Kato, K., 2006. Stabilization of wrist position during horseback riding at trot. Equine and Comparative Exercise Physiology 3: 179-184.

Terada, K., Mullineaux, D., Lanovaz, J., Kato, K. and Clayton, H., 2004. Electromyographic analysis of the riders muscles at trot. Equine and Comparative Exercise Physiology 1: 193-198.

Tranfield, D., Denyer, D. and Smart, P., 2003. Towards a methodology for developing evidence-informed management knowledge by means of systematic review. British Journal of Management 14: 207-222.

Trowbridge, E.A., Cotterill, J.C. and Crofts, C.E., 1995. The physiological demands of riding in national hunt races. European Journal of Applied Physiology 70: 66-69.

Westerling, D., 1983. A study of physical demands in riding. European Journal of Applied Physiology 50: 373-382.

Withers, R., Sherman, W., Miller, J. and Costill, D., 1981. Specificity of the anaerobic threshold in endurance trained cyclists and runners. European Journal of Applied Physiology and Occupational Physiology 47: 93-104.

Wright, R. and Peters, D.M., 2008. A heart rate analysis of the cardiovascular demands of elite level competitive polo. International Journal of Performance Analysis in Sport 8: 76-81.