The role of heart rate monitoring to assess workload during maintenance interval training in National Hunt racehorses

Jane Williams[1*], Kieran Kenworthy[1], Tim Jones[2], David Marlin[3] and Gillian Tabor[1]

[1]Equestrian Performance Research and Knowledge Exchange Arena, Hartpury University, Gloucester, UK, GL19 3BE

[2] Equinity Technology™ Ltd., Hampdon House, Falcon Court, Preston Farm, Cleveland, UK, TS18 3TS.

[3] Cambridge, UK.

*Corresponding author: jane.williams@hartpury.ac.uk; 00 44 1452 702640

Highlights

1. Assessment of racehorse workload can be achieved through heart rate monitoring
2. During maintenance gallop exercise, racehorses should be working aerobically
3. No difference in racehorse %HRmax was found across 6 weeks of maintenance exercise
4. 74%, 43% & 2% of gallop runs exceeded anaerobic thresholds at 75%, 80% and 85%HRmax
5. HR monitoring is a more accurate appraisal of racehorse workload than visual observation

Abstract

Quantitative assessment of racehorse workload and fitness levels can be achieved through heart rate monitoring (HRM), an established reliable indicator of workload. Using HRM can aid trainers in formulating evidence-based training regimes as well as evaluating individual horses' progress during training. Despite this, HRM is not used consistently within racehorse training. This study aimed to evaluate how the maintenance workload of racehorses actively engaged in training and racing in the UK, varied across an interval-training regime (6 weeks). Ten thoroughbred racehorses (age: 9.1±1.9 years) of mixed level (British Horseracing Authority Official Rating: 127.2±7.95; career winnings: £34774.6±21548.64)) and experience in training (total races: 25±12) were recruited for the study. Equinity Technology™ Ltd HR monitoring systems collected weekly HR data for each horse during a maintenance interval training session (speed: 11m/s) on a 3 furlong (0.38m) all-weather gallop (sand, rubber and wax mixture; 8cm depth). Maintenance workload levels were determined by the same experienced National Hunt trainer; typical training sessions consisted of a warm up (walk and trot) to the gallop (1000m) followed by a canter interval run: 0.38km, after which horses walked 0.38km back to the start; this process was then repeated a further two times. Mean HR, mean speed and mean stride frequency (SF) for each run was recorded. Mean HR was used to calculate the mean percentage of HR maximum (%HRmean) for each horse between canter runs for individual training sessions and across the 6-week period. A series of One-way Anovas (significance: $P<0.05$) with post-hoc paired t-tests (Bonferroni adjusted alpha: $P<0.01$) examined if differences in %HRmean, mean speed and mean SF occurred across the cohort and for individual horses. No significant differences in %HRmax, mean speed or mean SF were found at cohort or individual level ($P>0.05$). The trainer rated all horses working at maintenance (aerobic) levels, however descriptive analysis identified that 74%, 43% and 2% of gallop runs exceeded the anaerobic threshold when set at 75%, 80% and 85% of HRmax. The results provide evidence that HRM can provide trainers with a more accurate appraisal of racehorse workload compared to visual assessment during training. Increasing industry understanding of how

HRM can be used to monitor fitness within training can enhance equine welfare by preparing horses appropriately for the demands of competition.

Keywords: training; horseracing; heart rate; fitness; equine; welfare

Introduction

Thoroughbred racing is a multi-million pound industry and encompasses National Hunt (NH) or jump racing, including steeplechase, hurdle and NH 'bumpers' (flat races). Hurdle and steeplechase races are run over distances between 2 miles and 4.5 miles (3200 to 7200m) including a variable number of fixed jumping efforts (Thiruvenkaden et al., 2009). These races require horses to use a combination of aerobic and anaerobic energy pathways to sustain their performance during the course of a race (Williams, 2015a). Effective oxygen utilisation is therefore a key performance variable related to success (McGowan et al., 2002), with racehorses which have a superior aerobic capacity and that can source energy using aerobic pathways for longer (i.e. are fitter) possessing a potential performance advantage over their competitors. Recent high profile cases of racehorse fatigue at the end of steeplechase races, such as the collapse and subsequent death at the end of the 2017 Cotswold Chase of former Grand National winner Many Clouds at Cheltenham racecourse, have led to the general public questioning the ethics and welfare of racehorses. Governing bodies in racing are working hard to showcase how the industry prioritises racehorse welfare. Yet despite this and the advances in scientific knowledge of equine physiology and injury, training practices are still acknowledged to be predominately based on anecdotal knowledge, experiential learning and tradition (Ely et al., 2010) rather than being centred scientifically informed training regimens (Williams, 2013; Rogers et al., 2007). This is in part due to the nature of the industry, individuals who wish to become racehorse trainers will work with existing trainers to learn their 'trade', whilst those who experience them often adopt the training practices utilised by successful yards. Evaluation of fitness and by association how prepared a horse is for the physiological demands of competition is important in all equestrian disciplines (Bitschnau et al., 2010). Embedding advanced technological systems such as heart rate monitoring (HRM) and global positioning systems (GPS) to obtain proxy measures of fitness and workload during training regimes has the potential to provide a tool for racehorse trainers to assess racehorse fitness and to be confident that they are protecting their horses' welfare by preparing them appropriately for racing.

Athletic performance

The horse is a superior athlete compared to other species due to its efficient cardiovascular responses to exercise, enabling oxygen to be transported efficiently and quickly from the lungs to the tissues that require it (Allen et al, 2016; Poole and Erikson, 2011) and their increased maximal oxygen capacity (VO_2max) compared to mammals of similar size (Butler et al., 1993). In racehorses, enhanced performance has been associated with factors such as increased heart size, which can improve cardiac output and, by association, VO_2max (Buhl et al, 2005; Poole et al, 2004). Assessing VO_2max in a field environment is challenging (Bitschnau et al., 2010), however the velocity at which maximum heart rate (VHRmax) or the velocity at which a HR of 200bpm (V200) are attained positively correlate to VO_2max, providing proxy measures of maximal oxygen capacity for use in the horse in the 'real-world' (Evans and Rose, 1987). VO_2max also exhibits a linear relationship with speed and heart rate during aerobic exercise and can consequently be a useful measure of how the aerobic fitness of a racehorse is progressing during training (Ainsworth et al., 2008). Therefore the regular application of HRM technology to measure workload during exercise could provide a quantitative and repeatable measure of performance within racehorse training regimes.

In disciplines where horses are required to exercise strenuously, HRs can increase tenfold from resting values, with horses attaining maximal HRs between 201-240 beats per minute (bpm) (Vincent et al, 2006). Within NH racing, peak HRs between 201 and 230 bpm typically occur during races

(Allen et al., 2015). Cardiac output, defined as the volume of blood leaving the left ventricle per minute (the product of HR x stroke volume (SV)), is the key determinant of maximal oxygen capacity at tissue level (Hobbs et al., 2015; Corley et al., 2003). Training cannot increase a horse's maximal HR but can increase the speed / distance at which (V) HRmax is attained (Fonseca et al., 2010). Long-term athletic training such as observed in the training of racehorses, induces structural and functional adaptations to the CV system (Allen et al., 2015). These include cardiac chamber hypertrophy expanding the volume capacity of the heart's chambers alongside hypertrophy of the cardiac muscle (Young et al., 1999, 2003) providing greater power during ventricular contraction, which alongside the larger volume capacity results in greater SVs and superior cardiac output (Allen et al., 2015).

The role of training

Performance exercise testing in horses can be used to assess how an individual horse responds to training throughout the season or to evaluate if training regimens adequately prepare horses for racing (Allen et al., 2016). Serrano et al (2002) and Kingston et al (2006) suggest that traditional training regimens used for racehorses do not fully prepare these horses for the demands of racing and as such may predispose the horse to injury (Evans, 2007), as well as resulting in suboptimal performance (Williams, 2015a). It is important that racehorse trainers can assess how hard horses are working at different stages of training to prevent overload which can lead to injury and to ensure individual horses are working hard enough to progress their fitness (Rogers et al., 2007). Modern HRM systems can reliably monitor HR and are usually linked to global positioning systems to concurrently record speed, making them valuable tools for training (Williams et al., 2015; Allen et al 2015). The use of HRM can offer a reliable indicator of cardiovascular workload, a proxy measure of VO2max and fitness in horses (Allen et al., 2015), providing trainers with an evidence based measure to ascertain progress and efficacy of training regimes

Training or conditioning programmes in racehorses are designed to improve an individual's performance capacity, delay the onset of fatigue, improve skills and minimise injuries, which combine to prepare the horse for the demands placed upon it during racing (Williams, 2015a; Rogers et al., 2007). The metabolic demands of equestrian sport, including NH racing, are predominately aerobic in nature (Rogers et al., 2007). Workloads equivalent to 50–60% of VO_2max are required to improve aerobic capacity, but higher intensities are necessary to improve strength (c. 80% of VO_2max) and anaerobic capacity (up to 165% of VO_2max) (Rogers et al., 2007). The calculation of the percentage of a designated HR maximum a horse is working at during exercise has been used to provide an indication if exercise is aerobic or anaerobic for that individual animal (Williams and Fiander, 2014). Vincent et al (2006) suggest that horses are working anaerobically when they surpass the lactate threshold at between 75 and 85% of their maximum heart rate, which translates approximately to exercise HRs greater than 180 bpm. Training in racehorses takes the form of interval training, with horses completing exercise sessions of variable duration and intensity at set frequencies, with the aim to increase or maintain fitness depending on the stage of training they are at (Rivero et al., 2007). Anecdotally, training regimes usually integrate canter and gallop sessions defined by the speed of work combining maintenance (¼ or ½ speed, aerobic gallops) and fast work (3/4 or full speed, often anaerobic gallops) as well as the use of horsewalkers, swimming, treadmill and hacking exercise. Traditionally, racehorse trainers have assessed racehorse workload by observation, verbal feedback on the horse's performance from the work rider or by monitoring speed. However advances in telemetric HRM systems, offer the potential to integrate HR as a more accurate measure of a horse's workload during training. The aim of this study was to evaluate if the maintenance workload of racehorses, actively engaged in training and racing in the UK, varied across an interval-training regime over a 6 week period.

Materials and methods

Ten thoroughbred racehorses, of variable age, sex and handicap rating, actively engaged in National Hunt training were recruited from a racing yard in the South West of England. The horses were selected for inclusion by their experienced National Hunt trainer (33 years) who regarded them as race fit, they had competed in races during the current season and were in training to maintain their existing fitness levels throughout the study period. The trainer assessed racehorse performance visually and from feedback provided by work riders and prior to the study had not used HR monitors within their training regimes. Data collection took place between January and March 2016 during the British National Hunt (jump racing) season. Training regimens were determined by the trainer; horses completed one 'easy' (maintenance: defined as one or two interval runs at a maximum speed of 25 miles per hour; 11.2m/s) interval training session at the start of the week, after a day off. in addition horses completed three fast work interval training sessions every two days, one of which integrated a jump training session as well as being exercised for two hours per day on the horse walker. Ethical approval for the study was obtained from the University of the West of England (Hartpury) Ethics Committee.

For the purposes of this study, horses' workload: heart rate, speed and stride frequency during maintenance training sessions was reviewed. Prior to exercise, horses were fitted with an equinITy™ continuous heart rate monitor and global positioning system integrated into a neoprene girth sleeve (Figure 1). Horses wore their regular tack: half tree racing saddles, bridle, saddle pad and felt pad, were tacked up within their own stable and were ridden by their normal work rider. Once mounted, horses were warmed up by walking 1000m to the base of the gallops. Each horses had their own training programme and completed between three and four repetitions of 603.5 metres (3 furlongs) duration at a trainer defined speed: 25mph (11.2m/s), fast canter / slow gallop, to work the horses at a maintenance level: aerobically, below the lactate threshold (Vincent et al., 2006). After each interval up the gallop was completed, horses were walked back to the start of the gallop (603.5m) before undertaking the next interval run; once interval training was finished, they were then walked back to the training yard (1000m) as a warm down. Training sessions alternated between two, three furlong all weather gallops containing a mix of sand, rubber and was at a depth of 20.32cms (8 inches) with the same incline.

A


B

Figure 1: Placement of the equinITy™ heart rate monitoring system and girth.

Prior to mounting, the left hand side of the horse underneath the girth was dampened with a water spray and the neoprene girth sleeve was secured over the horse's normal girth (Figure A), with the HR unit (yellow sensor) and receiver pocket positioned on the left portion of the barrel behind the horse's left elbow (Figure B). The HR unit was turned on and placed in the pocket prior to exercise.

Mean HR, mean percentage of heart rate maximum (%HRmax), mean speed and mean stride frequency (SF) were recorded for each training session for all horses in the Equinity Technology™ database, which the trainer had access to for the duration of the study. Subsequently, mean HR, mean speed and mean SF data for individual interval training runs for each horse during each training session they had completed were exported from the trainer's Equinity Technology™ database to a Microsoft Excel Version 2010 spreadsheet. Mean HR, mean speed and mean SF were then calculated for each training session. Mean HRs were converted into the mean %HRmax horses were working at using Formula 1 advocated by Vincent et al. (2006) for each training session. As HRmax has been shown to reduce with increasing age in horses (Allen et al., 2015; Betros et al., 2002) and maximal exercise testing to determine individual horse's HRmax was not feasible, an approximation of HRmax adapted for age determined the proxy HRmax for the participating horses (Vincent et al., 2006).

Formula 1:

%HRmax working at (%) = mean HR (beats per minute) / individual horse's HRmax (beats per minute)* x 100%

*Individual horse's HRmax (beats per minute) = 240 (beats per minute) – horses age (years) (Vincent et al., 2006)

The lactate threshold, representing the shift from aerobic to anaerobic exercise for horses occurs at workloads between 75 and 85% of HRmax (Allen et al., 2015). Therefore to determine if horses were working at a maintenance level during training, the frequency of runs which exceeded lactate thresholds, defined as >75%, >80% and >85% of HRmax, were calculated as a percentage of total runs completed. Horse profiles outlining the age, British Horseracing Authority Official (handicap) Rating (OR) at the time of each training session and racing history (number of races and prize money to date) of each horse were also compiled using data from the Racing Post website (RacingPost.com).

Data analysis

Data met parametric assumptions therefore a series of repeated measures Anovas (significance set at P<0.05) with post hoc paired t-tests (Bonferroni adjusted alpha: P<0.01) examined if differences occurred in mean %HRmax, mean speed and mean SF between the training sessions for individual horses and across the cohort. Data analysis was conducted in SPSS version 24. A Pearson's Product Moment correlation established if there was any relationship between training performance defined as mean %HRmax horses were working at and BHA OR values (significance set at P<0.05).

Results

The racehorses selected varied in age (range: 5 to 11 years), performance level (OR range: 115 to 134), race experience (10 to 50 races) and race success (Table 1). Data were collected from a total of 42 training sessions representing 126 individual gallop runs, with each horse on average completing 4 training sessions consisting of 3 interval training repetitions (gallop runs) per training session. The trainer visually rated all gallop sessions monitored as maintenance (aerobic) workload.

Table 1: Racing profiles of the horses sampled

The age, Official Rating (a performance handicap rating assigned by the British Horse Racing Authority which determines weight carried by horses; higher ratings equate to enhanced performance), number of races under British Horse Racing rules and total prize money (£) was recorded for each horse that participated in the study.

Horse number	Age (years)	Official British Horseracing Authority handicap rating (OR)	Number of races undertaken under rules	Prize money won (£)
1	11	126	50	72103
2	9	134	14	18947
3	11	131	30	43439
4	8	122	10	11338
5	5	131	12	25795
6	9	116	24	16895
7	8	132	21	18781
8	11	115	35	23560
9	9	125	26	56386
10	10	140	31	60502
Mean	9	127	25	34775
Standard deviation	2	8.0	12	21549

No significant differences in mean %HRmax (Figure 2), mean speed (Figure 3) or mean SF (Figure 4) were found between the maintenance exercise sessions during training for any individual horses (P>0.05) or across the cohort (P>0.05), suggesting horses were training at a consistent workload across the period examined on 'easy cantering' or maintenance exercise days. However the descriptive data suggests horses could be working beyond the maintenance workloads the trainer was aiming for in these maintenance exercise sessions. Across the cohort, the mean workload (%HRmax) of horses exceeded the anaerobic threshold, and therefore maintenance workload levels, with the lactate threshold set at >75% HRmax for 74% (n=93 runs) of exercise sessions, set at >80% HRmax for 43% (n=54 runs) of exercise sessions and set at >85% HRmax for 2% (n=3 runs) of exercise sessions during training. There was also no correlation between %HRmax horses worked at and their performance (OR) rating (P>0.05; r=-0.12, n=93).

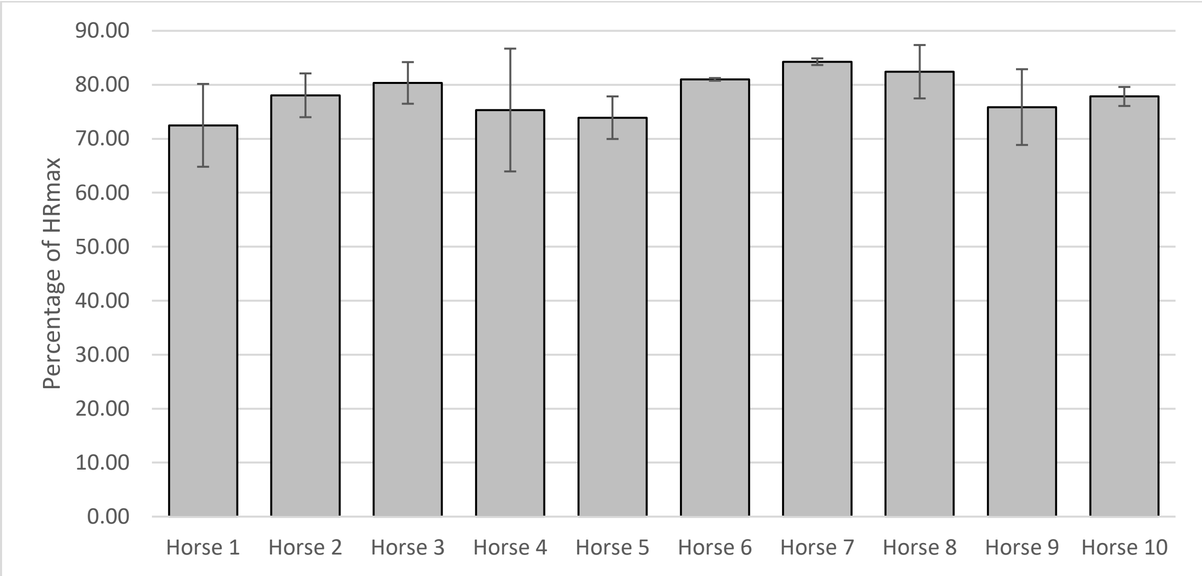

Figure 2: Age adjusted mean and standard deviation for percentage heart rate maximum (beats per minute) horses were working at, for individual horses across all training sessions

The mean HR of each horse was recorded from the Equinity Technology™ database and was converted into an age adjusted percentage heart rate maximum (%HRmax) using the method advocated by Vincent et al. (2006) for each gallop within training sessions. An overall mean and standard deviation for %HRmax was then calculated for each horse to compare average workload across the 6 week period evaluated.

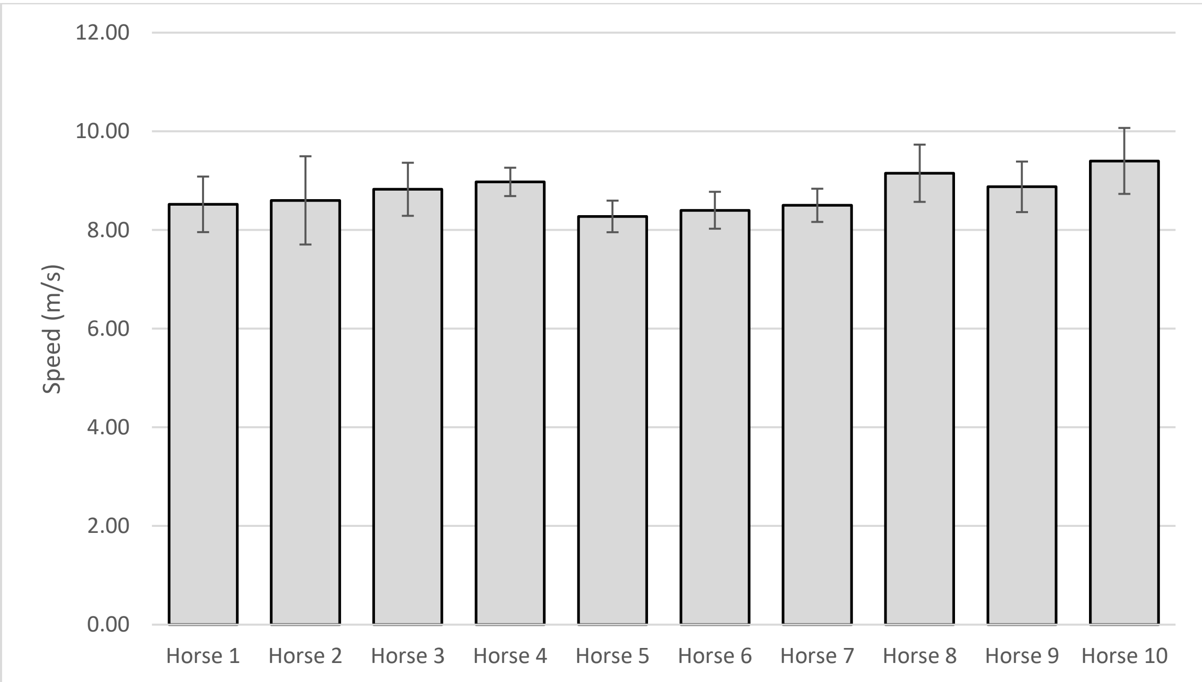

Figure 3: Mean speed and standard deviation (metres / second) for individual horses across training sessions

The mean speed for each gallop for individual horses within training sessions was recorded from the Equinity Technology™ database, then an overall mean and standard deviation for speed was calculated for each horse to compare average speed across the 6 week period evaluated.

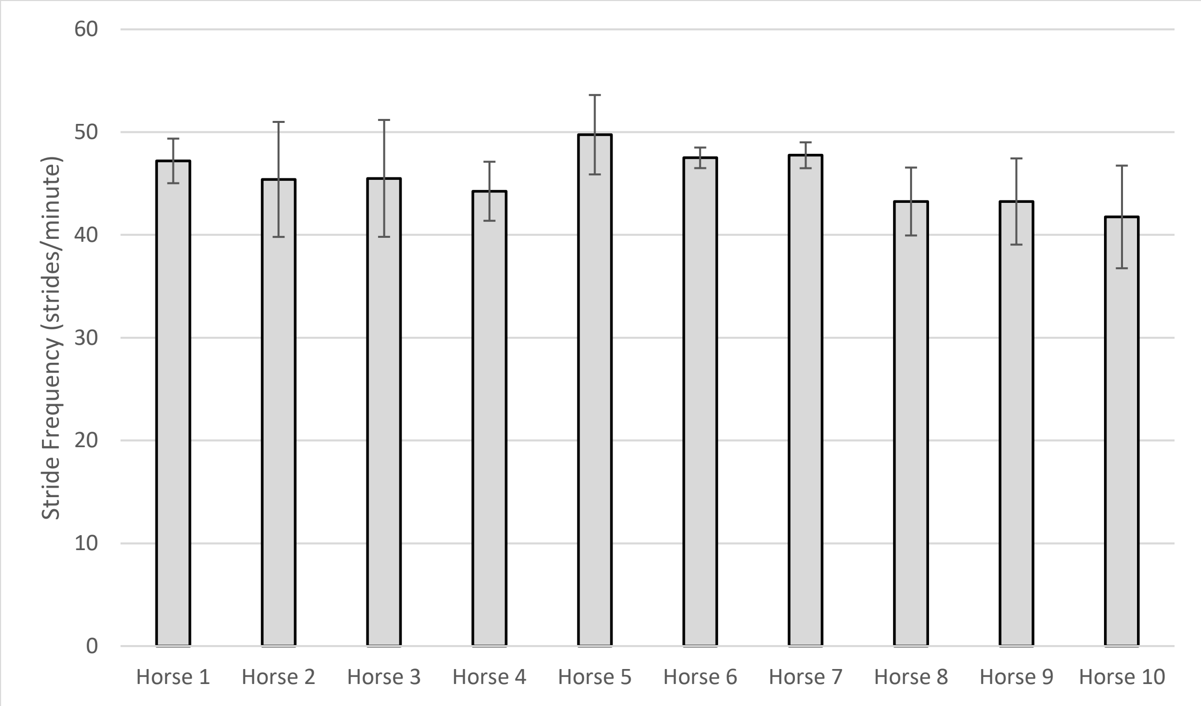

Figure 4: Mean stride frequency and standard deviation (strides per minute) for individual horses across training sessions

The mean stride frequency for each gallop for individual horses within training sessions was recorded from the Equinity Technology™ database, then an overall mean and standard deviation for stride frequency was calculated for each horse to compare average stride frequency across the 6 week period evaluated.

Discussion

Racehorse workload (%HRmax), mean speed and mean stride frequency did not significantly change during the six weeks of maintenance training sessions evaluated. These results are not unsurprising given the experience and successful career of the racehorse trainer. Speed was designated by the trainer by verbal instruction and implemented by experienced work riders, and although exercise speeds were consistent, horses exercised at speeds lower than the 25mph (11m/s) the trainer intended them to work at. Stride frequency increases linearly as speed increases during overland gallop exercise in thoroughbreds (Witte et al., 2006), therefore the consistent speeds recorded also explain the lack of differences observed in stride frequency. However, HR monitoring did identify that despite the extensive experience of the trainer, whilst horses were working consistently, the subjective visual rating of maintenance workload, did not correspond to racehorses working within aerobic heart rate zones. The percentage of runs where horses exceeded aerobic exercise levels varied depending on the percentage of HR maximum the anaerobic threshold was set at. The racehorses used in this study had an average OR of 127, therefore these horses should be racing in NH Class 3 races (handicap OR: ~120 to 135) suggesting superior performance ability but they are not currently rated at elite NH racehorse handicap levels. For example racehorses in the 2017 Grand National (Class 1, Grade 3 race) represented a handicap OR range of 143 to 161 and horses competing in the Class 1, Grade 1 Cheltenham Gold Cup in 2018, had a handicap OR range of 156 to 169. Based on the handicap ratings of the horses and the 'test' a NH race presents, it may be that for these horses the lower anaerobic threshold of 75% (which would correspond to an average HR threshold of 173bpm for this group of horses), suggested as the lower anerobic threshold by Vincent et al. (2006), may not represent their actual anaerobic threshold. For racehorses in training for NH racing an anaerobic threshold rating >80% (Vincent et al., 206) may be more appropriate. Previous work by Kingston et al. (2000) reported differing HR responses to exercise between individual racehorses at the same training load. Interestingly in this study, whilst average speed corresponded to the trainers' speed calculations using a stopwatch, peak speeds differed significantly. The level of fitness represented by HRmax (Vermeulen and Evans, 2010) or the capacity for a horse's response to exercise at a consistent workload due to natural ability. Therefore the performance ratings (OR) of this group of horses or the underestimation of training load due to peak speeds during exercise could explain the higher percentage (74%) of runs which exceeded the trainer's rating of maintenance work. The only way to accurately ascertain horse's anaerobic threshold is to undertake a maximal exercise test, which was not feasible in this group of horses, as they were actively engaged in training, not acclimatised to the high-speed treadmill and the trainer would not permit this. Further work is required to ascertain whether the minimum of maximum range for the anaerobic threshold is most appropriate for NH racehorses and if these thresholds should also be adapted based on individual's race distances.

The application of the aggregation of marginal gains as a successful strategy to enhance performance in equestrian sport has been suggested (Williams, 2013). The use of HRM to collate HR and speed data would allow trainers to develop an evidence base for training for individual horses and which facilitate objective assessment of fitness and progress. HR increases can also indicate the presence of pain and variability from baseline norms could indicate a subclinical issue within a horse (Pritchard et al., 2003). Whilst HR monitoring can be argued to present a performance advantage through increased knowledge of the horse's physiological fitness, it could also be used to ensure horses were prepared sufficiently for the demands of racing and are therefore fit to compete or race. The regular implementation of standard exercise or performance testing (SET) is also advocated in racehorse training to provide a comparative measure of fitness throughout a season (Allen et al., 2016). Within racehorse training, most yards will have access to standardised gallops of a set distance and incline. Therefore regular assessment of HR during a standard speed exercise session (as the horse's fitness increases, HR would decrease) or monitoring the distance it takes for a horse to obtain V200 (as the horse's fitness increases, the distance to V200 would also increase) would represent suitable SET to assess fitness levels (Allen et al., 2016; Vermeulen and Evans, 2010). This knowledge could then be used by trainers to implement individualised and evidence based training regimes which optimise racehorse health, welfare and performance.

The results of this study suggest HR monitoring can provide an objective and reliable indicator of workload, which can aid trainers in formulating evidence-based training regimes and therefore could be used to evaluate individual horses' fitness in racing and for other equestrian disciplines. Interestingly the advancement of HR monitoring systems resulting in them being more portable and affordable, the value of the data obtained and the ease of use via a girth sleeve was viewed positively by the trainer who subsequently purchased the system to use within their daily training practice. However it should also be noted that excitement and anticipation can influence HRs at submaximal exercise levels (Allen et al., 2015) which could influence the interpretation of HR data in the current study. HR in horses becomes almost entirely sympathetically dominated above ~160bpm (88% of recorded runs), providing a more reliable indicator of workload as it is minimally impacted by behaviour and the horses' anticipating galloping or reacting to the environment they were trained in (Physick-Sheard et al., 200; Snow et al., 1992). Therefore, given the high proportion of horses' data, which were above 160bpm, we are confident that the results reported are accurate. The results also represent a snapshot covering three months of training and not the entirety of the NH season, once the horses were considered race-fit by the trainer, and only focused on maintenance training sessions. No assessment of racehorse fitness was undertaken and the inclusion of a standard exercise test at regular intervals within the study period would have been beneficial to evaluate either how fitness was being maintained or if it was still progressing (Williams, 2015b). Therefore, to fully evaluate the potential benefit of using regular HRM within NH racehorse training regimes, monitoring of HR data should encompass the duration of the season and pre-training periods.

Conclusion

Racehorses worked at a consistent level throughout the series of maintenance training sessions evaluated. However individual horses were not always working at the targeted maintenance level within aerobic heart rate zones, despite trainer perception that they were. The results provide evidence that HRM can provide trainers with an accurate and objective appraisal of workload during racehorse training which could replace subjective visual assessment of workload. Increasing industry understanding of how HRM can be used to monitor fitness within training can enhance equine welfare by preparing horses appropriately for the demands of competition.

Conflicts of Interest

No conflicts of interest apply to this work.

Acknowledgements

We would like to thank the stable staff, work riders, assistant trainers and trainer for their enthusiasm and participation in our study.

Ethics statement

This study was approved by the University of the West of England, Hartpury Ethics Committee and complied with all institutional requirements for working with animals.

Authorship statement

The idea for the paper was conceived by Jane Williams.

The experiments were designed by Jane Williams, Kieran Kenworthy and Tim Jones.

The experiments were performed by Kieran Kenworthy.

The data were analysed by Jane Williams, Kieran Kenworthy and Gillian Tabor.

The paper was written by Jane Williams, Gillian Tabor and David Marlin.

References

Allen, K.J., Young, L.E. and Franklin, S.H., 2015. Evaluation of heart rate and rhythm during exercise. Equine Vet Ed, 28 (2), 99-112.

Allen, K.J., van Erck-Westergren, E. and Franklin, S.H., 2016. Exercise testing in the equine athlete. Equine Vet Ed, 28 (2), 89-98.

Ainsworth, D.M., 2008. Lower airway function: responses to exercise and training. Equine Exerc Physiol: The Science of Exercise in the Athletic Horse, p.193.

Betros, C.L., McKeever, K.H., Kearns, C.F. and Malinowski, K., 2002. Effects of ageing and training on maximal heart rate and VO2max. Equine Vet J, 34(S34), 100-105.

Bitschnau, C., Wiestner, T., Trachsel, D.S., Auer, J.A. and Weishaupt, M.A., 2010. Performance parameters and post exercise heart rate recovery in Warmblood sports horses of different performance levels. Equine Vet J, 42(s38), 17-22.

Buhl, R., Ersbøll, A.K., Eriksen, L. and Koch, J., 2005. Changes over time in echocardiographic measurements in young Standardbred racehorses undergoing training and racing and association with racing performance. J Am Vet Med Assoc, 226(11), 1881-1887.

Butler, P.J., Woakes, A.J., Smale, K., Roberts, C.A., Hillidge, C.J., Snow, D.H. and Marlin, D.J., 1993. Respiratory and cardiovascular adjustments during exercise of increasing intensity and during recovery in thoroughbred racehorses. J Expt Biol, 179(1), pp.159-180.

Corley, K.T., Donaldson, L.L., Durando, M.M. and Birks, E.K., 2003. Cardiac output technologies with special reference to the horse. J Vet Internal Med, 17(3), pp.262-272.

Ely, E.R., Price, J.S., Smith, R.K., Wood, J.L.N. and Verheyen, K.L.P., 2010. The effect of exercise regimens on racing performance in National Hunt racehorses. Equine Vet J, 42(s38), pp.624-629.

Evans, D.L., 2007. Welfare of the racehorse during exercise training and racing. In: The Welfare of Horses, Ed: N. Waran, Kluwer Academic Publishers, Dordrecht, The Netherlands. pp 181-201.

Evans, D.L. and Rose, R.J., 1987. Maximum oxygen uptake in racehorses: changes with training state and prediction from submaximal cardiorespiratory measurements. In: Equine Exercise Physiology 2, Eds: J.R. Gillespie and N.E. Robinson, ICEEP publications, Davis. pp 52-67.

Fonseca, R.G., Kenny, D.A., Hill, E.W. and Katz, L.M., 2010. The association of various speed indices to training responses in Thoroughbred flat racehorses measured with a global positioning and heart rate monitoring system. Equine Vet J, 42, pp.51-57.

Gramkow, H.L. and Evans, D.L., 2006. Correlation of race earnings with velocity at maximal heart rate during a field exercise test in thoroughbred racehorses. Equine Vet J, 38(S36), 118-122.

Hobbs, S.J., Northrop, A.J., Baxter, J.C. and Clayton, H.C., 2015.Human exercise physiology and biomechanics. In Training for Equestrian Performance, Eds: J. Williams and D. Evans. Wageningen Publishers: Wageningen. pp. 46-50.

Kingston, J.K., Soppet, G.M., Rogers, C.W. and Firth, E.C., 2006. Use of a global positioning and heart rate monitoring system to assess training load in a group of Thoroughbred racehorses. Equine Vet J, 38 (S36), 106-109.

McGowan, C., Posner, R. and Christley, R., 2002. Incidence of exertional rhabdomyolysis in polo horses in the USA and the United Kingdom in 1999/2000 season. Vet Record 150, 535-537.

McGreevy, P.D. and McLean, A.N., 2007. Roles of learning theory and ethology in equitation. J Vet Behav: Clinical Applications and Research, 2(4), 108-118.

Physick-Sheard, P.W., Marlin, D.J., Thornhill, R. and Schroter, R.C. 2000. Frequency domain analysis of heart rate variability in horses at rest and during exercise, Equine Vet J, 32(3), 253-262.

Poole, D.C. and Erickson, H.H., 2011. Highly athletic terrestrial mammals: horses and dogs. Compr Physiol, 1(1), pp.1-37.

Poole, D.C., 2004. Current concepts of oxygen transport during exercise. Equine Compr Exerc Physiol, 1(1),5-22.

Pritchett, L.C., Ulibarri, C., Roberts, M.C., Schneider, R.K. and Sellon, D.C., 2003. Identification of potential physiological and behavioral indicators of postoperative pain in horses after exploratory celiotomy for colic. Applied Anim Behav Science, 80(1), 31-43.

RacingPost.com https://www.racingpost.com/ Accessed: 20th June 2017.

Rivero, J.L.L., Ruz, A., Martí-Korff, S., Estepa, J.C., Aguilera-Tejero, E., Werkman, J., Sobotta, M. and Lindner, A., 2007. Effects of intensity and duration of exercise on muscular responses to training of thoroughbred racehorses. J Applied Physiol, 102(5), 1871-1882.

Rogers, C.W., Rivero, J.L.L., Van Breda, E., Lindner, A. and van Oldruitenborgh-Oosterbaan, M.S., 2007. Describing workload and scientific information on conditioning horses. Equine Compr Exerc Physiol, 4(1), 1-6.

Serrano, M.G., Evans, D.L. and Hodgson, J.L., 2002. Heart rate and blood lactate responses during exercise in preparation for eventing competition. Equine Vet J, 34 (S34), 135-139.

Snow, D.H., Harris, R.C., MacDonald, I.A., Forster, C.D. and Marlin, D.J. 1992. Effects of high intensity exercise on plasma catecholamines in the Thoroughbred horse. Equine Vet J, 24 (6), 462-467.

Thiruvenkadan, A.K., Kandasamy, N. and Panneerselvam, S., 2009. Inheritance of racing performance of Thoroughbred horses. Livestock Science 121: 308-326.

Vermeulen, A.D. and Evans, D.L., 2006. Measurements of fitness in thoroughbred racehorses using field studies of heart rate and velocity with a global positioning system. Equine Vet J, 38(S36), pp.113-117.

Vincent, T.L., Newton, J.R., Deaton, C.M., Franklin, S.H., Biddick, T., McKeever, K.H., McDonough, P., Young, L.E., Hodgson, D.R. and Marlin, D.J., 2006. Retrospective study of predictive variables for maximal heart rate (HRmax) in horses undergoing strenuous treadmill exercise. Equine Vet J, 38(S36), 146-152.

Williams, J., 2013. Performance analysis in equestrian sport. Comp Exerc Physiol, 9(2): 67-77.

Williams, J.M. 2015a. Defining performance and measuring success. In Training for Equestrian Performance, Eds: J. Williams and D. Evans. Wageningen Publishers: Wageningen. pp. 25 to 35.

Williams, J.M. 2015b. Evaluation of fitness. In Training for Equestrian Performance, Eds: J. Williams and D. Evans. Wageningen Publishers: Wageningen. pp. 25 to 35.

Williams, J.M., Moore, G., St. George, L. and Lesniak, K. 2015. Performance analysis in equestrian sport. In Training for Equestrian Performance, Eds: J. Williams and D. Evans. Wageningen Publishers: Wageningen. pp. 355 to 362.

Williams, J.M. and Fiander, A., 2014. The impact of full vs. half chukka playing strategies on recovery in low goal polo ponies. Compr Exerc Physiol, 10(2), 139-145.

Witte, T.H., Hirst, C.V. and Wilson, A.M., 2006. Effect of speed on stride parameters in racehorses at gallop in field conditions. J Expt Biology, 209(21), 4389-4397.

Young, L.E., 1999. Cardiac responses to training in 2-year-old Thoroughbreds: an echocardiographic study. Equine Vet J, 31(S30), 195-198.

Young, L.E., 2003. Equine athletes, the equine athlete's heart and racing success. Expt physiol, 88(5), 659-663.