



Equine Research

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

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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 and 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 and 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: $\pounds 34774.6 \pm 21548.64$) and experience in training (total races: 25 ± 12) were recruited for the study. Equinity Technology™ Ltd HRM systems collected weekly heart rate (HR) data for each horse during a maintenance interval training session (speed: 11 m/s) on a 3 furlong (0.38 m) all-weather gallop (sand, rubber, and wax mixture; 8 cm 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 (1000 m) followed by a canter interval run: 0.38 km, after which horses walked 0.38 km 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 (%HRmax) 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 the 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.

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Introduction

Thoroughbred racing is a multimillion 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 (3200–7200 m) including a variable number of fixed jumping efforts (Thiruvankadan 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 utilization 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

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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 prioritizes 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 centered scientifically informed training regimens (Rogers et al., 2007; Williams, 2013). 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,” whereas those who experience them often adopt the training practices utilized 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 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 ($VO_2\text{max}$) 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, $VO_2\text{max}$ (Buhl et al., 2005; Poole, 2004). Assessing $VO_2\text{max}$ in a field environment is challenging (Bitschnau et al., 2010); however, the velocity at which maximum heart rate (HR) or the velocity at which an HR of 200 beats per minute (bpm) (V_{200}) is attained positively correlates to $VO_2\text{max}$, providing proxy measures of $VO_2\text{max}$ for use in the horse in the “real-world” (Evans and Rose, 1987). $VO_2\text{max}$ also exhibits a linear relationship with speed and HR during aerobic exercise and can consequently be a useful measure of how the aerobic fitness of a racehorse is progressing during training (Ainsworth, 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 and 240 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 $HR \times \text{stroke volume}$), is the key determinant of $VO_2\text{max}$ at tissue level (Corley et al., 2003; Hobbs et al., 2015). Training cannot increase a horse's maximal HR but can increase the speed/distance at which (V) HR_{max} 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, 1999, 2003) providing greater power during ventricular contraction, which alongside the

larger volume capacity results in greater stroke volumes 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), 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 (Allen et al., 2015; Williams et al., 2015). The use of HRM can offer a reliable indicator of cardiovascular workload, a proxy measure of $VO_2\text{max}$ 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 programs in racehorses are designed to improve an individual's performance capacity, delay the onset of fatigue, improve skills, and minimize injuries, which combine to prepare the horse for the demands placed on it during racing (Rogers et al., 2007; Williams, 2015a). The metabolic demands of equestrian sport, including NH racing, are predominately aerobic in nature (Rogers et al., 2007). Workloads equivalent to 50%–60% of $VO_2\text{max}$ are required to improve aerobic capacity but higher intensities are necessary to improve strength (c. 80% of $VO_2\text{max}$) and anaerobic capacity (up to 165% of $VO_2\text{max}$) (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 HR, 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 ($\frac{1}{4}$ or $\frac{1}{2}$ speed, aerobic gallops) and fast work ($\frac{3}{4}$ or full speed, often anaerobic gallops), as well as the use of horse walkers, 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 NH training were recruited from a racing yard in the South West of England. The horses were selected for inclusion by their experienced NH 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 before the study had not used HR monitors within their training regimes. Data collection took place between January and March 2016 during the British NH (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; 11.2 m/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 and 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 such as HR, speed, and stride frequency (SF) during maintenance training sessions was reviewed. Before exercise, horses were fitted with an equinITy™ continuous HR 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 1000 m to the base of the gallops. Each horse had its own

training program and completed between three and four repetitions of 603.5 meters (3 furlongs) duration at a trainer-defined speed: 25 mph (11.2 m/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 (603.5 m) before undertaking the next interval run; once interval training was finished, they were then walked back to the training yard (1000 m) as a warm down. Training sessions alternated between two and three furlong all weather gallops containing a mix of sand, rubber, and was at a depth of 20.32 cms (8 inches) with the same incline.

Mean HR, mean percentage of HR maximum (%HRmax), mean speed, and mean 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 (bpm)/individual horse’s HRmax (bpm)* × 100%

*Individual horse’s HRmax (bpm) = 240 (bpm)–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 that 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: 5–11 years), performance level (OR range: 115–134), race experience (10–50 races), and race success (Table). 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



Figure 1. Placement of the equinITy™ heart rate monitoring system and girth. Before 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 (A), with the HR unit (yellow sensor) and receiver pocket positioned on the left portion of the barrel behind the horse’s left elbow (B). The HR unit was turned on and placed in the pocket before exercise. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Table
Racing profiles of the horses sampled

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

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.

trainer visually rated all gallop sessions monitored as maintenance (aerobic) workload.

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 ($P > 0.05$; $r = -0.12$, $n = 93$).

Discussion

Racehorse workload (%HRmax), mean speed, and mean SF 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 25 mph (11 m/s) the trainer intended them to work at. SF 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 SF. However, HRM did identify that despite the extensive experience of the trainer, while horses were working consistently, the subjective visual rating of maintenance workload did not correspond to racehorses working within aerobic HR 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 –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 143–161 and horses competing in the class 1, grade 1 Cheltenham Gold Cup in 2018, had a handicap OR range of 156–169. Based on the handicap ratings of the horses and the “test,” an 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 173 bpm for this group of horses), suggested as the lower anaerobic threshold by Vincent et al. (2006), may not represent their actual anaerobic threshold. For racehorses in training for NH racing, an anaerobic

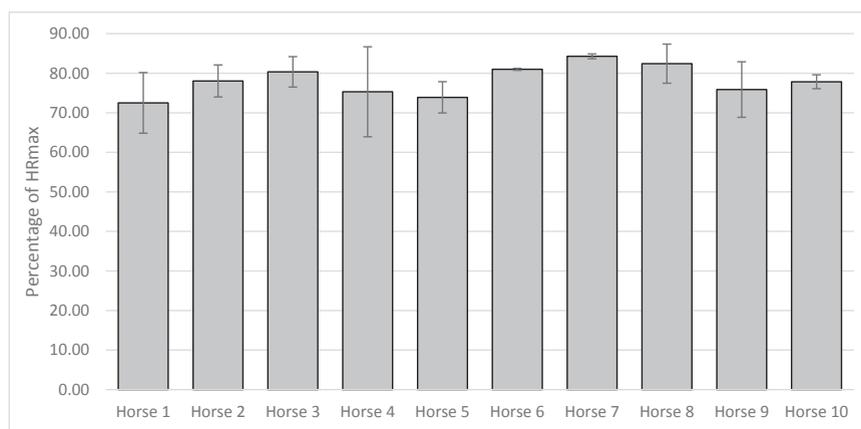


Figure 2. Age-adjusted mean and standard deviation for percentage heart rate maximum (beats per minute) horses were working at, for individual horses across all training sessions. The mean HR of each horse was recorded from the Equinity Technology™ database and was converted into an age-adjusted percentage HR 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.

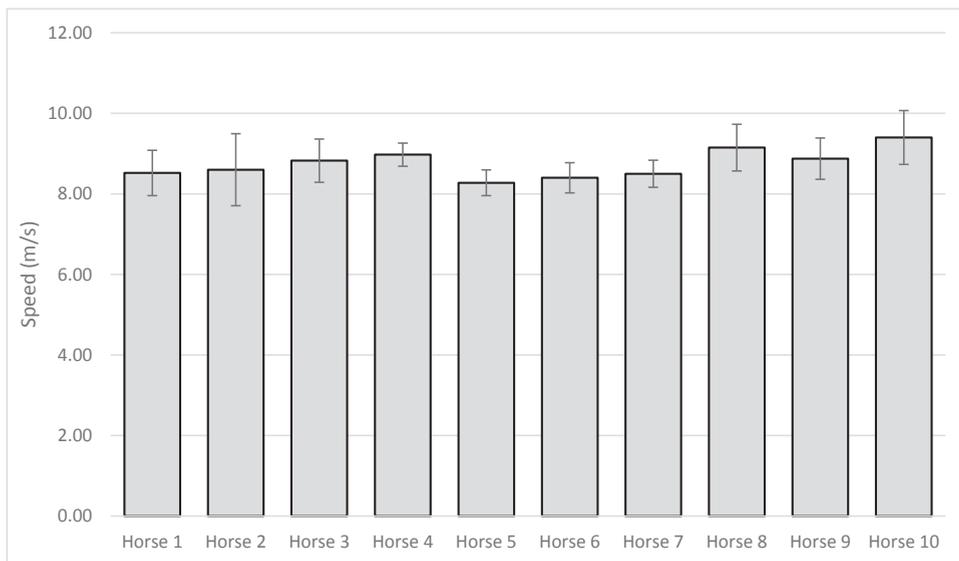


Figure 3. Mean speed and standard deviation (meters/second) for individual horses across training sessions. The mean speed for each gallop for individual horses within training sessions was recorded from the Equinity Technology™ database, then an overall mean and standard deviation for speed was calculated for each horse to compare average speed across the 6-week period evaluated.

threshold rating >80% (Vincent et al., 2006) may be more appropriate. Previous work by Kingston et al. (2006) reported differing HR responses to exercise between individual racehorses at the same training load. Interestingly, in this study, while average speed corresponded to the trainers' speed calculations using a stopwatch, peak speeds differed significantly. The level of fitness was represented by HRmax (Vermeulen and Evans, 2006) 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

acclimatized 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 facilitates 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 (Pritchett et al., 2003). Although HRM can be argued to present a performance advantage through increased knowledge of the horse's physiological fitness, it

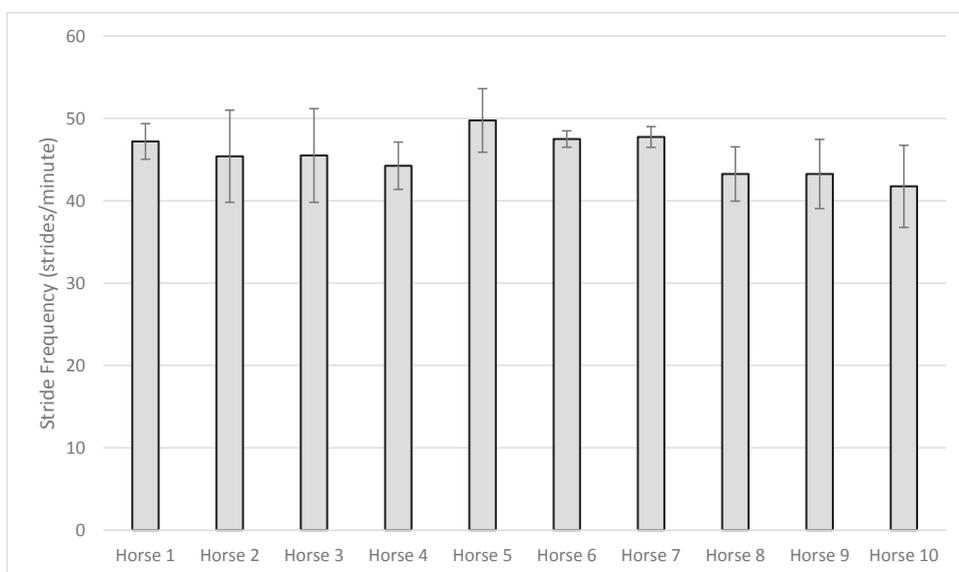


Figure 4. Mean stride frequency and standard deviation (strides per minute) for individual horses across training sessions. The mean SF for each gallop for individual horses within training sessions was recorded from the Equinity Technology™ database, then an overall mean and standard deviation for SF was calculated for each horse to compare average SF across the 6-week period evaluated.

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 standardized 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, 2006). This knowledge could then be used by trainers to implement individualized and evidence-based training regimes which optimize racehorse health, welfare, and performance.

The results of this study suggest HRM 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 HRM systems resulting in them being more portable and affordable, the value of the data obtained and the ease of use via a girth sleeve were viewed positively by the trainer who subsequently purchased the system to use within the trainer's 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 present study. The HR in horses becomes almost entirely sympathetically dominated above ~160 bpm (88% of recorded runs), providing a more reliable indicator of workload as it is minimally impacted by behavior and the horses' anticipating galloping or reacting to the environment they were trained in (Physick-Sheard et al., 2000; Snow et al., 1992). Therefore, given the high proportion of horses' data, which were above 160 bpm, 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 pretraining 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 HR 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.

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Authors' contribution The idea for the article 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 analyzed by Jane Williams, Kieran Kenworthy, and Gillian Tabor. The article was written by Jane Williams, Gillian Tabor, and David Marlin.

Ethical considerations

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.

Conflicts of interest

No conflicts of interest apply to this work.

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