DR. ASHLEIGH VICTORIA MORRICE-WEST (Orcid ID : 0000-0003-2776-4273)
DR. PETA LEE HITCHENS (Orcid ID : 0000-0002-7528-7056)
DR. CHRIS WHITTON (Orcid ID : 0000-0003-0012-4065)

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Training practices, speed and distances undertaken by Thoroughbred racehorses in Victoria, Australia

A. V. Morrice-West[1], P. L. Hitchens[1], E. A. Walmsley[1], M. A. Stevenson[2] and R. C. Whitton*[1]

[1]U-Vet Equine Centre, Melbourne Veterinary School, University of Melbourne. 250 Princes Hwy, Werribee, Victoria 3030, Australia and

[2]Melbourne Veterinary School, Faculty of Veterinary and Agricultural Sciences, The University of Melbourne, Parkville, Victoria, Australia.

*Corresponding author email: cwhitton@unimelb.edu.au

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Summary

Background: Musculoskeletal injuries (MSI) in racehorses are commonly due to bone fatigue, a function of the number of cycles (strides) and the magnitude of load applied to the limb. These parameters can be estimated using speed and distance, with greater than 6,000 m/month at a gallop (>14 m/s), in combination with canter distances greater than 44,000 m/month, reported to increase fracture risk. Despite their importance there are limited data on the distances and speeds horses are exposed to during training.

Objectives: Estimate training volume at different speeds undertaken by Australian Thoroughbred racehorses.

Study design: Cross-sectional study

Methods: Registered trainers (n = 66) in Victoria, Australia were surveyed. Questions were designed to assess the full training workload from initial pre-training to training performed to achieve and maintain race fitness, as well as information on rest periods. Descriptive analyses were stratified by trainer- and horse-level factors, with assessment of variance within and between groups. Cluster analyses were used to identify similar workload intensity groups.

Results: Horse-level factors (age, targeted race-distance) were associated with workload (younger<older, sprinters<stayers). Trainer categorisation did not influence workload, but there was significant variation in volume of total gallop exercise between trainers [median gallop distance 8,000 m/month (IQR 6,400-12,000)]. Cluster analyses identified four workload programs (medians): low-intensity (4,800 m/month), medium-volume (8,000 m/month), medium-volume with a higher proportion of high-speed workouts (12,800 m/month) and high-volume programs (19,200 m/month), with 23%, 50%, 17% and 9% of trainers predominately training racehorses under each of the respective programs. Horses three-years and older were rested twice yearly for 6.3 (95%CI 5.7, 6.8) weeks, with more experienced trainers resting horses for shorter periods ($p = 0.03$).

Main limitations: Possible selection bias, subjective reporting of workloads by trainers.

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Conclusions: Australian Thoroughbred training programs include high volumes of galloping with more than half exceeding previously reported risk levels for MSI.

Introduction

Musculoskeletal injuries (MSI) in Thoroughbred racehorses are a common cause of lost training days, early retirement, and death [1]. The majority are attributable to bone fatigue; the degradation of bone mechanical properties due to repetitive loading [2]. Fatigue is a function of the magnitude of applied load and number of load cycles [3]. An important determinant of the magnitude of load applied to equine limbs is the speed of the gait and the number of cycles is a function of distance travelled [4]. Verheyen *et al.* [5] showed an interaction between canter and galloping distances and found 7,700 bone loading cycles at a canter (up to 14 m/s) in conjunction with 880 loading cycles of galloping (over 14 m/s) per month increased the risk of fracture. However, because bone can adapt to its loading environment, both the total volume of high-speed training and the rate at which the training load is accumulated are important. In human sports medicine, the recent focus for injury prevention has been the balance between acute and chronic workload where a high acute-to-chronic workload ratio, indicative of a rapid increase in workload, is associated with injury [6].

To understand the loading environment of the equine skeleton, quantification of the speeds and distances undertaken by horses in training is required. If variation in training volumes exist, exploration of associated success and injury rates is warranted. Rest periods without training similarly have the potential to influence bone's ability to remodel and repair following intensive training schedules [7]. Identifying current practices is necessary to allow future investigations to determine the most appropriate regimen(s) for reducing injury.

With this background, our objectives were to determine: (1) the volume and variation of training workloads at different speeds; (2) the duration, frequency and variation of rest periods for healthy Thoroughbred racehorses; and (3) to assess for differences across levels of trainer licencing. We hypothesised that there is large

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variation between trainers in the training volumes and rest periods used for horses under their care.

Materials and methods

Study participants

This was a cross-sectional study of registered Thoroughbred trainers Victoria, Australia. The source population comprised all Thoroughbred trainers registered with *Racing Victoria Ltd* (RVL) in 2016-2017 (n = 889)[a]. Victorian trainers are categorised by the type of training licence held: Class A (n = 86), General (n = 418) or Restricted (n = 385) corresponding to most to least experienced (Supplementary Item 1).

Separate *a priori* sample size calculations were performed based on the binary and continuous data collected for two sister studies investigating racehorse management practices. Binary (yes/no) outcome calculations required a higher number of trainers (n = 65; based on activity prevalence of 50% with a power of 0.80, a Type I error probability of 0.05 and an absolute error of 20%), the results of which are presented elsewhere [8]. For the present study, calculations were conducted to determine the number of trainers to sample to reject the null hypothesis that monthly gallop distances across the three trainer groups were equal with a probability (power) of 0.80 and a Type I error probability of 0.05. Our *a priori* estimate of the distance galloped per month was derived from the 'typical Australasian' monthly gallop distance described by Firth *et al*. [9] of 4,800 m. We then consulted industry experts (n = 2) to determine the minimum and maximum plausible monthly gallop distances, given the paucity of published literature in this area. Estimates of the minimum and maximum monthly gallop distances were 1,600 m and 6,400 m, respectively. Assuming the distribution of monthly gallop distance followed a normal distribution our estimate of the standard deviation of monthly gallop distance was (6,400 - 1,600) ÷ 6 = 800 m. We assumed that the monthly gallop distance varied across trainer class with mean monthly gallop distances for Class A, General and Restricted trainers to be 5280 m, 4800 m and 4300 m, respectively. Based on these assumptions, a total of 45 trainers (15 for each trainer group) were required to meet the objectives of the present study.

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Interviews were conducted between November 2016 and August 2017. Training tracks were classified as metropolitan, provincial or country according to their distance from urban areas[b]. An article explaining the project to Victorian trainers was published in "Inside Racing" an official RVL Thoroughbred racing industry publication and in addition, trainers listed in the official registry[a] were contacted via telephone to set up an in-person interview. We made a cross-tabulation of trainers by licence level and training track. The first round of participant selection was through veterinarian and industry personnel recommendations based on likely willingness to participate, with representation of a cross-section of training methodologies and reasonably sized operations. We then consulted our cross-tabulation and weighted the remainder of the trainers to be sampled by the underrepresented trainer licence level-training track combinations. A random number generator was used to pick the remaining trainers to be contacted from the official trainer registry. Multiple trainers at all major training centres in Victoria were selected (i.e. all metropolitan and provincial training tracks) as well as trainers from regional areas. All trainers who agreed to participate were interviewed. Where a face-to-face interview was not possible, the survey was conducted via telephone (n = 2). Interviews were arranged within one month of the date of agreeing to participate. All interviews were conducted by the first author (A.M.W.).

Survey

Trainer responses were recorded in a custom designed form (Supplementary Item 2)[c]. Trainers were asked to provide details about stable management, pre-training arrangements, training regimens and typical rest periods. Trainers were specifically asked about intended workout and rest practices for healthy horses in the absence of injury or other training limiting factors. Pre-training was classified as the period of initial training for young horses to walk, trot and canter under saddle with control and reasonable fitness, and for initial fitness for older horses following a rest period.

Speed categories: Slow-speed workouts typically consisted of trot and cantering at <10 m/s, but also include trail rides, lungeing, walkers, treadmills and/or swimming. Speed categories for fast workouts were based on trainers' descriptions (Supplementary Item 3) in seconds per furlong (s/f). A slow gallop ('even time') or 15

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s/f, equates to 13.33 m/s. Speeds of fast gallop increase from that point, with trainers generally describing speeds of 14½, 14, 13½, 13, 12½, 12, 11½, or 11 s/f (13.3-18.2 m/s).

Data analysis

Data analyses were conducted using Stata 15.0[d]. Keyword searches were manually performed for questions on training program design and rest period rationale that were answered in free-text format (Supplementary Item 1). Count data (the number of trainers undertaking a particular practice) are presented as the number of trainers out of the total (n = 66 unless otherwise specified). Continuous variables were assessed for normality using frequency histograms and the Shapiro-Wilk test. Data were reported as mean, standard deviation (s.d.) and 95% confidence-intervals except when they were non-normally distributed (median, interquartile ranges and minimum-maximum). Descriptive statistics for each outcome variable were stratified by horse-level (age, targeted race distance) and trainer-level characteristics (trainer licence category, size of training yard, region).

In most situations, trainers preferred to provide their response to a given question (e.g. 'For what period of time do you rest your horses in work?') as a range rather than as a single numeric value. Where trainers provided their response as a range, we calculated an expected mean and expected standard deviation for the variable, assuming the variable was consistent with a normal distribution. For each horse within each stable we took a random draw from this specified distribution, providing a credible estimate of the variable for each individual horse. A trainer mean was then calculated using the vector of individual horse random draws. We reasoned that this approach was necessary (in preference to simply taking the mid-point of the range of reported values) because it allowed for inherent variability in the stable-level mean where the number of horses per stable was small. Training-yard makeup of horse-ages was obtained using RVL's horse and trainer profiles on 7/8/2017[a]. Reported pre-trial workloads were divided into two-year-old and mature horse programs (three-years and above). Race-fit programs were categorised according to age, targeted race distance and horses considered superior performers by the trainer. Seven broad types of galloping programs for race-fit horses are commonly used in the

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Australian racing industry; two-year-old (Type 1); three- to five-year-old (Type 2); horses six-years and older (Type 3); sprint race <1300 m (Type 4); middle-distance 1301-2100 m (Type 5); staying race >2100 m (Type 6), and elite horse (Type 7). With a study population of 66 trainers and the six types of programs for mature race-fit horses (excluding two-year-olds), 379 trainer-program combinations were present, compared with a theoretical maximum of 66 × 6 = 396 trainer-program combinations.

Differences between groups were assessed by linear regression or Kruskal-Wallis equality-of-populations rank test according to data distribution. Variance within groups (and therefore variation between individual trainers) was assessed using Brown and Forsythe's F statistic (median).

To assess grouping of trainer programs across the study population, cluster analysis was performed using k-means or medians [10]. Three separate analyses were performed according to age and stage of preparation ([1] pre-trial two-year-old programs; [2] pre-trial three-year-old and above programs; and [3] maintenance [race-fit] programs of mature horses). For our cluster analyses, where the trainer did not report undertaking exercise in a given speed category, we recorded this as zero metres. Variables relating to workloads were chosen for input into the cluster analysis through forwards and backwards selection to identify significant determinants of the cluster structure. Dendrograms (see example Supplementary Item 4) were used to identify clusters of training groups. A series of dendrogram analyses were carried out where the number of candidate clusters was serially increased, with the most appropriate number of training group clusters assessed visually [11,12].

Each of the six mature horse race-fit programs in use for each of the n = 66 trainers were tabulated. A series of univariable multilevel, ordered logistic regression models were developed where the outcome of interest was the training group cluster (a four-level categorical variable) and, for each model, the explanatory variable was one of the trainer- or program-level factors listed in Supplementary Item 5. In each model a zero-mean, Gaussian distributed random intercept term was included to account for lack of independence in the data arising from race-fit program types clustered within individual trainers. All assessed explanatory variables satisfied the proportional odds

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assumption, except for whether or not a trainer had two-year-olds in work [13]. The contribution of the unobserved trainer-level effects to the total unaccounted-for variation in the data (the intraclass correlation coefficient, ICC) was calculated as $\sigma_T^2 \div (\sigma_T^2 + \pi^2/3)$ where σ_T^2 represents the estimated variance of the trainer-level random effect term [14].

To allow us to make general statements about the most common mature race-fit horse training regimens (cluster) used by each trainer, the number of horses in each program type by trainer (N_p) was estimated by multiplying the reported proportions of stable make-up (horse program types; *n* = 6) by the number of horses in each age group obtained from the official repository. A trainer's estimated number of horses assigned to each of the four clusters (N_c) was calculated by summing the N_p for each cluster group. The cluster group with the highest number of assigned horses (N_c) was then determined to be the most common workload group for that trainer.

Results

Study group

Sixty-six trainers with 1,720 horses in training at the time of interview, were surveyed. Participating trainers were recruited predominately based on veterinary or industry personnel recommendation (*n* = 15 and 36, respectively), with the remaining 15 trainers selected at random from the registry. Participants included 19 Class A, 24 General, and 23 Restricted trainers (of the population of 86, 418 and 385 trainers, respectively) that used 19 metropolitan, 36 provincial and 11 country training tracks. Trainers had a median of 18 horses in training at the time of survey [IQR 4-35; range 0-190 (trainers could have zero horses in work at the week of interviewing e.g. single horses on a rest break, but still have a starter for the season to maintain their licence)], compared to the average number of individual starters (8,752 horses) by each trainer in Victoria of 10. This included a median of three two-year-olds (IQR 1-10), 13 three- to five-year-olds (IQR 3-21), and 15 horses six-years of age or above (IQR 4-24).

Pre-training programs

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Fifty-six percent (37/66) of trainers performed their own pre-training. A further 16 (24%) pre-trained the majority (at least 90%) of horses in their care, whereas 13 trainers (20%) predominately used external pre-trainers. Time in pre-training for two-year-olds ranged from two to eight weeks (mean 4.5; 95%CI 4.1, 4.9), generally not achieving speeds above canter (<10 m/s).

For horses older than two-years, 60% of trainers reported immediate re-entry to the training stable following a rest period, 24% reported an interim two to four-week preparation phase, and 16% reported greater than four-week preparatory phase during which horses typically exercised up to canter (<10 m/s).

Slow workouts

Horses performed slow-workouts a median of six days/week (range 4-7 days/week for two-year-olds, 5-7 days/week for mature horses). Fourteen (21%) trainers included one day of swimming and/or exercise on mechanical walkers rather than slow-workouts under saddle.

Ten trainers provided details on the slow-workout distances and generally did not differentiate distances of trot versus canter. For two-year-olds, the median distance of slow-workouts per month was 60,000 m (IQR 57,200-74,400) and 73,200 m (IQR 62,400-90,750) for mature horses. Older horses (16/66; 24% of trainers), colts (4/66; 6%), horses described to be ‘heavy’ or ‘overweight’ by the trainer (8/66; 12%), and stayers (14/66; 21%) were reported to undertake greater distances than younger, lighter horses, fillies and sprinters. There were insufficient numbers of responses to stratify slow work distances by trainer category. For pace work (11.1-12.5 m/s) median reported distances per month were 1,600 m (IQR 1,200-3,200; n = 4) for two-year-olds, mature horses 5,200 m (IQR 2,400-8,640; n = 17) and older horses 4,400 m (IQR 3,200-9600; n = 10).

Fast workouts

Trainers provided 24 distinct reasons as rationale for the distance and speed of each training session. Age and race distance were commonly reported by trainers as important in training program design (32% and 24% of trainers, respectively),

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therefore the results are stratified by these factors. Other common factors result in individual tailoring to the horse which included performance in previous workouts (24/66; 36%), recovery from workouts (19/66; 29%) and demeanour (15/66; 23%), followed by previous injuries (13/66; 20%), weight (11/66; 17%), appetite (8/66; 12%), level of fitness (8/66; 12%), and upcoming races (7/66; 11%). Twenty-five trainers (38%) reported specifically tailored programs, ten (15%) standardised and 25 standardised with horse specific minor adjustments (38%). Seventeen trainers (26%) reported that they started all horses with a standardised program (of which 11 also reported individual adjustments by horse).

Two-year-olds fast galloped a mean of 1.7 times per week (95%CI 1.5, 1.8). Eight trainers (12%) never galloped two-year-olds. Horses older than two-years of age were galloped a mean of twice per week (95%CI 1.8, 2.2).

Ten trainers (15%) did not allow two-year olds to participate in trials. Of the 85% of trainers who trialled two-year-olds (56/66), 33% reported they would not subsequently race those horses as two-year-olds. For trainers who reported participating in trials and/or racing of two-year-olds, 88% of their horses were expected to trial and 50% to race.

Progressive program to trial fitness: Two-year-old horses that trialled took a mean of 10.5 (95%CI 9.7, 11.2) weeks to reach trialling stage from paddock fitness, including a mean of 4.6 (95%CI 4.1, 5.0) weeks of an initial slow-workout phase. Horses three-years and older took a mean of 9.5 (95%CI 9.0, 9.9) weeks to trial, including a mean of 4.0 weeks (95%CI 3.7, 4.3) of an initial slow-workout period. The slow phase generally commenced with speeds up to 11.8-13.2 m/s, followed by introduction of slow gallops at 13.3-14.3 m/s with gradual increases in speed and distance in preparation for trialling. Gallop programs typically included early stages of 13.3-14.3 m/s, with a mid-stage introducing 'improving speed gallops' at 14.4-15.4 and/or 15.5-16.7 m/s, followed by a late stage adding in gallops of 15.5-16.7 and/or ≥16.8 m/s as horses became fit enough to trial. From the end of the initial slow-workout stage to trial, two-year-olds accumulated a mean of 6,500 m (95%CI 5,500, 7,500) of gallop workouts, or 1,200 m per week over a mean of 5.7 weeks (SD.1.9). By increasing categories of speed this equated to a mean of 4,300 m (95%CI 3,500, 5,000) at

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13.3-14.3 m/s, 2,100 m (95%CI 1,600, 2,500) at 15.5-16.7 m/s and 200 m (95%CI 100, 300) at ≥16.8 m/s.

For preparation of two-year-olds for trialling, there were three clusters of programs (in addition to the subset of trainers who avoided fast workouts and/or trialling, Supplementary Item 6, and program glossary Supplementary Item 7): (1) 'high-volume over extended time' had the highest cumulative gallop distance (≥13.3 m/s) over the longest preparatory period (*n* = 7); (2) 'moderate programs' had an intermediate duration of fast training and trial preparation, with a moderate overall gallop distance cumulating over the program (*n* = 23); and (3) 'fast and light' trainers had the shortest duration in fast training and shortest preparation before trialling with the lowest cumulative gallop distances ≥13.3 m/s (*n* = 26); Fig 1.

Cumulative program distances prior to trialling were higher for horses three-years and over compared with two-year-olds in each speed category, and for combined speeds ≥13.3 m/s (approximately 40% greater total gallop distance, $p \leq 0.05$) (Supplementary Items 6 and 8), excluding 14.4-15.4 m/s, for which there were too few reported values in the two-year-old group. Horses three-years of age and older galloped a mean of 9,700 m (95%CI 8,400, 11,000) during the fast training phase approaching trialling (5.9 weeks), averaging 1,800 m per week over the program. This equated to a mean of 6,300 m (95%CI 5,200, 7,400) at 13.3-14.2 m/s, 100 m (95%CI 0, 100) at 14.4-15.4 m/s, 3,100 m (95%CI 2,600, 3,600) at 15.5-16.7 m/s and 300 m (95%CI 0, 500) at ≥16.8 m/s. Programs for horses aged three-years and older were similarly clustered into three types of progressive program workloads; high-volume with slower speed galloping, moderate, and fast and light (Supplementary Item 8). There was less program variation in total time to trial and time in fast training compared to two-year-olds.

Race-fitness workloads: Reported racing frequency was a mean of 2.3 weeks between starts (95%CI 2.1, 2.4). Total monthly galloping distances (≥13.3 m/s) for a fit racehorse was a median of 8,000 m and varied according to trainer and horse level factors (Table 1). General trainers had greater variance in training distance for all gallop speeds ($p = 0.03$). At 13.3-14.3 m/s, provincial trainers reported lower monthly distances than metropolitan or country trainers (χ^2 9.8; 2 *df*; $p<0.01$).

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Metropolitan trainers had higher monthly distances for speeds of 14.4 to 16.7 m/s ($p<0.01$) but provincial trainers had the highest distance of race speed gallops (≥16.8 m/s, $p<0.01$).

Two-year-olds were trained over shorter distances compared to mature horses over all speeds (Table 1; $p<0.01$). Within each age category there was a large spread of distances worked ($p<0.01$). Differences in distance travelled between sprinters, middle distance horses and stayers were greatest for slow-speed gallops (13.3-14.3 m/s; $p<0.001$). For fast galloping (>14.3 m/s) there was no difference between these groups of horses. The spread of distances within sprinters, middle distance and stayers was also different ($p<0.01$), with greater variations between trainers as race distance increased across all speed categories except race speed gallops (≥16.8 m/s).

Cluster analyses performed across 379 mature race-fit programs identified four distinct workloads (Table 2), with frequency of galloping increasing for each cluster: (1) low-volume programs (n = 90; 24%); (2) medium-volume programs (n = 173; 46%); (3) medium-volume programs with greater high-speed workouts (n = 76; 20%); and (4) high-volume programs (n = 50; 11%). Fifty trainers (76%) had at least one program in cluster (1), 37 trainers (56%) in cluster (2), 31 (47%) in cluster (3) and 18 (27%) in cluster (4). Three- to five-year-old horses tended to be within the low- and medium-volume cluster. Older horses were most commonly in the medium-volume, with programs also in the low and medium with greater high-speed exercise intensity clusters, but rarely the high volume (5%). The high-volume cluster contained the highest number of stayer programs, though programs for stayers were evenly distributed across all except the low-volume group. Sprinters tended to be within the first two clusters (low- or medium-volume) and middle-distance horse programs across all four, but predominantly in the two medium-intensity groups. Clustering for volume of training for elite horses were distributed similarly to basic maintenance-programs, however there were limited numbers of trainers with elite horses.

The proportion of unaccounted-for variation in the data attributable to the trainer was 69% (95%CI 57, 78). Trainer factors were not associated with workload clustering

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(Supplementary Item 5). The proportion of programs within clusters increased from low to high-volume as targeted race distance increased (p<0.001).

The main clusters [(1)-(4), low-volume through to high-volume] in which each trainers' programs predominately fell, weighted by the distribution of horse types in each training stable, were 15 (23%), 32 (50%), 11 (17%) and six (10%), respectively. An additional two trainers had an even distribution across a combination of two to three clusters.

Rest periods

The rationale for rest periods was typically made by individual horse rather than a set regimen. The most common reasons for resting were a change in horse demeanour (36/66; 55%), reduced racing or training (22/66; 33%) performance, poor appetite (17/66; 26%), seasonal horse preferences for track surface hardness (14/66; 21%), preparation for future campaigns (13/66; 20%), physical fatigue (9/66; 14%), for growth and skeletal development (9/66; 14%), lack of appropriate races (6/66; 9%) or loss of condition (5/66; 8%). As trainer licensing-level decreased, rest periods lengthened for mature horses (p = 0.03) and two-year-olds (p = 0.06; Table 3). Two-year-old rest periods were longest for country trainers compared to provincial and to metropolitan trainers (p = 0.02).

Discussion

Thoroughbred trainers surveyed for this study reported relatively large volumes of monthly galloping exercise in the horses under their care with two-year-olds undergoing less total gallop distance than older horses, and sprinters less than stayers. We identified four levels of training intensity; horses in the highest volume group undertook four times the gallop distance of those in the lowest volume group. Higher classed trainers rested horses for shorter periods of time, and country trainers, for longer periods.

Trainers reported high monthly distances at all speeds. Comparison with international findings is difficult due to the lack of consistency in reporting of training speeds. Firth *et al.* [9] described a typical Australasian two-year-old monthly regimen

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of 63,200 m canter (8.9 m/s) and 4,800 m at 'gallop' (~14.6 m/s), a similar distance of canter but lower gallop distance than trainers reported in this study. USA studies reported 19,300 m 'jogging' (5 m/s), 28,400 m 'galloping' (11 m/s), and 1,000 m 'breezing' (15-16 m/s) per month, and based on GPS recordings 2,130 m per session (23,004 m per month) at >8 m/s [15,16]. Although not directly comparable, Australian trainers report substantially greater monthly distances at all speeds. Studies in the UK report 26,800 m/month slow-speed exercise (≤14 m/s) and 2,800 m galloping (>14 m/s) [5], each of which are considerably lower than reported by Australian trainers. Similarly, two-year-olds in the UK are reported to undertake 4,200 m/week at ≤13.4 m/s and 380 m/week at >13.4 m/s [17], less than Australian two-year-olds.

The rate of introduction of speeds above 13.3 m/s has been proposed as a risk factor for MSI [18]. There are, however, limited data on training programs transitioning horses from rest to race-level fitness. A twelve-week period has been detailed, from beginning training to first trial for two-year-old horses in New Zealand (NZ) of three stages; slow canter (weeks one-four), faster-canter (9 m/s, weeks five-eight), and then the introduction of biweekly galloping from week nine [13]. We report a slightly shorter time to trial (10 weeks, including four weeks initial slow phase). Also, in the current survey Australian two-year-olds undertook some fast workouts in the lead up to trial, compared to NZ where there was minimal or no galloping exercise of 13.3 m/s and above [19]. UK regimens are reportedly longer compared to those described here, with slow-speed training phases of three months and longer, particularly for two-year-olds in training [20]. Conventional timeframes for a nine-week program in the USA includes the introduction of fast breezing (15-15.8 m/s) from the seventh week [20].

We observed significant variation in prescribed workload between trainers. Comparison with other studies is difficult because wide ranges in workload will be reported when examining a population of horses where individual animals can influence the extremes and horses are not stratified by type. For example, UK horses showed a range of zero to 82,400 m and zero to 17,700 m per month of canter and gallop, respectively [5]. In our study, the unaccounted-for trainer-level variation in the intercept only model (that did not include explanatory variables) was 69% of the total

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variation. However, when the designated horse program (targeted race distance) was included as a fixed effect, the proportion of unexplained variation increased to 82%. This is likely because the variation in distance exercised within a designated horse program increased as the intended race distance increased, as shown in Table 1.

We found that trainers rest horses on average twice yearly for short time periods. A previous Australian study also found that two-year-olds spend longer resting than older horses [21]. New Zealand trainers report resting horses less frequently (once a year) but for longer (median 8.7 weeks) [22]. Rest period frequency and duration depend on trainer and horse factors, but also on climate, racing seasons and availability of spelling facilities. For example, the Hong Kong racing season includes a mandatory two-week break with otherwise year-round racing [23]. In previous studies it is difficult to distinguish between voluntary and involuntary (e.g. due to injury) rests, and methods of data collection are not consistent with some derived from trainer data and others estimated from breaks between race events. In NZ it is reported that horses spend approximately 30% of their time resting, but less than 50% of rest periods are voluntary [24].

More than 10% of trainers avoided training gallops for two-year-old horses. This is despite evidence of benefits in career longevity and a protective effect of galloping on fracture risk [5,25]. It has been demonstrated that high-speed workouts, over short distances in a training environment, stimulates appropriate adaptation of bone for future racing [15]. Our findings are consistent with those from NZ where only 50% of two-year-olds were in active training and 20% intended to race at that age [22]. Of trainers participating in two-year-old trials that we surveyed, all exposed their horses to some fast gallop workouts in the lead up to trialling.

Categories of trainer were not associated with cluster grouping suggesting that there are factors other than region, size of stable or trainer licence that influence individual trainers' decisions on appropriate regimens. This is supported by findings of an Australasian study of two-year-old musculoskeletal injuries where differences in distances between trainers were present after accounting for all study factors [18]. The only exception was a trend for country trainers' programs to belong to the lowest

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three volume groups rather than the high-volume group. We did not identify any change in training practices with increasing trainer licence-level. We speculate that this lack of convergence with increasing trainer experience or in the higher profile metropolitan training centres over time indicate that training volumes may have limited effect on success, warranting further investigation. Others have found both low- and high-volumes of training are associated with poorer performance in individual horses [26].

Investigations of associations between training volumes and MSI indicate a complex relationship with both low- and high-volumes of high-speed training associated with increased MSI risk [5,27-29]. This is consistent with a bone fatigue model of injury in that an optimum amount of high-speed exercise is required for appropriate adaptation of the skeleton to racing without exceeding the fatigue life of the bone [2]. Many injuries develop gradually and it is challenging to differentiate between forced reductions in workload due to injury and planned training levels. By exploring how trainers intended to train their horses in the absence of restricting factors we avoided the confounding effect of injury. There are no data on the association of MSI with training volume under Australian conditions however in horses trained in the UK exceeding 44,000 m at canter and 6,000 m at gallop per month increases the risk of fractures [5]. Differences in speed definition make it difficult to compare the slower speed training however our second gallop speed category onwards (14.4 m/s) are similar to the reported UK gallop speeds (>14 m/s). By combining the medians of these speed categories, at least 50% of Australian trainers have horses exceeding the galloping 6,000 m/month risk point. Despite the high volume of galloping we have identified, fatal MSI rates in Australia are lower than in the UK [1,30]. Focussing solely on total workload is simplistic as it is not the only training management factor that may influence injury. The rate of workload increase is also likely to be important as found in human athletes [6]. In addition, the proportion of time resting from training will influence the bone repair process [6,7]. Reasons for lower catastrophic injury rates in Australia compared with the UK could include shorter duration of training periods, more rest periods, better adaptation to high work-loads by commencement of galloping at a younger age or by the methods used to introduce horses to fast exercise over time.

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Resting horses from race training enhances bone repair through remodelling but also may increase the risk of injury when horses return to training due to the resultant increased porosity of their bone [7,31]. Longer time periods in training without rest has been shown to be a risk factor for third metacarpal condylar fractures, and longer periods of rest are associated with lower grade of subchondral bone injury in the distal metacarpus [32,33].

Limitations of this study include a possible selection bias as trainers with a desire to understand the effects of their workloads may have been more willing to participate. We targeted larger stables in the first phase of sampling, and therefore our median number of horses in training was higher than the state average (18 *vs* 10), and our proportionate number of Class A trainers was higher than the other classes. The study population was therefore likely to be more representative of more intensively managed horses compared to the general population. Even though we explicitly asked about rest periods in the absence of injury or illness, we cannot be certain that horses were not unknowingly affected by subclinical or undiagnosed issues. Speeds that trainers report and the speeds actually achieved may differ, and manual records of gaits or approximated speed workouts are potentially inaccurate when compared with calculated recording data [34]. There were a multitude of reasons provided for tailoring workout plans and rest practices to the individual horses but it was our purpose to determine general practices by trainers rather than what each individual horse might achieve, to enable characterisation of training loads that are not clouded by the effects of injury or other limitations. Some trainers described responses in a range which may indicate that they are tailoring to individual horse needs and although we attempted to estimate a mean individual value there may be inaccuracy in our data as a result. Further validation is required through more advanced technological recording methods on individual horses and investigations into the effect of adjunctive exercise means requires further examination.

Conclusions

This study provides baseline information on training practices for Thoroughbreds in Australia and showed a wide variation in the volume of workloads across all categories of trainer. There is a need for more detailed research to improve

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understanding of the interaction between workloads, performance and injury, and effective communication of findings to industry stakeholders. Our findings demonstrate that there is considerable opportunity to modify training volumes with potential implications for the industry given the costs involved in training horses and the risks to riders and horses alike.

Authors' declaration of interests

No competing interests have been declared.

Ethical animal research

Approval was obtained from the Faculty of Veterinary and Agricultural Sciences Human Ethics Committee at the University of Melbourne (reference 1647911.1).

Owner informed consent

Data from individual animals were not collected. Participating trainers consented to their inclusion of their data in the study.

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Authorship

All authors contributed to the study design, preparation of the manuscript, and final approval of the manuscript. A. Morrice-West was responsible for the study execution.

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A. Morrice-West, P. Hitchens and M. Stevenson contributed to data analysis and interpretation.

Manufacturers' addresses

[a]Racing Victoria Limited 2017, www.racing.com

[b]Racing Australia Limited 2017, www.racingaustralia.horse

[c]SI. SurveyMonkey. San Mateo, California, USA.

[d]Stata Statistical Software, StataCorp LLC, College Station, Texas, USA.

Figure legend

Fig 1: Example of programs of progressing gallop workloads of two-year-old Thoroughbred racehorses as they approach trialling in Victoria, Australia. Each plot represents an example of an individual trainer's program in each of the three clusters of workload volume and intensity, where time at zero weeks indicates entry into work following a paddock (or equivalent) rest period. Groups of workload intensity represent: (1) High volume workload over extended time-period; (2) Moderate program and (3) Fast and light workload.

Supplementary Information

Supplementary Item 1: Supplementary methods.

Supplementary Item 2: Survey proforma.

Supplementary Item 3: Australian Thoroughbred speed terminology.

Supplementary Item 4: Cluster group diagram.

Supplementary Item 5: Ordered logistic regression of trainer and designated horse-program factors to clustered training intensity.

Supplementary Item 6: Progressive programs to trial (two-year-olds).

Supplementary Item 7: Training program glossary.

Supplementary Item 8: Progressive programs to trial (mature age).

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TABLE 1: Monthly gallop distances by speed for horses of ages three-year old and above at race-level fitness, according to trainer and horse factors from n = 66 trainers in Victoria, Australia.

	Median (IQR) distance galloped per month (m) at incremental gallop speeds (m/s)				Combined speeds[1]
	13.3-14.3 m/s	14.4-15.4 m/s	15.5-16.7 m/s	≥16.8 m/s	(≥13.3 m/s)
Total Cohort	4000(2400-6400)	1600(1600-3200)	2400(1600-3200)	2400(1600-4000)	8000(6400-12000)
Trainer Factors					
Licence category					
Class A	4,800(2,400-6,400)	4,000(3,200-4,800)	2,400(1,600-3,200)	2,400(1,600-4,800)	8,000(6,400-11,200)
General	4,800(1,600-7,200)	2,400(800-10,000)	3,200(1,600-4,800)	1,600(1,600-4,800)	9,600(6,400-12,800)
Restricted	4,000(2,400-4,800)	1,600(1,600-1,600)	2,400(1,600-3,200)	2,400(1,760-2,800)	8,000(6,400-11,200)
KW p-value[2]	0.724	0.0068	0.8209	0.5143	0.1388
BF p-value[3]	0.0052	0.0000	0.0000	0.0292	0.0000
Region					
Metropolitan	4,800(3,200-7,200)	4,800(3,200-10,000)	3,200(1,600-4,000)	1,600(1600-3,200)	8,000(6,400-12,000)
Provincial	3,200(2000-5,600)	1,600(1,600-2,000)	2,400(1,600-3,200)	2,400(1,600-4,800)	8,000(6,400-12,000)
Country	4,800(3,200-6,400)	1,600(1,600-1,600)	2,400(1,200-4,800)	800(800-800)	8,000(6,400-9,600)
KW p-value	0.0076	0.0006	0.0214	0.0496	0.192
BF p-value	0.5298	0.0000	0.0000	0.0081	0.0000
Number of horses in work					
1-5	4,000(2,400-6,400)	1,600(1,600-1,600)	2,400(1,600-3,200)	2,400(1,120-2,400)	8,000(6,400-12,000)
6-20	4,800(2,400-7,200)	2,400(800-2,400)	3,200(1,600-4,800)	4,800(3,200-4,800)	8,000(4,800-11,200)

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21-30	3,200(1,600-4,800)	10,000(10,000-10,000)	3,200(1,600-3,200)	1,600(1,200-1,600)	8,000(4,800-10,800)
31-50	4,800(3,200-6,400)	4,000(3,200-4,800)	2,400(1,600-3,200)	1,600(1,600-2,800)	8,000(6,400-9,600)
51+	4,800(1,600-6,400)		3,200(1,600-4,800)	1,600(1,600-4,800)	9,600(6,400-12,000)
KW p-value	0.1034	0.0014	0.0586	0.0287	0.0001
BF p-value	0.8947	0.0000	0.0000	0.0053	0.0000
Horse Factors					
Age (Years)					
2	3,200(1,600-4000)		1,600(1,600-3,200)	1,600(1,120-2,400)	6,400(4,800-8,000)
3-5	4,800(2,400-7200)	1,600(1,600-3,200)	2,400(1,600-3,600)	2,400(1,600-4,800)	9,600(6,400-12,800)
6+	4,800(3,200-6400)	1,600(1,200-5,800)	3,200(1,600-4,800)	2,400(1,600-4,800)	9,600(6,400-11,200)
KW p-value	<0.001	0.6	0.001	0.03	<0.001
BF p-value	<0.001	<0.001	<0.001	0.4	<0.001
Desired race distance					
Sprinter	3,200(1,600-4,800)	2,000(1,600-2,400)	2,400(1,600-3,200)	2,400(1,600-3,200)	8,000(6,400-9,600)
Middle Distance	4,800(3,200-7,200)	1,600(1,600-2,400)	3,200(1,600-4,000)	2,800(1,600-4,800)	9,600(8,000-12,800)
Stayer	7,600(3,600-9,600)	3,200(2,400-4,000)	3,200(1,600-4,800)	3,600(1,600-4,800)	12,800(9,600-16,000)
KW p-value	<0.001	0.2	0.2	0.5	<0.001
BF p-value	0.001	<0.001	<0.001	0.6	<0.001

[1]Combined speed column was derived from all raw data inclusive of Speed Categories 1-4, i.e. all gallop workouts at speeds of 13.3 m/s and above (therefore not a simple summation across columns.)

[2]Differences between groups were assessed by Kruskal-Wallis equality-of-populations rank test, with corresponding p-values reported here (KW).

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[3]Variance within groups was assessed via Brown & Forsythe's F statistic (median) with corresponding p-values reported here (BF).

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TABLE 2: Cluster analysis generated groups of gallop training programs of mature Thoroughbred racehorses (≥three-year-old) at race-level fitness from n = 66 trainers in Victoria, Australia.

Program Group[1]	Program Description	Time between starts [weeks; mean(s.d.)]	Frequency of fast work [gallops per week; weeks; mean(s.d.)]	Distance per month [m; median (IQR)], by speed of galloping (m/s)				
				13.3-14.3 m/s	14.4-15.4 m/s	15.5-16.7 m/s	≥16.8 m/s	Combined speeds (≥13.3 m/s)
1	Low-Volume programs	2.15(0.42)	1.43(0.52)	1,600(0-2,400)	1,600(1,200-1,600) [2]	2,400(1,600-4,000)	1,600(1,600-3,200) [2]	4,800(3,600-5,600)
2	Medium-Volume programs	2.39(0.64)	1.98(0.34)	4,800(3,200-4,800)	1,100(1,100-1,100) [2]	3,200(3,200-4,800)	2,400(1,600-4,800) [2]	8,000(8,000-9,600)
3	Medium-Volume programs with greatest high-speed workouts	2.23(0.6)	2.11(0.44)	8,000(6,400-9,600)	2400(1,600-10,000) [2]	4,800(2,400-6,000)	4,800(3,200-5,400) [2]	12,800(11,200-14,400)
4	High-Volume programs	1.97(0.39)	2.8(0.37)	12,000(11,200-14,200)	2,400(2,400-2,400) [2]	4,800(3,200-7,200)	2,400(1,600-4,800) [2]	19,200(16,800-19,200)

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[1]Workload intensity groups were generated via k-medians according to frequency of galloping and racing, type of racing participated in and cumulative monthly gallop distances.

[2]For speed categories of 14.4-15.4 and ≥16.8 m/s, median gallop distances were zero [0(0-0)]. This was due to the low number of trainers reporting typically training at these speeds (therefore calculated as zero reported metres). To better demonstrate the range of data, the median and inter-quartile ranges were therefore recalculated with zero excluded for 14.4-15.4 m/s and ≥16.8 m/s to be displayed here. Cluster analyses were conducted according to raw data unadjusted data.

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TABLE 3: Rest periods frequency and duration in Thoroughbred Racehorses in training in Victoria, Australia, by horse age and trainer factors from n = 66 trainers [mean(s.d.)].

		Two-year-olds		Mature Horses (Three-years and above)	
	Number of contributing trainers (%)	Frequency of rest-periods (rests/year)	Length of rest-period (weeks)	Frequency of rest-periods (rests/year)	Length of rest-period (weeks)
Total Cohort		2.1(0.9)	6.6(2.5)	1.9(0.7)	6.3(2.4)
Licence category					
Class A	19(28.8%)	2.2(0.7)	5.5(1.4)	2.1(0.5)	5.5(1.6)
General	24(36.4%)	1.8(0.9)	6.7(2.3)	1.7(0.8)	6.0(2.3)
Restricted	23(34.9%)	2.2(1.0)	7.4(3.1)	1.7(0.8)	7.3(2.6)
p-value		0.3	0.06	0.33	0.03
Region					
Metropolitan	19(28.8%)	2.3(1.1)	6.1(1.8)	2.1(0.6)	5.9(2.1)
Provincial	36(54.6%)	2.2(0.7)	5.5(1.4)	2.1(0.5)	5.5(1.6)
Country	11(16.7%)	2.0(0.9)	8.6(3.3)	1.9(0.9)	6.8(2.5)
p-value		0.51	0.02	0.36	0.56
Number of horses in work					
1-5	18(27.3%)	2.1(0.8)	7.3(2.9)	1.9(0.7)	7.4(2.7)
6-20	18(27.3%)	1.6(0 .9)	6.9(2.6)	1.5(0.7)	6.7(2.6)
21-30	11(16.7%)	2.2(0 .9)	6.3(2.44)	2.2(0.8)	5.2(2.0)
31-50	11(16.7%)	2.3(0.5)	5.8(2.4)	2.1(0.5)	5.4(1.5)
51+	8(12.1%)	2.7(1.1)	6.1(0.9)	2.1(0.5)	6.2(1.5)
p-value		0.06	0.56	0.04	0.09

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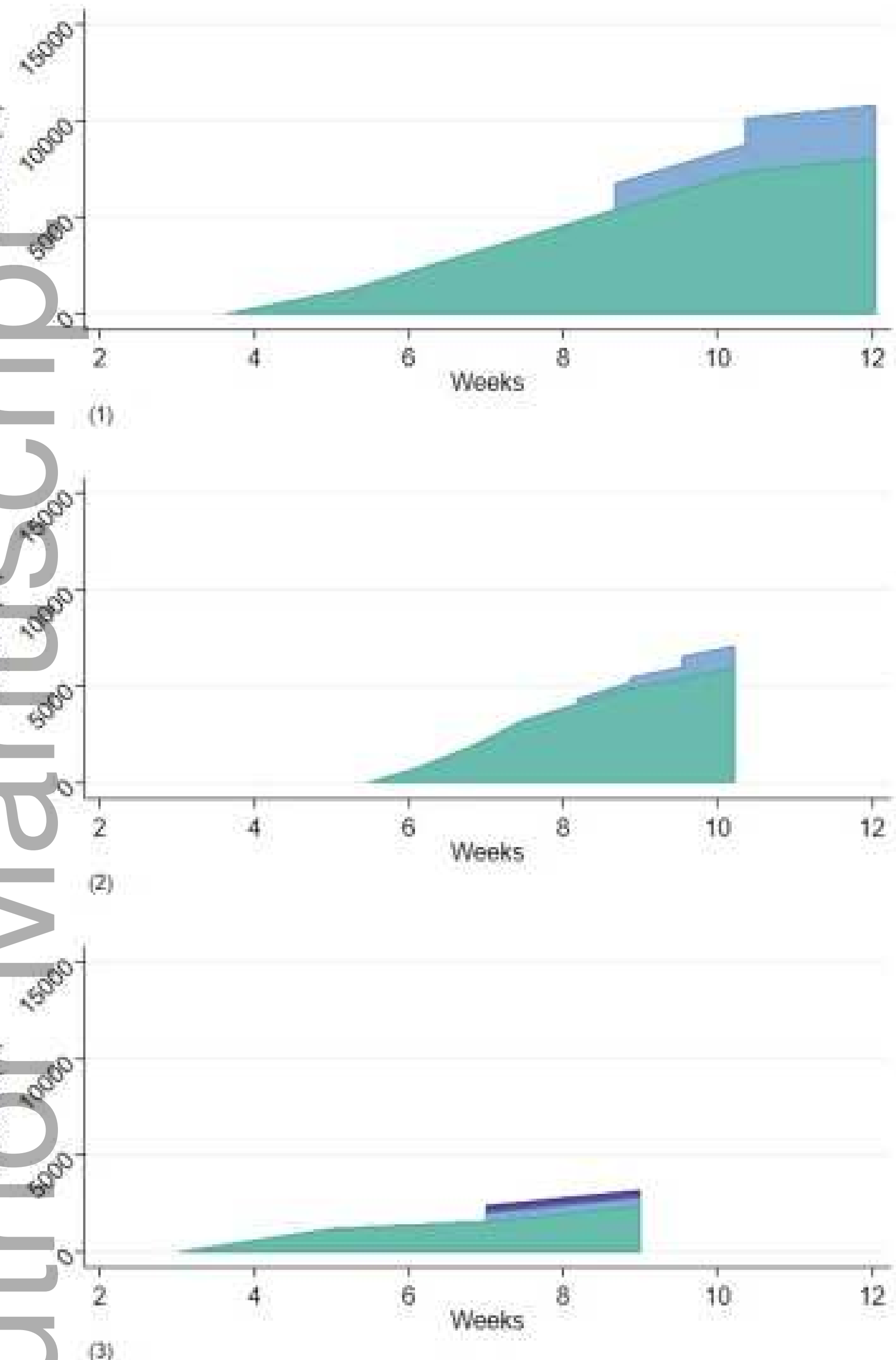

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