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Associations between turn out practices and rates of musculoskeletal disease and injury in Thoroughbred foals and yearlings on stud farms in the United Kingdom

Rebecca Mouncey[1] | Juan C. Arango-Sabogal[1,2] | Amanda de Mestre[3] | Kristien K. L. Verheyen[1]

[1]Department of Pathobiology and Population Sciences, Royal Veterinary College, Hatfield, UK

[2]Département de Pathologie et Microbiologie, Faculté de Médecine Vétérinaire, Université de Montréal, Quebec, Canada

[3]Baker Institute for Animal Health, College of Veterinary Medicine, Cornell University, Ithaca, New York, USA

Correspondence
Rebecca Mouncey, Department of Pathobiology and Population Sciences, Royal Veterinary College, Hawkshead Lane, North Mymms, Hatfield, AL9 7TA, UK.
Email: rmouncey18@rvc.ac.uk

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Abstract

Background: Early-life locomotor activity during turn out may alter susceptibility to musculoskeletal disease and injury via modulation of behaviours and tissue development during growth.

Objectives: Investigate associations between turn out practices and rates of musculoskeletal disease and injury in young Thoroughbreds on stud farms in the United Kingdom.

Study design: Prospective cohort.

Methods: Daily records were kept on location and duration of turn out for 134 Thoroughbred foals on six stud farms, from birth until leaving the farm or study exit. Data on veterinary-attended episodes of musculoskeletal disease or injury were collated concurrently. Average daily turn out times (hours), areas (acres) and group size (*n* foals) were calculated for rolling 7- and 30-day periods of age. Multivariable Cox regression, including farm as a random effect, was used to investigate associations between turn out practices and musculoskeletal disease and injury.

Results: The overall incidence of musculoskeletal disease or injury was 5.3 cases/100 foal-months at risk (95% confidence interval [CI]: 4.2–6.6). Compared with 24/7 turn out, average daily turn out times of between 9 and 23 hours over a 7-day period were associated with a 4.6-fold increase in musculoskeletal injury rate (95% CI: 1.7–12.3; $P < 0.001$), adjusting for farm and paddock area. Each 1-acre increase in the average daily turn out area during the 4th month of life, reduced the rate of musculoskeletal disease and injury between 6 and 18 months of age by 24% (hazard ratio 0.76, 95% CI: 0.58–0.99; $P < 0.001$), adjusting for farm and turn out time.

Main limitations: Non-random sample of participants may affect generalisability. Use of veterinary-attended events likely underestimates disease/injury rates.

Conclusions: Results suggest that disruptions or alterations to turn out time routines increase injury risk and should be avoided where possible. Turn out in larger

paddocks, particularly before weaning, may confer protection against subsequent musculoskeletal disease and injury.

KEYWORDS
disease, exercise, foal, horse, injury, musculoskeletal

1 | INTRODUCTION

Evidence suggests that early-life activity and exercise levels can influence musculoskeletal disease and injury risk.[1–6] In experimental studies of foals,[1–3] moderate increases in locomotor activity levels increased bone size and strength and advanced the development of cartilage and tendon,[2,7] changes which were hypothesised may be protective against injury and disease.[2,7] However, too little (box rest) or too much (repetitive forced high-intensity activity) activity had deleterious effects, which were hypothesised may leave tissues such as bone and cartilage more vulnerable to injury.[1] Imaging studies investigating osteochondrosis in juvenile horse populations found that both larger turn out areas in very young foals[8,9] and turn out strategies that were hypothesised to result in an increased risk of trauma to the musculoskeletal system (such as rough paddock terrain, turn out following stable confinement, and mixing or changing of groups),[4,8,9] were associated with an increased risk of radiographic lesions or lesion severity score.

Studies using global positioning satellite (GPS) technology to record activity levels of both feral[10,11] and domesticated foals kept extensively at pasture 24/7,[12] demonstrated that over the first months of life total workload (distance x speed) decreased as the amount of time spent grazing increased, although the intensity of activities such as cantering, galloping, rearing and bucking increased. It is postulated that these high-intensity locomotor activities[12] are likely to play an important role in musculoskeletal development by stimulating positive adaption of tissues, for the given stage of development of the foal.[13] Factors such as paddock size, turn out time, turn out routine and pasture groupings are recognised as influencing activity levels and behaviours during turn out in horses.[12,14–21]

We therefore hypothesised that stud farms' turn out practices influence rates of musculoskeletal injury and disease in young Thoroughbreds. The objectives of this study were to investigate associations between (i) weekly turn out practices and the rate of musculoskeletal disease and injury and (ii) turn out practices in the first 6 months of life and rates of musculoskeletal disease and injury between 6 and 18 months of age in young Thoroughbreds on stud farms in the United Kingdom (UK). Findings can be utilised to inform management strategies aimed at improving musculoskeletal health in this population. The study reported here forms part of a larger body of work, further description of disease and injury in this population is published elsewhere,[22] descriptions of turn-out regimes and other farm management practices will be presented separately (Mouncey et al., unpublished data).

2 | MATERIALS AND METHODS

2.1 | Sample size calculation

Calculations were performed in Stata (Release 16, StataCorp LP).[23] Using survival analyses methods (Cox regression), it was estimated that a hazard ratio (HR) of between 4 and 2 could be detected in a cohort of 24–75 foals with 80% power and a 5% type 1 error, assuming an accrual interval of 180 days, an additional follow-up period of 365 days, 25% loss to follow-up and a hazard rate in 'unexposed' foals of 0.2.

2.2 | Data collection

Details of the study design and data collection methods are described in detail elsewhere.[22] Briefly, a prospective cohort study was set up, collecting data from a convenience sample of stud farms across the UK between 1 January 2019 and 31 December 2020. All foals born on recruited farms were entered into the study and under observation from birth until exiting the study or entering pre-training/training for racing at 18–20 months of age. Participating farms kept daily records of the location and duration of any turn out foals received, indicating dates of any veterinary-attended episodes of musculoskeletal injury or disease. Turn out locations' area (in acres) and further details of veterinary-attended injury or disease were collated from farm and veterinary records. All data were entered into a custom-designed Microsoft™ Access database.

2.3 | Data processing

All data were imported into Stata (Release 16, StataCorp LP). Cumulative totals of the number of days turned out (number of turn out observations), turn out time (to the nearest hour), turn out area (acres to the nearest 0.5) and group size (number of foals) were created. On days when foals were not turned out (i.e., box rest), all turn out variables were recorded as 0. From the cumulative totals, a total for the 7 days before each observation was calculated by taking the total on the date of the observation and subtracting the total on the observation 7 days previous; only 7-day periods for which complete data were available were utilised. Daily averages of turn out time, turn out area and group size for the 7-day periods were then calculated by dividing the total by 7. Using similar methods, total numbers of days turned out and average daily figures (turn out time, area, group size)

were generated within each month of age of foal (30-day period of age) for the first 6 months of life.

For the veterinary data, an age-at-event variable (in days) was created by subtracting the foal's date of birth from the date of veterinary attendance. Data were inspected to identify events where foals received veterinary intervention for the first time for a new condition affecting the musculoskeletal system. Veterinary attendance for continuation of an ongoing condition or recurrence of a previous one was not included in any analyses. Case definitions and lists of key descriptive terms were created from existing literature; details are given in Table S1. Developmental orthopaedic conditions were separated into congenital, that is, those where the condition was present at birth and non-congenital as cases of congenital DOD were not included as outcome events, due to lesions being present before foals were turned out, that is, before the main exposure of interest. Farms and veterinary surgeons were consulted for verification as required. Event data were independently assessed by two veterinary-qualified researchers (RM, JCA-S) and in the case of disagreement, a third reviewer (KV) was available to enable a consensus decision to be made. Daily activity and musculoskeletal disease data were then merged using the foal name and observation dates (veterinary attendance and turn out). Data were visually inspected to identify any instances where farms may have elected to box-rest or restrict foals before seeking veterinary intervention. Such cases were identified as having had a change in turn out routine prior to the date of veterinary intervention, which was different from the rest of their turn out group. For example, in a group turned out 24/7, one individual was recorded as having been box rested for 3 days before the date of veterinary intervention, while all others remained turned out 24/7. Under such circumstances, the date of disease or injury was set as the first day that box rest or turn out modification was instituted, rather than the date of veterinary intervention; participating farms and veterinary surgeons were consulted for verification as necessary.

2.4 | Data analysis

Histograms were plotted and visually inspected for normality. Data were described using mean, standard deviation (SD) and range if normally distributed and median, inter-quartile range (IQR) and range if non-normally distributed. Proportions and 95% confidence intervals (CI) were calculated for categorical data. Incidence risk was calculated as total number of new cases/number of foals and incidence rates were estimated by fitting empty (no fixed effects) Cox regression models with farm as a random effect. To investigate associations between turn out practices and musculoskeletal disease and injury cox regression methods were used that allowed for time-varying exposures (turn out practices) and adjusted for any effect of age, as foals were considered at risk and under observation from birth until leaving the study.

To investigate associations between weekly turn out practices and rates of (i) musculoskeletal disease or (ii) injury, seven exposure variables were evaluated: foal sex, month of birth, whether the foal had required veterinary intervention for congenital DOD, total number of days turned out, average daily turn out time, area and group size (per 7-day period).

To investigate associations between turn out practices in the first 6 months of life and musculoskeletal disease and injury rates between 6 and 18 months of age, 28 exposure variables were evaluated: foal sex, month of birth, whether the foal had required veterinary intervention for congenital DOD, whether the foal had required veterinary intervention for other musculoskeletal injury or disease in the first 6 months of life, and the total number of days turned out, average daily time, area and group size for each 30-day period of foal age.

Farm was fitted a priori as a random effect in all analyses as significant between-farm variation in turn out practices had been observed in the dataset (Mouncey et al., unpublished data). Other potential cluster variables (mare and stallion) were evaluated by fitting them individually as random effects (shared frailty terms) in an empty Cox model with the outcome of interest. If the likelihood ratio test (LRT) *P*-value comparing the random effect to the empty model was <0.05, the variable was fitted alongside farm as a random effect in all models. The shape of the association between continuous exposure variables and the outcome of interest was explored using LRT for departure from linear trend, where LRT $P < 0.05$ variables were modelled as categorical. Under such circumstances, individuals receiving no turn out during either the 7- or 30-day period were assigned to a separate category for all turn out exposures (time, area and group size). A further 3 categories were created, based on data distribution and knowledge of farm turn out practices. For turn out time, farms reported either having individuals stabled overnight with some turn out during the day which resulted in daily turn out times of between 1 and 8 hours or turning individuals out 24/7. Hence 1–8 hours and 24 hours were chosen as categories. Creating these categories left around 30% of the data (in both 7- and 30-day data), which were assigned to a fourth category of 9–23 h. Daily averages in this category resulted from either individuals generally being turned out 24/7 but experiencing some aberration from this routine, or individuals changing from being in at night and out during the day to being out 24/7, during either the 7- or 30-day period. For turn out area, farms reported when electively providing 'restricted' turn out utilising areas less than 1 acre for this purpose, hence a category of less than 1 acre was generated. Excluding turn out locations of <1 acre, the median area of turn out locations utilised in the study was 6 acres hence the remaining two categories were chosen as 1–6 acres and >6 acres. A similar approach was taken with group size, resulting in categories of 1 foal, 2–5 foals and >5 foals (median group size being 5 foals).

Variables with a univariable LRT $P < 0.20$ were taken forward to be considered for inclusion in a multivariable model. Where turn out variables were deemed to be highly correlated (Spearman's rho >0.7) two models, one using each of the correlated variables, were built and the one with the lowest Akaike Information Criterion (AIC) was retained as the final model. Models were built using a forward stepwise approach with inclusion based on a LRT $P < 0.05$. There was deemed to be evidence of confounding if HR estimates changed by

>20% with inclusion of the second variable in the model, in which case the confounding variable was retained in the final model. Interaction was assessed between all variables retained in the final model, as well as a priori between all turn out variables and between turn out variables and age using a foal age (days) at observation variable (calculated by subtracting the foal's date of birth from the date of each observation). Although the Cox regression controlled for the effect of age ('time since birth'), it was felt that interaction between age and turn out variables was plausible. Interaction was deemed to be present if the LRT comparing a model with the interaction term to a model without resulted in $P < 0.05$, and the interaction term retained in the final model as appropriate.

Where appropriate to further understand relationships between variables in the final models, the relative hazard (predicted hazard ratio) was calculated for the outcome of interest over the available range of the predictor variable(s) using Stata's margins suite[24] of commands, and the estimated smooth hazard function[25] was calculated across time (foal age at observation) using Stata's stcurve suite[26] of commands. Fit of the final model was evaluated by plotting the cumulative hazard (−ln Kaplan–Meier survival function) against the Cox–Snell residuals. Potential influential observations were checked by plotting DF-Beta residuals[27] against time (foal age at observation). Influential observations were manually checked for errors.

3 | RESULTS

3.1 | Available data

A total of 41 480 daily observations (turn out $n = 40\,173$ or box rest $n = 1307$), equating to 1383 foal-months at risk, were available for 134 foals born from 126 mares, on six farms over two seasons ($n = 115$ in 2019 and $n = 19$ in 2020; only two farms enrolled foals in both seasons). Foals were sired by 65 different stallions. Median age at observation was 225 days (IQR 255, range 1–682). Figure S1 describes numbers of daily observations, losses to follow-up and destinations of individuals leaving the stud farm, by foal age for the study period.

The mean number of foals per farm was 22 (SD 5, range 13–31). Fifty-three percent were colts ($n = 71/134$, 95% CI: 44–61) and 47% fillies ($n = 63/134$, 95% CI: 39–55). Seven percent of foals were born in January ($n = 9/134$, 95% CI: 4–12), 27% in February ($n = 36/134$, 95% CI: 20–35), 37% in March ($n = 50/134$, 95% CI: 30–46), 23% in April ($n = 31/134$, 95% CI: 17–31) and 6% in May ($n = 8/134$, 95% CI: 3–11).

A total of 73 events where veterinary intervention was required for a new case of musculoskeletal injury or disease were recorded between birth and leaving the study, affecting 42% of foals ($n = 56/134$, 95% CI:% 34–50), equating to an overall rate of 5.3 cases/100 foal-months at risk (95% CI: 4.2–6.6). A summary is provided in Table 1; further description of disease, injury and mortality is reported elsewhere.[22]

3.2 | Associations between weekly turn out practices and musculoskeletal disease or injury

Sufficient data were available to evaluate associations between weekly turn out practices and two outcome variables: non-congenital developmental orthopaedic disease (DOD) and musculoskeletal injury (all injury types combined, but excluding DOD and miscellaneous conditions).

3.2.1 | Non-congenital developmental orthopaedic disease

A total of 45 events where veterinary attention was required for the first time for DOD between birth and leaving the study were recorded, affecting 29% of foals ($n = 39/134$, 95% CI: 22–37). In 53% of these events ($n = 24/45$, 95% CI: 39–67) (Table 1) the DOD lesion was reported as being present at birth and considered congenital in nature. The remaining 47% of DOD events ($n = 21/45$, 95% CI: 33–61) (Table 1) were classified as being non-congenital and were used as outcome events to evaluate associations between DOD and turn out practices prior to the requirement for veterinary intervention. The rate of non-congenital DOD was 1.5 cases/100 foal-months at risk (95% CI: 1.0–2.3). Presentations of non-congenital DOD requiring veterinary intervention are reported in Table 1.

There was evidence of clustering by farm (Theta = 0.57, LRT $P = 0.02$ when comparing an empty Cox model with a model including farm fitted as a shared frailty term), but not by mare ($P = 0.10$) or stallion ($P = 0.26$). Univariable results are given in Table S2. Average daily turn out area and average daily group size were correlated (Spearman's rho 0.76, $P < 0.001$). No confounding or interaction was identified. No turn out variables were retained following multivariable analysis and it was concluded that weekly turn out practices were not significantly associated (at $P < 0.05$) with the rate of non-congenital DOD.

3.2.2 | Musculoskeletal injury

A total of 25 events where foals required veterinary intervention for an injury to the musculoskeletal system were recorded during the study period, equating to a rate of 1.8 cases/100 foal-months at risk (95% CI: 1.2–2.7). Three cases were diagnosed as fractures (pedal bone $n = 2$, sesamoid $n = 1$) and six cases as haematomas. In the remaining 16 cases no specific diagnosis was made other than that of a traumatic injury, where the attending veterinary surgeon described clinical symptoms such as lameness, heat, pain and/or swelling with no further diagnostic testing or imaging undertaken.

There was no evidence of clustering by farm ($P = 0.5$), mare ($P = 0.7$) or stallion ($P = 0.8$). Univariable results are given in Table S3. It was not possible to evaluate number of days turned out over the 7-day period as cases only occurred in individuals turned out for 7 days, hence HR estimates could not be generated. Average daily turnout area and average daily group size were highly correlated

TABLE 1 Summary of new cases of musculoskeletal disease or injury requiring veterinary intervention in a cohort of 134 foals on six farms between 1 January 2019 and 31 December 2020.

Condition	*n* cases	*n* foals	Incidence risk[a]	95% CI
Developmental orthopaedic disease-all types	45	39	33.6	26.1–41.9
Congenital (present at birth)	24	24	17.9	12.3–25.3
Flexural deformity	*21*	*21*	*15.7*	*10.5–22.8*
Angular deformity	*3*	*3*	*2.2*	*0.8–6.4*
Non-congenital	21	21	15.7	10.5–22.8
Flexural deformity	7	7	5.2	2.5–10.4
Physitis	5	5	3.7	1.6–8.4
Angular deformity	4	4	3.0	1.2–7.4
Subchondral bone cyst	3	3	2.2	0.8–6.4
Cervical vertebral malformation	1	1	1.0	0.1–4.1
Osteochondrosis dissecans	1	1	1.0	0.1–4.1
Musculoskeletal injury	25	22	18.7	13.0–26.1
No specific diagnosis	*16*	*13*	*11.9*	*7.5–18.5*
Haematoma	*6*	*6*	*4.5*	*2.1–9.4*
Fracture	*3*	*3*	*2.2*	*0.8–6.4*
Miscellaneous (all other)	3	3	2.2	0.8–6.4
Sesamoiditis	*2*	*2*	*1.5*	*0.4–5.3*
Splint	*1*	*1*	*0.7*	*0.1–4.1*
All	73	56	54.5	46.0–62.7

Abbreviation: CI, confidence interval.
[a]Incidence risk calculated as number of cases/total number of foals.

TABLE 2 Results of multivariable Cox regression analysis to investigate associations between weekly turn out practices and musculoskeletal injury requiring veterinary intervention ($n = 25$) in a cohort of 134 young Thoroughbreds on six stud farms between 1 January 2019 and 31 December 2020 (Farm fitted as a random effect).

Predictor	Category	HR	95% CI	Wald *P*	LRT *P*
Average daily turn out time in previous 7 days	0 h		No cases		<0.001
	1–8 h	0.87	0.14–5.28	0.9	
	9–23 h	4.62	1.72–12.38	0.002	
	24 h	*Ref*			
Average daily turn out area in previous 7 days[a]		0.86	0.73–1.00	0.05	

Note: Theta (farm) = 0.45, Likelihood ratio test (LRT) $P = 0.13$ compared with a Cox model without farm as a random effect.
Abbreviation: CI, confidence interval; HR, hazard ratio; *Ref*, reference category.
[a]Confounder, turn out area measured in acres.

(Spearman's rho 0.74, $P < 0.001$). Confounding was observed between average daily turn out time and average daily turn out area. The final multivariable model is presented in Table 2.

Compared with 24/7 turn out, average daily turn out times of between 9 and 23 h over a 7-day period were associated with a 4.6-fold increase in musculoskeletal injury rate (95% CI: 1.7–12.3; $P = 0.002$), adjusting for farm and turn out area. The use of larger paddocks was associated with a decreased rate of musculoskeletal injury (HR 0.86, 95% CI: 0.73–1.00, $P = 0.05$). For example, the use of a 2-acre paddock compared with a 1-acre paddock reduced the hazard by around 14%, although effects of area were only marginally significant ($P = 0.05$). Farm was not associated with the hazard of musculoskeletal injury requiring veterinary intervention (Theta 0.45, LRT $P = 0.1$). A plot of the estimated smoothed hazard function (estimated hazard rate; cases/100 foal-months at risk) from the final model stratified by average daily turn out time for the study period (foal age) is given in Figure 1.

3.3 | Associations between turn out practices in the first 6 months of life and musculoskeletal disease and injury between 6 and 18 months of age

Case numbers for musculoskeletal disease and injury were low in individuals aged 6–18 months, therefore all reported new cases were combined for analysis. A total of 21 events were reported

(musculoskeletal injuries $n = 12$ ($n = 10$ no specific diagnosis, $n = 2$ haematoma), DOD $n = 7$ and $n = 2$ sesamoiditis), which affected 18% of foals remaining in the study beyond 180 days of age ($n = 17/92$, 95% CI: 12–28), giving an incidence rate of 2.6 cases/100 foal-months at risk. All foals were turned out individually (with their dam) in the first month of life hence group size was not evaluated in this month.

There was no evidence of clustering by farm ($P = 0.2$), mare ($P = 0.1$) or stallion ($P = 0.3$). Univariable results are given in Table S4. Average daily turn out area and average daily group size were highly correlated in all months of foal age (Spearman's rho >0.70, $P < 0.001$). Confounding was observed between average daily turn out area and average daily turn out time in the 4th month of age. The final multivariable model is given in Table 3.

Increasing the average daily turn out area by 1 acre during the fourth month of life, reduced the hazard of musculoskeletal disease or injury requiring veterinary intervention between 6 and 18 months of age by around 24% (HR 0.76, 95% CI: 0.58–0.99, $P = 0.04$), adjusting for the effects of farm and turn out time. Farm was not significantly associated with the hazard of musculoskeletal disease or injury (Theta $= 1.27 \times 10^{-18}$, LRT $P = 0.50$). A plot of the predicted hazard ratio at fixed values of the covariates in the final model is displayed in Figure 2, in which paddocks of less than ~4 acres are associated with an increased hazard (relative HR >1) of musculoskeletal disease and injury.

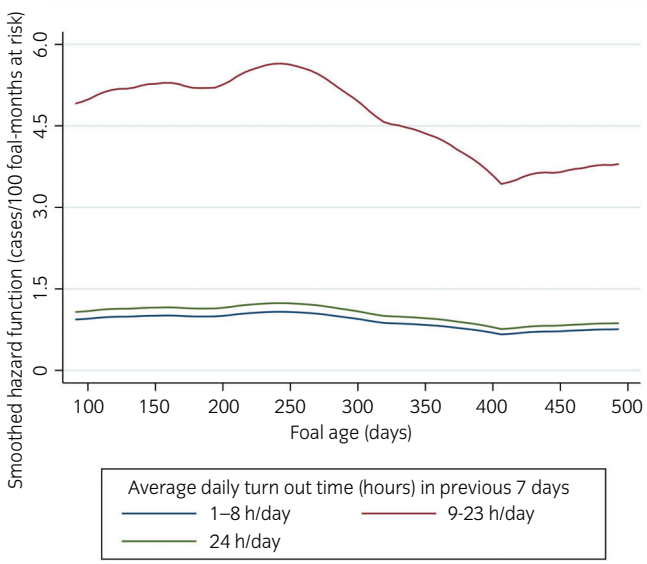

FIGURE 1 Plot of the hazard function (estimated hazard rate; cases/100 foal-months at risk) of musculoskeletal injury requiring veterinary intervention by age of foal (in days) for fixed values of 7-day average turn out time (hours) in a cohort of 134 Thoroughbred foals on six stud farms between 1 January 2019 and 31 December 2020.

4 | DISCUSSION

Despite a growing body of evidence that early-life locomotor activity has the potential to promote musculoskeletal development toward greater resistance to injury and disease,[1–3] to date, there is no evidence-base to inform optimum turn out strategies for Thoroughbred foals and yearlings under field conditions. This study describes, for the first-time, associations between turn out practices and rates of musculoskeletal disease and injury in Thoroughbred foals and yearlings on stud farms in the UK, providing important and novel data for the industry. Turn out practices resulting in an average turnout time of between 9 and 23 h/day over a 7-day period were associated with

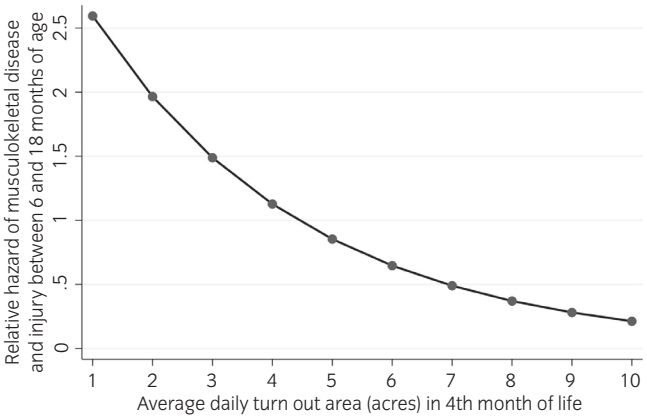

FIGURE 2 Plot of the relative hazard of musculoskeletal disease or injury requiring veterinary intervention between 6 and 18 months of age over fixed values of average daily turn out area (acres) in the 4th month of life in 134 Thoroughbred foals on six stud farms between 1 January 2019 and 31 December 2020.

TABLE 3 Results of multivariable Cox regression analysis to investigate associations between turn out practices in the first 6 months of life and musculoskeletal disease and injury requiring veterinary intervention between 6 and 18 months of age in a cohort of 134 young Thoroughbreds on six stud farms between 1 January 2019 to 31 December 2020 (Farm fitted as a random effect).

Predictor	Category	HR	95% CI	Wald *P*	LRT *P*
Average daily turn out area (acres) in month 4		0.76	0.58–0.99	0.04	<0.001
Average daily turn out time in month 4[a]	24 h	*Ref*			
	1–8 h	1.05	0.52–21.27	>0.9	
	9–23 h	5.28	0.63–44.29	0.1	

Note: Theta (farm) $= 1.27 \times 10^{-18}$, Likelihood ratio test (LRT) $P = 0.50$ when compared with a Cox model without farm as random effect.
Abbreviation: CI, confidence interval; HR, hazard ratio; *Ref*, reference category.
[a]Confounder.

an increased rate of musculoskeletal injury. Increasing turn out area in the fourth month of life was associated with a reduced rate of musculoskeletal disease and injury between 6 and 18 months of age.

Average daily turn out times of between 9 and 23 h/day over a weekly period occurred as a result of two main scenarios: an interruption to routine, for example individuals that were turned out 24/7 undergoing a short period of stabling on 1 day for farriery, or a change to routine, for example, spending part of the week in at night and out during the day and part of it turned out 24/7. It is possible that these aberrations to turn out routine resulted in increased levels of compensatory high intensity locomotor activities over and above those undertaken by individuals in a routine of stabling at night and turn out during the day (average daily turn out times of 1–8 h), which in turn, led to the observed increased rates of musculoskeletal injury in this group. In an observational behavioural study of foals under various management regimes, compared with foals kept at pasture 24/7, foals that spent some of the 24-h period stabled, exhibited increased levels of high intensity locomotor activities such as trotting and cantering when they were turned out.[12] Similarly, compensatory or rebound locomotor activity has frequently been observed in adult horses, with increases in activities such as cantering, galloping, bucking and turning, consistently described during turn out following stable confinement,[19,20,28,29] alongside increases in aggression behaviours when turn out occurs in groups.[30] Such activities and behaviours are likely to readily apply forces outside of the sagittal plane of the horses' limbs, which could more easily lead to trauma and injury of musculoskeletal tissues.[31] Increases in turn out area appeared to offer a degree of protection against musculoskeletal injury, in the face of irregularities or changes to turn out routine. Larger turn out areas may result in compensatory activities, such as tight turning or sudden stopping, occurring less frequently or with less abruptness and load, leading to a reduction in biomechanical forces outside of the sagittal plane,[31] and a reduced risk of injury to muscular skeletal tissues. Similarly, the invasion of 'personal' space is a common cause of aggression within groups of horses,[32] and the use of larger paddocks may also reduce these types of behaviours and facilitate more room for escape from aggression if it does occur.[19,33]

The graph showing the estimated hazard function against foal age (time), suggests that hazard of musculoskeletal injury was greatest at around 8–9 months of age (220–280 days). This time period coincides with the winter months of foals' first year of life (October–February, depending on month of birth). It is likely that grass availability would be at its lowest during this period, which could have encouraged more aggression behaviours due to lack of forage.[34,35] In grazing horses, aggressive interactions are also reported when horses receive supplementary feeding.[36] Such data were not recorded in the present study, however it is likely that supplementary feed would be provided during this period, which, combined with reduction in overall forage intake, could have encouraged behaviours that contributed to the increased hazard of injury.

It is interesting to note in the present study, that in the majority (64%) of cases diagnosed as musculoskeletal injury, specific diagnoses were rarely given, and instead an assumption of an injury was made on the basis of clinical signs such as heat, pain, swelling or joint distention with or without lameness. Diagnostic imaging was very rarely undertaken unless there were concerns about a possible fracture. As such, it is possible that some of these presentations could in fact have been previously sub-clinical osteochondral or subchondral cystic lesions, which were exacerbated by compensatory activities at turn out, resulting in seemingly acute clinical signs.[37] This theory is supported by findings from three previous studies investigating osteochondrosis in young horses,[4,5,37] the first of which, describing histological features of medial femoral condyle cystic lesions in juvenile Thoroughbreds, concluded that early lesions arise due to focal trauma from forces across the joint.[37] Two further epidemiological studies reported changes and irregularities to turn out routines and routines comprising of a mixture of stabling and turn out, to be associated with an increased risk or severity of osteochondral lesions at radiographic examination.[4,8,9] Authors hypothesised that compensatory locomotor activities exhibited in response to aberrations to turn out routines, caused inappropriate biomechanical loading of the osteochondral junction of the joints, resulting in trauma and deterioration of osteochondral lesions.[4,5,8] In the present study, rates of non-congenital DOD were not associated with weekly turn out practices, however as discussed it is possible that DOD presentations such as osteochondral and subchondral cystic lesions may be underrepresented in this study population due to lack of diagnostic imaging.

More extensive turn out practices (paddocks >4 acres; Figure 2, 24/7 turn out; Table 3) during the fourth month of life were associated with reduced rates of musculoskeletal disease and injury between 6 and 18 months of age in the present population. It could be that these practices provided increased opportunity to achieve sufficient activity during a critical stage of growth, resulting in musculoskeletal tissue adaptation that was protective against later-life musculoskeletal injury and disease. In addition, increased activity at turn out may also enhance later-life neuromuscular function, strength and coordination[38] and provide greater opportunity for the development of herd social skills which may in turn reduce the risk of traumatic injury. Thoroughbred foals complete the period of most rapid infantile growth at around 4–6 months of age, when they reach around 40% of their adult body weight.[39,40] During this period, as demonstrated by a number of experimental studies,[6,13,40–42] musculoskeletal tissues, particularly articular cartilage and tendon but also muscle and bone, display their greatest capacity for modulation of developmental processes and functional adaptation in response to locomotor activity. Observational studies utilising GPS trackers of mares and foals kept 24/7 at pasture also demonstrate that, over this seemingly critical period, despite foal's total workload (distance × speed) at pasture decreasing with age as more time is spent grazing, the intensity and vigour of bouts of locomotor play activities increase.[12,13] This behaviour appears to mirror the requirements of bone adaptation, in which cumulative cycles of load followed by periods of rest, result in a greater osteo-inductive response.[43] Hence such changes in foals' time budgets at pasture and increasing intensity of locomotor play activities as the foal ages, are thought to be due to the requirement for greater peak load and force to stimulate appropriate adaptation, as body and bone mass of the axial skeleton increase due to the rapid growth occurring

during this period.[13] In the present population, weaning was undertaken on average at 5 months of age, as is convention in Thoroughbreds,[44] which would likely result in an abrupt cessation to this rapid growth phase and closure of the critical window for tissue adaptation. It is, therefore, proposed that in the fourth month of life prior to weaning, the highest frequencies and intensities of locomotor activities are required to achieve adequate load and force both to stimulate optimum musculoskeletal tissue adaptation and to condition neuromuscular coordination. It is recognised that both foals and adult horses are more active and cover greater total distances when turned out in larger areas,[12,14,17,18] where it is likely also, that greater peak speeds and loading forces are more readily and frequently achieved.

When interpreting the findings from this work, it must be acknowledged that assumptions of relationships between turn out practices and activity levels and behaviours were made based on available evidence from other studies. Technologies such as GPS trackers to estimate total workloads and quantify behaviours have the potential to confirm the existence of presumed relationships. However, these are currently not routinely used on stud farms and, at the time of study inception, no small and lightweight GPS trackers with sufficient battery life for extended live tracking and recording, were available to make this a practical option for activity monitoring in a large study cohort. Methods of recording turn out time, area and group size were therefore considered to be more practical in the present study, to ensure that findings were directly applicable at farm-level to maximise their impact to the target audience. A potential limitation of the study was the inevitable loss of some individuals due to death or loss to follow up (Figure S1) over the lengthy study period, which could have affected study power in some analyses. The self-selection of farms to participate in the study should be taken into consideration when extrapolating findings to the wider population. The use of only veterinary-attended episodes of disease and injury likely underestimates true rates in the population and may be affected by variation in farms' elected levels of veterinary intervention; however, between-farm variation was adjusted for in all models. As previously discussed, some diagnoses, particularly of traumatic lesions, were made only on presenting clinical signs without diagnostic imaging, meaning that a diverse range of injuries are likely to have been included as outcomes in this study. It is also possible that, due to lack of diagnostic imaging, developmental orthopaedic conditions such as osteochondrosis and subchondral cystic lesions, may be underrepresented and/or misclassified as traumatic lesions.

5 | CONCLUSIONS

This work provides novel epidemiological information, which can be utilised to inform management strategies aimed at improving musculoskeletal health in Thoroughbred foals and yearlings. Changes or disruptions to turn out routine in terms of time, increase the risk of musculoskeletal injury, most likely by encouraging compensatory high intensity behaviours, and should be avoided where possible. Where unavoidable, the use of larger paddocks may offer some protective effect. The use of larger paddocks prior to weaning reduces the risk of post-weaning musculoskeletal disease and injury, presumably by promoting appropriate levels of locomotor activity and positive tissue adaptation during a key phase of growth and musculoskeletal development.

AUTHOR CONTRIBUTIONS

All authors met the following authorship criteria: (1) substantial contributions to conception and design of the study (Kristien K. L. Verheyen, Rebecca Mouncey, Amanda de Mestre), or acquisition of data (Rebecca Mouncey) or analysis (Rebecca Mouncey) and interpretation of data (Rebecca Mouncey, Juan C. Arango-Sabogal, Amanda de Mestre, Kristien K. L. Verheyen), (2) drafting the article (Rebecca Mouncey) or revising it critically for important intellectual content (Rebecca Mouncey, Juan C. Arango-Sabogal, Amanda de Mestre, Kristien K. L. Verheyen), (3) final approval of the version to be published (Rebecca Mouncey, Juan C. Arango-Sabogal, Amanda de Mestre, Kristien K. L. Verheyen), and (4) to be able to be accountable for all aspects of the work (Rebecca Mouncey, Juan C. Arango-Sabogal, Amanda de Mestre, Kristien K. L. Verheyen).

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DATA AVAILABILITY STATEMENT

Data are available from the author upon reasonable request. Open sharing exemption granted by the editor due to lack of provision within the informed consent process.

DATA INTEGRITY STATEMENT

The corresponding author confirms that she had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

ETHICAL ANIMAL RESEARCH

Ethical approval was granted by the Royal Veterinary College's Clinical Research Ethical Review Board (URN: 2018 1843).

INFORMED CONSENT

Informed consent was gained from participating farms.

ORCID

Rebecca Mouncey https://orcid.org/0000-0001-9850-7878
Juan C. Arango-Sabogal https://orcid.org/0000-0003-3395-8410

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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