Age-Associated Differences in Paddock Locomotor Activity Among Senior Horses: A Pilot Observational Study

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Article

Age-Associated Differences in Paddock Locomotor Activity Among Senior Horses: A Pilot Observational Study

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Simple Summary

As horses age, changes in daily movement may reflect their health and overall well-being. However, there is limited objective information about how normal aging affects movement in older horses under everyday management conditions. In this study, we investigated whether a short turnout period in a paddock could reveal age-related differences in movement in senior horses. Twenty-eight older sport horses aged 17 to 35 years were monitored during 122 turnout sessions lasting two hours, over a period of approximately two and a half years. Movement was recorded using a small wearable tracking device that measured how far and how fast the horses moved. We found that older horses generally covered less distance and moved more slowly than younger senior horses. These differences were mainly observed between different horses rather than as clear declines within the same horse over time. Our findings suggest that short turnout monitoring may help identify differences in activity levels among older horses and could support welfare monitoring at the group level. Larger studies are needed before this approach can be used to assess health changes in individual horses.

Abstract

Turnout locomotor activity is a potentially informative indicator of health and welfare in older horses, yet objective field data in seniors remain limited. We examined whether a brief turnout recording could detect associations between chronological age and locomotor activity in senior horses under routine conditions. In this single-site observational study, 28 senior Selle Français horses (17–35 years) contributed 122 paddock sessions (2 h each), with total distance and mean speed quantified using a Polar Team Pro sensor. Associations with age were assessed using linear mixed-effects models adjusted for temperature and precipitation. Age was decomposed into between-horse and within-horse components. Log-transformed total distance was negatively associated with age ($\beta = -0.062$ per year, 95% CI −0.094 to −0.032; $P < 0.001$), driven by the between-horse component ($\beta = -0.063$; $q = 0.003$), with no within-horse association ($P = 0.75$). Mean speed showed a similar pattern, with a significant between-horse association ($\beta = -0.060$; $q = 0.003$) and no within-horse effect ($P = 0.87$). These findings suggest that brief paddock actimetry may help characterize between-horse heterogeneity and support group-level welfare monitoring. Larger multi-site cohorts with denser follow-up and external validation are needed before individual trajectories or clinical interpretation can be established.

Keywords: horses; ageing; locomotion; monitoring; welfare

1. Introduction

Ageing in horses has been associated with progressive changes in aerobic capacity and musculoskeletal function, including declines in maximal cardiovascular and aerobic capacity (e.g., reduced maximal heart rate and maximal oxygen consumption) [1–6]. Ageing may also involve changes in muscle metabolic properties and broader alterations in body composition and metabolic–endocrine regulation, which may contribute to reduced exercise performance capacity and potentially constrain everyday mobility even in the absence of acute disease [3,7,8].

Epidemiological and clinical field studies of geriatric horses report a high burden of chronic abnormalities affecting multiple systems, with locomotor impairment being particularly prevalent and potentially constraining movement behavior during turnout and overall activity [9–12]. Notably, veterinary examinations frequently identify a substantially higher prevalence of lameness and musculoskeletal abnormalities than owners report, highlighting that clinically meaningful mobility limitations may be under-recognized in the field [13,14]. Recent work using wearable monitoring in older horses illustrates the feasibility of quantifying activity patterns and time budgets under field conditions and underscores substantial heterogeneity in activity profiles among geriatric individuals [15]. This motivates the search for simple, field-deployable metrics that can capture functional differences among older horses under routine management conditions.

At the same time, older horses represent a heterogeneous group. Many continue to participate in ridden exercise or even athletic activity into advanced age, while management practices (exercise routines, preventive care, turnout patterns) vary markedly across individuals and contexts [9,11]. In human ageing research, wearable accelerometry has been widely used to quantify free-living movement behavior in large observational cohorts, providing low-burden and scalable measures of inter-individual variability in everyday activity [16–18]. A comparable question in equine practice is whether spontaneous locomotor behavior recorded during turnout can provide an objective characterization of age-related differences in movement behavior under routine management conditions. Here, spontaneous is used in an operational sense and refers to unprompted locomotor behavior during a 2-h individual turnout window without forage provision or environmental enrichment. Turnout locomotion in horses is a composite behavioral phenotype shaped by intrinsic functional capacity and strong contextual constraints (e.g. environment, management routines, and social context) [19–21]. Under a standardized paddock protocol, wearable sensors can therefore provide an objective summary of observed turnout movement behavior in routine management conditions, enabling the investigation of age-related differences in turnout movement behavior.

Wearable sensors offer an objective, scalable approach to quantifying locomotor activity in field conditions. In horses, wearable motion sensors, including accelerometry-based devices and Global Navigation Satellite System (GNSS)-derived tracking, have been used to quantify activity patterns and movement intensity under controlled and free-living conditions [22–24]. However, the application of short field recording windows to investigate age-related differences in spontaneous locomotor activity remains underexplored.

In the present pilot study, we evaluated whether a 2-h paddock actimetry protocol can detect cross-sectional, age-associated differences in spontaneous locomotor activity among senior horses under routine management conditions. We modelled associations between age (17–35 years) and GNSS-derived locomotor metrics using mixed-effects models and decomposed age into between- and within-horse components.

Based on reported age-associated differences in exercise performance and the high prevalence of chronic musculoskeletal conditions in geriatric horses, we hypothesized that older age at recording would be associated with lower locomotor output during the 2-h paddock window (H1). Given the sparse and unbalanced follow-up, we expected that any observed age association would be supported primarily by between-horse differences rather than detectable within-horse change over the available follow-up (H2).

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2. Materials and Methods

2.1. Study Design and Setting

This observational field study analyzed locomotor activity collected during 2-h paddock recordings under routine management conditions between April 2022 and November 2024 at Chambergeot Équitation (Noisy-sur-École, Seine-et-Marne, France). The 2-h recording window was selected as a pragmatic duration compatible with routine yard constraints and repeated measurements across horses. Short turnout/free-exercise periods of a few hours, including 2-h turnout, are described in managed stabled sport horses in controlled studies, although daily turnout duration varies widely across management systems [25,26].

2.2. Study Population and Cohort Definitions

The dataset comprised 28 Selle Français horses (20 geldings, 8 mares) contributing 122 recordings (1–10 per horse; age range 17–35 years; mean age 23.0 ± 5.03 years). Estimated body mass was derived from morphometric measurements using the equation proposed by Martin-Rosset [27], based on height at withers and heart girth; mean estimated body mass was 473.8 ± 43.52 kg. A body condition score (BCS) was assessed by visual inspection and palpation of subcutaneous fat deposits using a 0–5 scale (0 = emaciated; 5 = obese) following the French Horse and Riding Institute (IFCE) field protocol for equine body condition scoring [28]. Scoring was performed across six anatomical sites (withers, neck crest, ribs, behind the shoulder, tailhead, and croup), and an overall BCS was calculated as a weighted mean of site scores (withers 0.50, neck crest 0.15, behind the shoulder 0.15, ribs 0.10, tailhead 0.05, croup 0.05). The mean horse-level BCS was 3.17 ± 0.49.

Definitions of “senior/aged” or “geriatric” horses vary across studies and depend on whether chronological, demographic, or physiological criteria are used. Aged/geriatric horses are commonly defined from approximately ≥15 years, with substantial inter-individual variability, and very old horses often considered ≥30 years [29,30]. In the present study, we operationally defined the senior cohort as ≥17 years to focus on an older segment within this commonly used range and to reduce overlap with mid-age mature horses under routine management conditions.

Information on routine health management and chronic medication use was collected from horse owners and yard records. Horses received routine preventive care (e.g., farriery and dental care) according to standard practice at the facility. Based on available owner/yard records, no horse in the analytical sample was reported to have recurrent lameness or to be receiving chronic medication, including long-term analgesics/non-steroidal anti-inflammatory drugs (NSAIDs) or pergolide. In addition, before each recording session, horses underwent routine screening for overt locomotor impairment using EquiSym® (Arioneo, Paris, France). However, health status was not established through a standardized veterinary diagnostic work-up (e.g., systematic lameness examination or endocrine testing for pituitary pars intermedia dysfunction (PPID) and equine metabolic syndrome (EMS)). Therefore, residual confounding due to unrecorded or subclinical comorbidities cannot be excluded. The number of recordings per horse varied because of real-world constraints in a privately owned yard (e.g., changes in ownership, changes in boarding location, and, in some cases, death or euthanasia of older horses during follow-up), resulting in an unbalanced repeated-measures dataset.

A small reference group of younger horses (<17 years; 5 geldings, 2 mares; race : Selle Français) recorded in the same facility under the same 2-h turnout protocol was available and was used for a secondary, contextual comparison only. This group was not used to define the senior cohort and was analyzed descriptively to provide context for locomotor outcomes under the same recording conditions (Table 1).

Table 1. Study population / descriptive characteristics.

Group	Horses (n)	Recordings (n)	Age (years)	EBW (kg)	BCS	SPH
Senior (≥17)	28	122	23.0 ± 5.03	471.7 ± 47.82	3.1 ± 0.56	4.4 ± 3.01
Younger (<17)	7	71	13.7 ± 3.45	479.6 ± 32.16	3.4 ± 0.30	5.5 ± 2.96

Note: EBW = estimated body weight (kg); BCS = body condition score; SPH = sessions per horse. Values are presented as mean ± standard deviation.

2.3. Recording Environment and Procedures

Recordings were conducted in four paddocks arranged as two rows of two paddocks separated by a central path. Each paddock measured approximately 50 m × 25 m, was sparsely grassed, and was located on flat, open terrain with an unobstructed sky view. Paddocks contained no shelters or environmental enrichment; no hay or supplementary feed was provided during the 2-h recording window. Each paddock was equipped with a water trough available ad libitum. Horses were kept alone in their paddock. They could see other horses but had no direct contact. To minimize proximity effects and reduce variation in social context, horses were rotated across paddocks such that paired horses were positioned on opposite corners across the central path.

Recordings were scheduled under stable yard routines and performed at similar times of day (within ~1 h when possible). Monitoring was planned at 3-month intervals, although intervals could occasionally extend to ~4 months due to practical constraints, resulting in repeated observations across seasons.

To reduce confounding from structured exercise, horses were not worked the day before recording. If turnout occurred the day before recording, it was limited to light activity not expected to induce fatigue. Prior to each paddock recording, horses underwent routine screening for overt locomotor compromise using (i) an EquiSym® (Arioneo, Paris, France) assessment aimed at detecting marked locomotor asymmetry [31–34], and (ii) a welfare-oriented evaluation using the IFCE “Cheval Bien-Être” application, an adaptation of the AWIN Horse protocol based on animal- and resource-based indicators across four welfare principles (feeding, housing, health, and behavior) and intended for welfare appraisal rather than veterinary diagnosis . For EquiSym® screening, each horse was trotted on two surfaces (firm and soft) under three conditions: a 30-m straight-line out-and-back, five circles to the left, and five circles to the right. EquiSym® outputs (vertical displacement curves and derived asymmetry indicators) were reviewed by a veterinarian to screen for marked left–right asymmetry at the time of recording. Because EquiSym® is a decision-support tool and does not provide a single universally applicable numerical cut-off for exclusion, screening relied on the veterinarian’s interpretation of the device-generated indicators within the standardized trot conditions described above. These procedures were used to document clinical status and to flag sessions potentially affected by acute impairment. No sessions were judged to show marked asymmetry consistent with overt lameness, and therefore no recordings were excluded based on EquiSym® or welfare evaluations.

2.4. Instrumentation and Outcomes

Locomotor activity and displacement were recorded using Polar Team Pro (Polar Electro, Finland) with 10 Hz GNSS sampling. Polar Team Pro has shown acceptable validity and reliability for distance- and speed-related metrics across controlled running conditions, with performance depending on setting (e.g., indoor vs outdoor) and movement pattern [35–38]. Although equine-specific validation of this device in paddock conditions is not available, GPS-based monitoring has been applied in horses in pasture settings [39]. Given the open-sky paddock environment and plausibility-based QC, GNSS-derived total distance and mean speed were used as session-level indicators of turnout locomotor activity in this exploratory study.

The sensor was started at the beginning of each 2-h recording and stored GNSS-derived data. At the end of the session, the sensor was retrieved and recordings were uploaded to the Polar platform, from which session data were exported in spreadsheet format for analysis.

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The primary outcome was total distance covered during the 2-h window, derived from GNSS displacement. A secondary locomotor outcome was mean speed over the same window.

2.5. Meteorological Covariates

Hourly temperature and precipitation totals (mm) were obtained from Météo-France (nearest station: Fontainebleau, Seine-et-Marne, France) and aggregated over each 2-h recording window using overlap-weighted summaries (temperature: mean; precipitation: sum), based on session start times extracted from the Polar platform.

2.6. Ethics Statement (France)

The study involved non-invasive actimetry and routine field measurements. Owners provided informed consent. Horses were accustomed to regular handling and equipment (riding gear). The monitoring device consisted of an externally worn belt and did not involve invasive procedures or any manipulation expected to cause pain, suffering, distress, or lasting harm. Under French regulations governing the use of animals for scientific purposes (Code rural et de la Pêche maritime, Articles R214-88 and R214-89) [40,41], activities not liable to cause pain, suffering, distress, or lasting harm equivalent to or greater than that caused by the introduction of a needle (good veterinary practice) fall outside the scope of regulated experimental procedures; accordingly, no formal project authorization/ethical review was sought for this observational monitoring.

2.7. Data Processing and Quality Control

Quality control additionally targeted GNSS artefacts that can disproportionately affect low-speed movement. Recordings were visually screened for unrealistic displacement spikes and non-physiological speeds. We applied rule-based plausibility checks at the epoch level (10 Hz), including removal of observations with instantaneous speed >15 $m\cdot s^{-1}$ and/or point-to-point displacement >5 m between consecutive samples (0.1 s), before computing session-level totals. Sessions with substantial GNSS signal loss (>20% missing/invalid epochs) or erratic traces were excluded from GNSS-derived analyses. Because low-speed GNSS can show higher relative error, analyses focused on aggregated 2-h session metrics obtained under an open-sky paddock set-up.

These QC steps were implemented a priori. No sessions exceeded the predefined GNSS exclusion thresholds in this dataset.

2.8. Statistical Analysis

All analyses were conducted at the recording level while accounting for repeated measurements within horses. Because multiple 2-h recordings were available for some horses (1–10 per horse), observations were not independent. Treating each recording as an independent data point would risk pseudo replication and overly optimistic standard errors [42]. Therefore, associations between age at recording and locomotor outcomes were evaluated using mixed-effects models (multilevel/hierarchical models) including a random intercept for horse to model within-horse clustering and account the unbalanced follow-up structure [42,43].

2.8.1. Primary Models (Distance and Speed)

For total distance covered during the 2-h paddock window, exploratory residual diagnostics (residuals vs fitted, Q–Q plots, and scale–location plots) indicated right-skew and heteroscedasticity on the natural scale, with improved variance stabilization and approximate normality after log-transformation; distance was therefore log-transformed and analyzed using a linear mixed-effects model:

$$\log(distance_{ij}) = \beta_0 + \beta_1\, age_{ij} + \beta_2\, temperature_{ij} + \beta_3\, precipitation_{ij} + u_{0i} + \epsilon_{ij} \quad (1)$$

with $u_{0i} \sim N(0, \sigma_u^2)$ denoting the horse-specific random intercept and $\varepsilon_{ij} \sim N(0, \sigma^2)$ the residual error. Mean speed was analysed using an analogous mixed-effects model (and log-transformed in sensitivity analyses when diagnostic checks supported improvement).

2.8.2. Between-Horse vs Within-Horse Age Decomposition

Because age varied across recording dates within some horses, age was decomposed into a between-horse component (horse-specific mean age across recordings) and a within-horse component (deviation from the horse mean) to separate cross-sectional from within-horse information:

$$age_{ij} = \overline{age_i} + (age_{ij} - \overline{age_i}) \tag{2}$$

Models were refitted with both terms to assess whether associations were driven primarily by between-horse differences or within-horse change.

2.8.3. Effect Modification (Age × Season, Age × Sex)

Potential effect modification by season and sex was explored a priori because (i) season may capture broad, unmeasured contextual influences on turnout behavior beyond contemporaneous weather covariates (e.g., photoperiod and management-related seasonal routines), and (ii) sex differences in locomotor behavior have been reported in managed horses. To limit multiple testing in this modest sample, we did not systematically screen interactions with additional horse-level covariates (e.g., BCS or estimated body mass) or paddock identity. Paddock effects were minimized by rotating horses across paddocks within a fixed, uniform paddock layout. Interaction models were evaluated using likelihood-ratio tests (ML fits); multiplicity across the four prespecified interaction LRTs (distance×season, speed×season, distance×sex, speed×sex) was controlled using Benjamini–Hochberg false discovery rate (FDR), with q-values reported [44,45].

2.8.4. Sensitivity Analyses and Model Reporting

For log-scale models, fixed-effect estimates are reported as β coefficients with 95% confidence intervals; where interpretation is provided, exp(β) is used to express multiplicative change per 1-year increase (percent difference on the original scale). For distance, a Gamma mixed model with a log link was fitted as a distributional sensitivity analysis for strictly positive outcomes. We retained the log-linear mixed model as the primary specification because it showed satisfactory diagnostic behavior on the transformed scale and provided straightforward interpretation and comparability across outcomes; the Gamma model yielded consistent age estimates. P values for linear mixed models were obtained using Satterthwaite's degrees-of-freedom approximation [46]. To control multiplicity across endpoints, p-values for the age effects (between-horse and within-horse components) across the two outcomes (total distance and mean speed) were adjusted using the FDR procedure, and FDR-adjusted q-values are reported alongside raw p-values. Marginal and conditional R^2 values were reported for mixed models to summarize variance explained by fixed effects alone and by the full model including random effects [47].

2.8.5. Secondary Contextual Comparison (Young vs Senior)

In addition to the senior cohort, a small reference group of younger horses (<17 years) was monitored in the same facility under the same recording protocol. As a secondary, contextual analysis, we compared locomotor outcomes between younger and senior horses using mixed-effects models with a random intercept for horse and adjustment for season, sex, and weather (temperature and precipitation). This comparison was intended to provide descriptive context for the magnitude of locomotor outcomes under the same recording protocol and was not included in the multiplicity correction applied to the primary age-effect hypotheses.

2.8.6. Software

Analyses were performed in RStudio (version 2026.01.0+392) using lme4 for model fitting, lmerTest for inference, and performance for diagnostic checks and model summaries [43,48,49].

3. Results

3.1. Total Distance Covered During the 2-h Paddock Window

In mixed-effects models accounting for repeated recordings (random intercept for horse; n = 122 recordings from 28 horses), log-transformed total distance covered during the 2-h paddock window decreased with age at the session (β = −0.062 per year, 95% CI −0.093 to −0.031; P < 0.001). Temperature (β = 0.011 per °C, 95% CI −0.005 to 0.028; P = 0.19) and precipitation (β ≈ 0.0004 per mm, 95% CI −0.039 to 0.040; P = 0.98) were not associated with log-distance. The intraclass correlation coefficient (ICC) for log-distance was 0.178 (adjusted).

Figure 1 displays the raw relationship between age at recording and total distance covered during the 2-h paddock window.

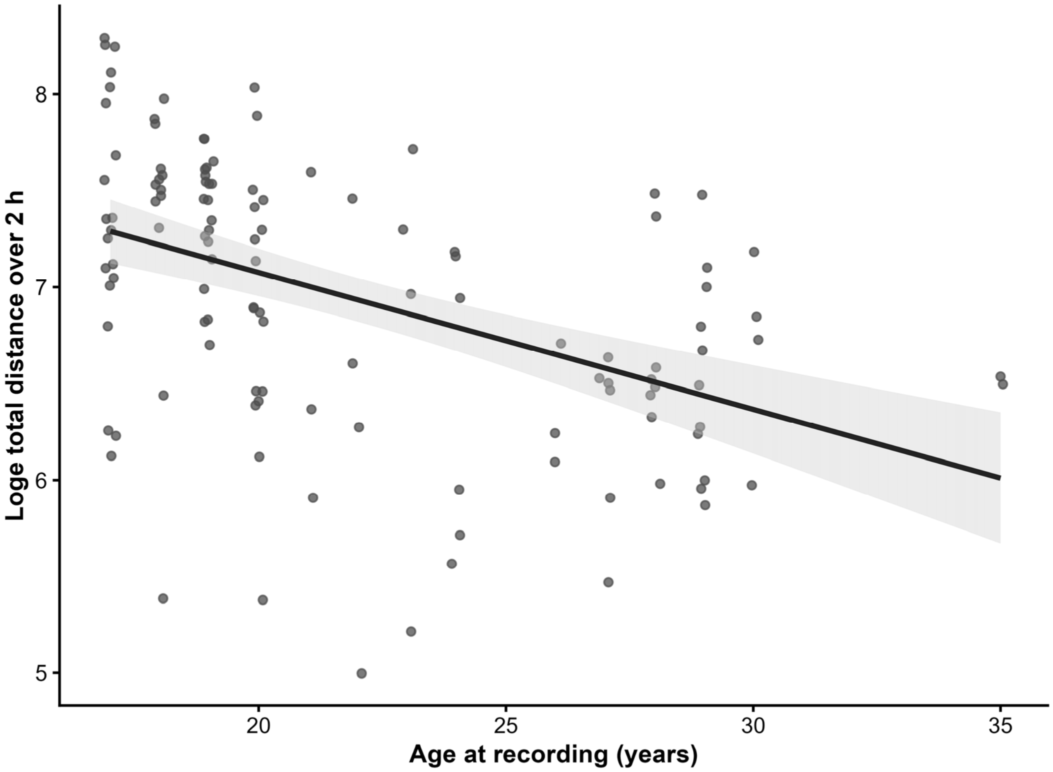

Figure 1. Raw relationship between age at recording and total distance covered during the 2-h paddock window. Scatterplot of 122 2-h recordings from twenty-eight horses. Total distance is shown on the natural log scale (ln). The fitted line is a simple linear regression displayed for visualization (shaded area: 95% confidence band); inferential analyses were performed using mixed-effects models with a random intercept for horse to account for repeated recordings.

To separate cross-sectional from longitudinal information, age was decomposed into between-horse and within-horse components. The between-horse component remained negatively associated with log-distance (β = −0.063 per year, 95% CI −0.094 to −0.032; P < 0.001; FDR q = 0.003), whereas the within-horse component showed no association (β = −0.031 per year, 95% CI −0.217 to 0.155; P = 0.75; FDR q = 0.872).

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As a sensitivity analysis, a Gamma mixed-effects model with a log link yielded consistent results, also showing a negative association between age and total distance (β = −0.058 per year; 95% CI −0.096 to −0.020; P = 0.003).

3.2. Mean Speed During the 2-h Paddock Window

Mean speed showed a similar pattern. In models fitted on the log scale to improve residual diagnostics, the between-horse age component was negatively associated with log(mean speed) (β = −0.060 per year, 95% CI −0.094 to −0.027; P = 0.00169; FDR q = 0.003), while the within-horse component was not supported (β = −0.016 per year, 95% CI −0.209 to 0.177; P = 0.87; FDR q = 0.872). Temperature (β = 0.011 per °C, 95% CI −0.006 to 0.028; P = 0.22) and precipitation (β = −0.005 per mm, 95% CI −0.046 to 0.036; P = 0.81) were not associated with log(mean speed). The ICC for log-speed was 0.192 (adjusted).

Age effects for distance and mean speed are summarized in Figure 2 (between- and within-horse components; log scale), with 95% confidence intervals and BH-FDR-adjusted q-values.

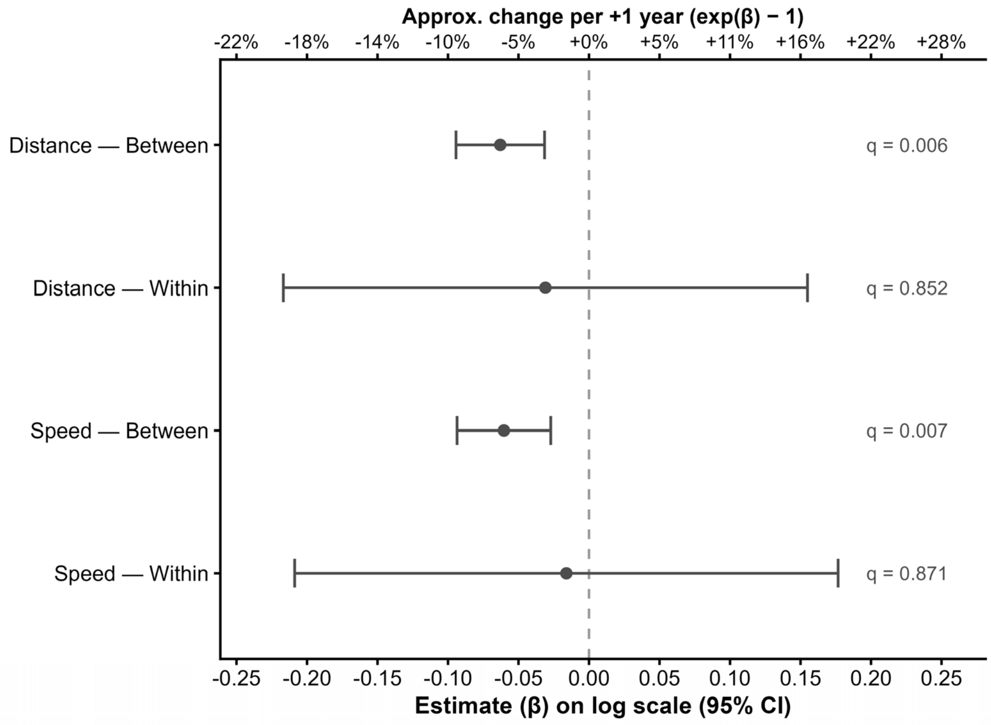

Figure 2. Between-horse and within-horse age effects on locomotor outcomes. Fixed-effect estimates (β) and 95% confidence intervals from mixed-effects models with random intercept for horse, after decomposing age into between-horse (horse mean age across recordings) and within-horse (deviation from horse mean) components. Outcomes are modelled on the log scale; exp(β) gives the multiplicative ratio associated with a 1-year difference in age. FDR-adjusted q-values (Benjamini–Hochberg) are reported for the age terms. For example, β = −0.063 corresponds to exp(−0.063) ≈ 0.94, i.e., an estimated ~6% lower total distance for a horse that is 1 year older (between-horse component), holding covariates constant. Over a 5-year difference, the expected ratio is exp(5×β) = exp(−0.315) ≈ 0.73, corresponding to ~27% lower distance for a horse that is 5 years older (e.g., 25 vs 20 years), under the model's assumption of a constant multiplicative change per year.

3.3. Summary of Explained Variance and Variability (Distance Model)

For the log-distance model, fixed effects explained approximately 20% of the variance (marginal R^2 = 0.20), while including the horse-level random intercept increased explained variance to 34%

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(conditional $R^2 = 0.34$), indicating substantial between-horse variability and residual within-horse variability under field conditions.

3.4. Exploratory Interaction Analyses

Exploratory interaction analyses provided no evidence that adding age×season interactions improved fit for total distance (LRT $\chi^2(9)$=11.42, P=0.248; BH-FDR q=0.331) or mean speed (LRT $\chi^2(9)$=9.26, P=0.414; BH-FDR q=0.414). Similarly, age×sex interaction models did not improve fit for distance (LRT $\chi^2(2)$=4.47, P=0.107; BH-FDR q=0.214) or speed (LRT $\chi^2(2)$=4.77, P=0.092; BH-FDR q=0.214). Type III Wald tests suggested a nominal age_mean_id×sex term for speed (P=0.047) (and a trend for distance, P=0.057), but these were not supported by the global LRTs and were not interpreted as confirmatory.

3.5. Secondary Contextual Comparison (Younger vs Senior Horses)

To provide a contextual reference for the magnitude of locomotor outcomes, we additionally analyzed a small group of younger horses (see Table 1) recorded in the same facility under the same 2-h turnout protocol. In mixed-effects models with a random intercept for horse and adjustment for season, sex, temperature, and precipitation, senior horses (≥17 years) showed lower locomotor activity than younger horses, with lower log-total distance ($\beta = -0.570$, 95% CI −0.930 to −0.211; P = 0.005) and lower log-mean speed ($\beta = -0.556$, 95% CI −0.921 to −0.192; P = 0.007). On the log scale, these estimates correspond to 44% lower total distance ($\exp(\beta) = 0.565$) and 43% lower mean speed ($\exp(\beta) = 0.573$) in seniors compared with younger horses. The ICCs for horse-level clustering were 0.318 (unadjusted) and 0.304 (adjusted) for log-distance, and 0.304 (unadjusted) and 0.293 (adjusted) for log-speed.

4. Discussion

This single-site observational field study suggests that a 2-h turnout recording protocol can detect cross-sectional associations between chronological age and GNSS-derived turnout activity metrics among senior horses under this facility's routine management. In mixed-effects models accounting for repeated measures, both total distance and mean speed were negatively associated with age after adjustment for meteorological covariates. Decomposing age into between-horse and within-horse components indicated that the associations were supported by the between-horse component, whereas within-horse change was not detectable with the available follow-up structure. A small, non-matched reference group of younger horses recorded under the same protocol showed higher locomotor metrics; this secondary comparison is reported for contextual description only.

4.1. Interpretation of Cross-Sectional Associations Between Age and Paddock Locomotion

The observed cross-sectional association between age and lower turnout activity may reflect multiple, non-mutually exclusive factors. Field studies report a high burden of chronic conditions in geriatric horse populations, including musculoskeletal abnormalities [13,14,50], and age-related changes in muscle properties have been described [3,7]. However, because we did not perform standardized clinical phenotyping, these literature-based factors cannot be evaluated in the present dataset and should be considered only as potential contributors.

Our study did not include standardized clinical examinations, diagnostic imaging, or systematic comorbidity assessment, and therefore cannot determine whether the observed age associations reflect intrinsic biological ageing processes, accumulated pathology (whether diagnosed or subclinical), cohort effects, or selective survival of less active individuals. The cross-sectional design further precludes inference about within-individual change over time. Alternative explanations include: (1) older horses in this population may have different lifetime athletic histories or management backgrounds compared to younger horses; (2) horses remaining in the population at advanced ages may represent a selected subset (survivor bias); (3) unmeasured factors such as hoof

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quality, dental status, metabolic or endocrine conditions (e.g., PPID, EMS), or chronic low-grade pain could confound age-activity associations.

Paddock actimetry captures self-selected locomotion under routine management rather than maximal performance capacity, and may therefore be sensitive to subtle, multifactorial constraints on voluntary movement. Determining the clinical correlates and drivers of lower turnout activity with age will require prospective studies combining repeated turnout recordings with standardized clinical phenotyping (e.g., systematic lameness examination and, where appropriate, diagnostic imaging and endocrine/metabolic assessment) and richer contextual covariate capture. Such studies would enable mechanistic testing of the hypotheses generated by the present cross-sectional observations.

4.2. Why the Association Is Mainly Made Between Horses

The absence of a statistically detectable within-horse age association does not demonstrate that individual horses show no change over time. Rather, it indicates that any within-horse trajectories could not be estimated with sufficient precision given the measurement variability and sparse longitudinal structure of this dataset [51,52]. In mixed-effects frameworks, within-horse effects are identified from deviations around each horse's own mean trajectory and therefore require sufficient within-subject variability and repeated observations to estimate slopes with acceptable precision [51,53]. Here, the follow-up structure was unbalanced (1–10 recordings per horse), with recordings separated by months and several horses contributing only one or two sessions, reflecting real-world constraints in a privately owned yard (e.g., changes in ownership or boarding location and, in some cases, death/euthanasia in very old horses), a common feature of applied longitudinal studies that can substantially reduce power for within-subject inference even when mixed models appropriately accommodate missingness and unequal sampling [52]. In practice, sparse sampling and variable follow-up intervals increase uncertainty around individual change estimates and make within-horse effects particularly sensitive to measurement noise and short-term fluctuations, whereas between-horse contrasts remain comparatively well-informed by cross-sectional differences [51,52]. In addition, turnout movement behavior is strongly shaped by contextual constraints that can amplify within-horse variability and reduce sensitivity to gradual functional decline. Equine time-budget and sensor-based studies consistently report large variation in locomotion and movement-related behaviors across farms and management systems, indicating that husbandry and environment can contribute substantial between-horse and between-context variance in free-living activity [24,54]. Even within the same broad category of horses (e.g., geriatric horses), activity phenotypes can appear similar or different depending on housing and management conditions, reinforcing the idea that contextual factors may mask subtle within-horse ageing trajectories when sampling is sparse [24]. Taken together, these considerations support the interpretation that the age association observed here is predominantly between horses, and that detecting within-horse ageing trajectories will likely require denser repeated measurements, longer observation horizons, and richer contextual covariate recording to reduce residual variance under field conditions.

4.3. Effect Modification by Season and Sex

Effect modification by season and sex was examined exploratorily because turnout behavior is context-dependent and both seasonal/management factors and sex have been reported to influence equine activity time budgets and movement patterns in field settings [24,54]. Interaction models provided no supported evidence that the age association differed by season or sex, and a nominal age×sex term suggested by a Wald test for speed was not supported by the corresponding global interaction test and was not interpreted as confirmatory. Power to detect effect modification was limited by the temporal sampling scheme (approximately one observation per season per horse in many cases), and denser repeated recordings would be required to characterize within-horse seasonal variability and improve sensitivity to interaction effects.

4.4. Variability Under Field Conditions and Implications for Measurement Strategy

The mixed-model R^2 values support this interpretation. Fixed effects explained about one-fifth of the variance in log-distance (marginal $R^2 = 0.20$), whereas including the horse-level random intercept increased explained variance to 0.34 (conditional $R^2 = 0.34$), highlighting substantial between-horse variability alongside considerable residual variability at the session level [43]. These results reinforce two practical implications for field use. First, repeated measurements within individuals are likely to be more informative than single cross-sectional observations when the outcome is behaviorally driven and subject to high day-to-day variability. Second, recording contextual covariates (e.g., paddock surface/condition, feeding timing, social context, and local weather during the 2-h recording window) may improve statistical adjustment and reduce unexplained variance in field monitoring. The absence of detectable effects of temperature and precipitation in this study should be interpreted cautiously, because station-derived measures—even when aggregated over the 2-h window—may not fully capture paddock micro-conditions experienced by the horse (e.g., wind exposure, solar radiation, localized surface moisture), and measurement error can attenuate associations [55,56]. In addition, limited ranges of weather conditions within a single facility or seasonally clustered sampling can further constrain power to detect modest meteorological effects on spontaneous locomotion.

4.5. Implications and Future Directions

From a practical perspective, these findings support the feasibility of short-duration field actimetry to provide an objective readout of functional variation among older horses under routine management conditions. In this dataset, the sampling structure and field variability limited the ability to resolve within-horse trajectories, which motivates future designs that prioritize stronger longitudinal inference.

Larger multi-site cohorts would increase heterogeneity in management and environmental contexts and improve generalizability, while also enabling explicit modelling of site-level effects. Denser repeated measurements within horses would increase precision for estimating within-horse change and help distinguish gradual decline from short-term behavioral fluctuation.

Longer monitoring windows (e.g., multi-day recordings) would better capture daily rhythms and time-budget structure, providing more stable individual activity signatures than a single 2-h snapshot. Future work should also implement finer context logging of the recording window by logging the ground/surface conditions (e.g., dry vs muddy), forage availability (hay/grass) during the 2-h period, and notable behavioral events (e.g., rolling, agitation or acute stress), because these factors can meaningfully influence turnout locomotion and inflate within-horse variance.

Beyond total distance and mean speed, extracting richer activity features that may be more robust to context, such as bout structure (number and duration of locomotor bouts), inactivity time, and within-session variability or fragmentation, could improve sensitivity to functional differences and enhance individual stability. Short-term repeatability should be quantified in a subset of horses using two to three closely spaced sessions (e.g., within the same week), as this would characterize measurement noise and inform the minimum number of repeats required for reliable monitoring.

Finally, systematic recording of comorbidities and medications (e.g., analgesics/anti-inflammatories, PPID treatment with pergolide), hoof/farriery status, and recent laminitis episodes will be important, because these factors can modify locomotor output and increase unexplained within-horse variability. Linking actimetry-derived outcomes to independent clinical endpoints, such as lameness and pain scores, endocrine status (e.g., PPID/EMS screening), structured muscle condition scoring, and owner-reported quality of life, will be important for validating the clinical meaning of reduced turnout locomotion and for developing multidimensional geriatric monitoring approaches. In this context, activity-derived digital phenotypes may ultimately contribute to functional ageing indices, but such applications will require prospective calibration and external validation.

4.6. Limitations

These findings should be interpreted considering several design, measurement, and clinical-characterization limitations. Indeed, external validity is limited because recordings were collected in a single private yard, which may restrict generalizability to other management systems and environmental contexts. The sample size was modest (28 horses; 122 recordings), and follow-up was unbalanced (1–10 recordings per horse). Although mixed-effects modelling accounted for repeated measures and unequal numbers of observations, the follow-up remained unbalanced. This reflected real-world attrition and management changes (including relocation, ownership changes, and, in some cases, death or euthanasia in older horses), which likely reduced precision for within-horse inference and introduced the possibility of informative missingness that could not be formally quantified. Residual confounding by health status also remains possible because horse-level clinical phenotyping was not standardized (e.g., systematic lameness examination, imaging, endocrine/metabolic screening, and comprehensive medication documentation), including no standardized veterinary diagnostic work-up for PPID or EMS. This is particularly relevant in senior horses, in whom subclinical comorbidities may influence spontaneous turnout locomotor activity. In addition, session-level contextual determinants of turnout locomotion (e.g., footing/substrate conditions, paddock micro-conditions, and salient behavioral events during the 2-h window) were not fully quantified, and station-derived weather covariates may incompletely capture paddock conditions during the specific recording period. Device validity represents another limitation. Polar Team Pro GNSS metrics have been validated primarily in humans, and equine-specific validation under paddock conditions is lacking. Measurement error, particularly at low speeds, may therefore have attenuated associations, despite plausibility-based quality control and an open-sky recording set-up. Finally, the 2-h recording window provides only a partial snapshot of turnout behavior, and short-term test–retest reliability of this window was not assessed.

5. Conclusions

Despite these limitations, the present findings support the feasibility of short-duration paddock actimetry as a low-burden, welfare-relevant field approach for characterizing locomotor activity heterogeneity in senior horses. In this single-site observational study, a 2-h paddock recording was sufficient to detect cross-sectional associations between chronological age and GNSS-derived turnout activity metrics under routine management conditions.

Across 122 recordings from 28 horses aged 17–35 years, older age at recording was associated with lower total distance and mean speed after accounting for repeated measures and meteorological covariates. Decomposition of age into between-horse and within-horse components indicated that these associations were driven primarily by between-horse differences, whereas within-horse age-related change could not be estimated with confidence given the sparse and unbalanced follow-up typical of field settings.

Overall, the results of this pilot study support the use of wearable paddock actimetry to describe age-related locomotor heterogeneity at the group level in senior equine populations, while emphasizing cautious interpretation of cross-sectional associations at the individual level. However, larger multi-site cohorts with denser longitudinal follow-up, standardized clinical phenotyping, and external welfare/clinical validation are needed before paddock actimetry can be interpreted as an individual monitoring tool for functional ageing in senior horses.

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Informed Consent Statement: Written informed consent was obtained from the owners of all horses prior to participation in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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