Journal of Equine Veterinary Science 88 (2020) 102971

Contents lists available at ScienceDirect

Journal of Equine Veterinary Science

journal homepage: www.j-evs.com

Original Research

Validation and Implementation of an Automated Chew Sensor–Based Remote Monitoring Device as Tool for Equine Grazing Research

Jennifer R. Weinert [a,*], Jessica Werner [b], Carey A. Williams [a]

[a] Department of Animal Sciences, Rutgers, The State University of New Jersey, New Brunswick, NJ
[b] Animal Nutrition and Rangeland Management in the Tropics and Subtropics, University of Hohenheim, Stuttgart, Germany

ARTICLE INFO

Article history:
Received 19 November 2019
Received in revised form
13 February 2020
Accepted 14 February 2020
Available online 2 March 2020

Keywords:
EquiWatch
RumiWatch
Chew sensor
Grazing behavior

ABSTRACT

Field studies characterizing equine grazing activity primarily rely on observational protocols, limiting the quantity and accuracy of collected data. The objectives of this study were to validate an automated chew sensor technology, the EquiWatch System (EWS), for detecting grazing behaviors and to demonstrate potential applications of the EWS in equine grazing research. Eight mature standardbred mares were used in this study. EquiWatch System validation was completed in two phases: grazing time was evaluated in experiment 1 and chew counts in experiment 2. The correlation between visual observations and system-recorded grazing time was high (concordance correlation coefficient [CCC] = 0.997). There was also a high agreement between the sum of manually counted bites and chews and total chew counts reported by the EWS (CCC = 0.979). Following validation, a pilot study was conducted using the EWS to assess feeding behaviors of horses with unrestricted pasture access (PAS) versus horses offered *ad libitum* hay (HAY). Horses spent more time engaged in feeding behavior on PAS (14.79 ± 0.48 hr/d) than HAY (11.98 ± 0.48 hr/d; $P < .0001$). Chewing rate also differed by forage (PAS 83.92 ± 1.61; HAY 68.50 ± 1.61 chews/min; $P < .0001$). However, although the magnitude of these behavioral parameters was influenced by treatment, the underlying 24-hour patterns were largely preserved regardless of forage type. These results demonstrate that the EWS can generate data necessary for characterizing feeding behavior in horses. Future studies implementing this tool could provide a greater understanding of biological, environmental, and nutritive factors driving grazing behavior in horses.

1. Introduction

Equine grazing studies that incorporate behavioral assessments have traditionally relied on observational methodologies for evaluation of grazing activity. These observational protocols limit both the accuracy and quantity of collected data. Observational studies are inherently time intensive and labor intensive. As a result, few such studies report a complete and continuous 24-hour dataset (but see, e.g., [1–5]). Rather, common practice involves collecting data within a subset of limited-duration representative observational periods and extrapolating from these data to estimate or draw conclusions regarding daily feeding/grazing behaviors (see, e.g., [6–10]). As grazing activity varies over the course of a day, the timing of designated observational periods may impact reported values [1,4,6]. In addition, the selected time interval between consecutive observations, particularly for longer duration observational periods, is often 10–15 minutes, with data reported from interobservational intervals as long as 30 minutes [1,3,6,7,11]. Obtaining a full 24-hour dataset using observational methodologies, thus requires concessions in experimental design. This has

Animal welfare/Ethical statement: The authors wish to confirm that the use of animals for all trials in the paper were approved by the Rutgers University Institutional Animal Care and Use Committee protocol #PROTO201800013.

Conflict of interest statement: The authors wish to confirm that there are no known conflicts of interest associated with this publication, and there has been no significant financial support for this work that could have influenced its outcome. The authors confirm that the manuscript has been read and approved by all named authors, and that there are no other persons who satisfied the criteria for authorship but are not listed. They further confirm that the order of authors listed in the manuscript has been approved by all of them. The authors confirm that they have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, with respect to intellectual property. In so doing, the authors confirm that they have followed the regulations of our institutions concerning intellectual property. The authors understand that the corresponding author is the sole contact for the Editorial process (including Editorial Manager and direct communications with the office). He/she is responsible for communicating with the other authors about progress, submissions of revisions, and final approval of proofs. The authors confirm that they have provided a current, correct email address, which is accessible by the corresponding author and which has been configured to accept email.

* Corresponding author at: Jennifer R. Weinert, Department of Animal Sciences, Rutgers, The State University of New Jersey, 84 Lipman Dr, New Brunswick, NJ 08901.
E-mail address: jennifer.weinert@rutgers.edu (J.R. Weinert).

https://doi.org/10.1016/j.jevs.2020.102971
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been accomplished in previous studies by reducing the resolution of observations [11], collating data from staggered or incomplete observational periods occurring over multiple days [1,3], and/or limiting the number of animals for which data are collected [1].

Observational studies are also limited by visibility concerns or line-of-sight obstructions, which are often difficult to overcome in a field setting. This is evidenced by the large volume of studies reporting only day-time grazing data [6–10]. Furthermore, the physical presence of observers could potentially influence natural feeding behaviors. However, close proximity of observers may be necessary, particularly when performing manual counts of parameters such as chews or bites, as such counts are challenging to collect accurately in real time in the field.

Continuous automated monitoring systems represent an alternate strategy for quantifying the behavior of horses maintained on pasture, but the application of this approach has seen limited use in equine pasture studies. Using the telemetry-based system, Ethosys (IMF Electronic; GmbH, Frankfurt, Germany), Berger et al [2] collected continuous 24 hour data for four horses over a period of a full calendar year; this is, to date, the most complete published equine grazing behavior dataset. The Ethosys system was subsequently used to characterize grazing behavior of a separate group of semiferal horses in a mixed-animal grazing study [12] and, more recently, to quantify grazing time for horses consuming pastures with varying available herbage allowances [5].

Although not widely adopted in equine grazing research, there is a comparatively extensive history of automated monitoring approaches in cattle grazing studies [13]. One such commercially available technology, the RumiWatch System (RWS; Itin + Hoch, GmbH, Liestal, Switzerland), functions as a chew sensor [14]. Initially developed by Nydegger and Bollhalder [14], the RWS has been validated for the detection of feeding behavior parameters in cattle managed in both indoor housing [15,16] and pasture grazing systems [17,18]. An equine version of the RWS, the EquiWatch System (EWS; Itin + Hoch; GmbH), was validated for the detection of jaw movement in stalled horses consuming small meals of concentrate, silage, or hay [19]. The percent agreement between the EWS and complementary visual observations was 93% across all feedstuffs tested and was 95% when forages were evaluated alone [19].

However, the accuracy of the EWS in reporting grazing behaviors of horses consuming pasture forage has not been previously evaluated. Therefore, the objective of this study was to validate the EWS as a measurement tool for detecting and quantifying grazing behaviors (including grazing duration and counts of bites and chews) of horses on pasture and to demonstrate potential applications of the EWS in equine grazing research.

2. Methods

All experiments were conducted at the Ryder's Lane Environmental Best Management Practices Demonstration Horse Farm (Rutgers, The State University of New Jersey) in New Brunswick, New Jersey (40.4862°N, 74.4518°W). The EWS validation was completed in two separate experiments over the months of July, August, and September 2018, followed by a pilot grazing trial in October to November 2018.

2.1. Animal Management

Use of animals for all trials was approved by the Rutgers University Institutional Animal Care and Use Committee protocol #PROTO201800013. Eight healthy mature Standardbred mares were used for both validation and pilot studies. Horses received regular veterinary and dental health care administered through the Rutgers University Animal Care Program, with the most recent dental examinations conducted within 6 months before the start of the study. Before the first phase of validation, horses had been maintained on previously established cool-season grass rotational pastures containing a mix of Inavale Orchardgrass, Tower Tall Fescue (endophyte-free), and Argyle Kentucky Bluegrass (DLF Pickseed, Halsey, OR) since the beginning of the grazing season in June 2018 and were offered supplementary mixed cool-season grass hay only when pasture forage availability was insufficient for grazing. Horses were managed in separate fields in two randomly assigned groups of four horses. Groups were age and body condition score (BCS; [20]) matched. Initial mean age, BCS, and body weight (BW) for each group is as follows: Group 1—18.0 ± 0.85 years; 5.5 ± 0.20 (BCS), 542 ± 14 kg; Group 2—17.7 ± 0.44 years; 5.75 ± 0.34 (BCS), 543 ± 21 kg.

2.2. EquiWatch System

The physical and software components of the EWS are the same as those for the RWS. The system components and their functions have been described in detail in previous publications [16,18,19,21]. In brief, EWS data are generated at a frequency of 10 Hz using output from two sensors, a pressure sensor (primary) and a triaxial accelerometer (secondary), which are built into the noseband of a halter. This output is stored in a data logger containing an SD card, which can be formatted to record and store data for up to a 4-month period (battery life with continuous recording is 100 days). The EWS units (halters) are managed and monitored through the software application RumiWatch Manager 2 (version 2.0.0). Raw data downloaded from the data logger on the EWS unit are then processed by the RumiWatch Converter (version 0.7.4.15) software. The algorithms of the RumiWatch Converter identify patterns in the raw output from the pressure sensor and accelerometer. Specific behaviors (eating, drinking, other activity, etc.) are assigned based on the recognized pattern signatures. The RumiWatch Converter includes a "Horse Mode" option for transforming the raw data collected from the EWS halters into summaries (Microsoft Excel format) of feeding behavior parameters at intervals specified by the user.

2.3. Validation Study

2.3.1. Experiment 1

The objective of this experiment was to determine if the EWS could accurately report the grazing time of horses on pasture. In the week before the first phase of validation, each horse was fitted with the EWS for an 8-hour period to provide acclimation to the EWS halter. Two observers were trained to conduct visual observations using a 1-minute scan sampling technique [22] previously employed for validation of the RWS in grazing cattle [18]. The agreement of these observers was then assessed over two consecutive 2-hour observational periods.

During testing periods, horses were maintained in their original groups and fields with full access to one rotational pasture section (0.3 ha) and a dry lot with a shelter and automatic waterer. Sixteen days of data collection were conducted over a 1-month period; data collection days were not consecutive because of weather-related constraints. On each day of data collection, two of the mares were selected for testing and fitted with EWS halters; the pair of observed horses for each day of the experiment was within the same group (of four horses). Each pair of horses was observed on four separate days. Observations were conducted during two separate 2-hour periods (0730–0930; 1,000–1,200) each day. In total, 16 hours of data were thus collected for each of the eight horses. On each day of the experiment, one of the two trained observers was randomly assigned to conduct complementary visual observations (one observer and two horses observed). The observer was positioned to have a complete and unobstructed view of the available pasture section and dry lot area. The observer classified horse behavior as either grazing activity (actively consuming pasture forage) or other activity (other behaviors such as free movement across fields, drinking, standing/resting, etc.).

2.3.2. Experiment 2

The objective of this experiment was to assess the ability of the EWS to accurately detect and count individual bites and chews in grazing horses. In this second phase of validation, a series of 12 separate 5-minute videos were recorded for each of the eight EWS-fitted horses during times in which horses were engaged in grazing activity. For each horse, one additional nongrazing video was recorded to serve as a negative control. During the negative control periods, horses were confined to a dry lot and were not allowed to graze or feed. Horses were, however, free to engage in other activities with an oral component such as drinking, licking, biting at flies, chewing on edges of shelter boards, and so on, during these periods. Videos were recorded between the hours of 7:30 AM and 12 noon.

Videos were recorded on a tablet device and subsequently uploaded to desktop computers where they were observed using media management software (Microsoft Movie Maker, Windows 10; Microsoft Inc, Redmond, WA) that allowed videos to be slowed to half-speed to improve count accuracy. Each grazing video was then observed at half-speed by two trained observers at two separate times, once to count prehensive bites (PBs) and a second time to count mastication chews (MCs). A jaw movement was classified as a PB whenever the incisors were used to grasp and tear pasture forage, bringing a new mouthful of grass into the horse's mouth. When the molars, but not the incisors, were engaged in grinding the ingested bolus, the jaw movement was interpreted as an MC. Bites and chews were counted using hand-held clicker-counters. Each observer thus conducted a total of 260 minutes of observations for each of the eight horses.

2.4. Pilot Study

Following the validation experiments, a pilot study was conducted to demonstrate potential research applications of the EWS. The objective of this study was to assess the influence of forage type (cool-season grass pasture [PAS] vs. *ad libitum* orchardgrass hay [HAY]) on equine feeding behaviors. This study implemented a randomized cross-over design in which the two groups of horses were randomly assigned to either PAS or HAY for one of two 7-day treatment periods. Each treatment period was preceded by a 7-day acclimation to the respective forage type. Areas used for the treatments were nonadjacent, preventing direct visual observation between groups of horses. During treatment periods, daily temperature and total precipitation were tracked using weather data from the New Brunswick Station obtained from the website for the Office of the New Jersey State Climatologist at Rutgers University [23].

2.4.1. Forage Treatments

Horses in the PAS treatment had access to two rotational pasture sections (0.25 ha/section) as well as an attached dry lot (0.16 ha) for a total accessible area of 0.66 ha. A shelter and an automatic waterer were located within the dry lot. On the day preceding each treatment period, available forage in PAS sections was estimated by hand-clipping four random 0.5 m $\times$ 0.5 m subquadrants in each rotational section to 7.6 cm (minimum allowable grazing height based on established pasture best management practices) using previously published methods [24]. Clipped samples were placed in a paper bag, dried at 60°C in a Thelco (Precision Scientific, Chicago, IL) oven to remove moisture content and obtain a dry matter (DM) weight, which was then used to estimate available herbage mass (kg/ha). On the first day of each treatment period, one composited hand-clipped (to a 7.6 cm height) pasture forage sample was collected from each of the two available pasture sections at 8 AM. Samples were dried, ground to 1 mm with a Wiley Mill (Thomas Scientific, Swedesboro, NJ) and submitted to Equi-Analytical Laboratories (Ithaca, NY) for wet chemistry analysis.

During the HAY treatment, horses were housed in a large dry lot (0.33 ha) with access to shelter and an automatic waterer. The feeding strategy for the HAY treatment was designed to mimic pasture conditions as closely as possible and avoid a confounding meal effect. Small square bales of orchardgrass hay were weighed before feeding to determine forage offered, and flakes were fed on the ground spread out throughout the dry lot. Hay was distributed the evening before the start of the treatment period and was replenished every 2–3 days as available forage diminished or weather conditions necessitated. All hay used in this trial was harvested at the same crop (first-cutting) and from the same field. One representative hay sample was collected for nutrient analysis (Equi-Analytical) by coring each of 10 bales in three separate locations.

2.4.2. Horse Measurements

All eight horses were fitted with EWS halters on the day before the start of each treatment period, and horses wore the EWS halters for continuous data collection for the duration of the treatment period. On three alternate days of each treatment period, global positioning system (GPS) monitors (Garmin Astro 430 Dog Tracking System, Olathe, KS) were attached to the crownpiece of the EWS halters for tracking of voluntary movement.

2.5. Data Preparation

Raw EWS data were transferred from EWS halter data loggers via the built-in micro-USB port and connected USB cable. Data were processed with the RumiWatch Converter to generate 1-minute summaries of feeding behavior parameters. For the purposes of this study, the following system parameters were used: EATUPTIME, EATDOWNTIME, EATUPCHEWS, EATDOWNCHEWS, GRAZEBITES, GRAZEBOUTSTART, GRAZEBOUTFINISH, GRAZEBOUTDURATION, and OTHERJAWMOVEMENTS. The system algorithms for EATDOWNTIME and EATUPTIME specify the duration of time within each minute that a horse was engaged in eating behavior with the head either down at sward level or elevated (but still chewing), respectively. Similarly, EATDOWNCHEWS and EATUPCHEWS parameters are defined by the system algorithms as the number of chews conducted with the head in either the down or up positions. The GRAZEBITES parameter provides the system's count of prehensive grazing bites. GRAZEBOUTSTART and GRAZEBOUTFINISH indicate that a grazing bout has commenced or ended (respectively), whereas GRAZEBOUTDURATION provides the total time of an individual grazing bout. The EWS software defines a grazing bout as a period of grazing activity extending for a minimum of 7 minutes with an interbout interval of 7 minutes. The OTHERJAWMOVEMENTS parameter serves as a count of all jaw movements detected by the EWS that the system classified occurring during nonfeeding behaviors.

For the validation study, the EWS output was then compared with recorded visual observations. For experiment 1, the total of EATUPTIME and EATDOWNTIME reported by the EWS was calculated and compared with the total time engaged in grazing activity for each of the 120-minute test periods. For Experiment 2, the manual PB and MC counts were each compared with EWS output parameters, including EATUPCHEWS, EATDOWNCHEWS, and GRAZEBITES. The sum of PB and MC counts were also compared with the sum of EATUPCHEWS and EATDOWNCHEWS reported by the EWS.

2.6. Statistical Analysis

2.6.1. Validation Study

Statistical analysis of validation study data was performed using SAS (version 9.4; SAS Institute, Cary, NC). Concordance correlation coefficients (CCCs) and Spearman's Rank correlations (r_s) between visual observations and data output from the EWS were generated using the CORR procedure and interpreted using previously defined criteria [25], wherein negligible = 0.0–0.3, low = 0.3–0.5, moderate = 0.5–0.7, high = 0.7–0.9, and very high = 0.9–1.00. Agreement between methods was also assessed through graphical Bland-Altman-Plot analyses by plotting differences (EWS output–visual observation) against the means of all measures (EWS and visual) to generate the bias (mean difference) and limits of agreement (95% confidence interval [CI]). Following previous interpretations [20,26], the bias was considered significant (significant underestimation or overestimation) if the line of equality was not within the 95% CI. Agreement between observers in Experiment 1 was evaluated by calculating Cohen's Kappa (κ) [27], with the κ values interpreted as follows: poor $\leq$ 0.00, slight = 0.00–0.20, fair = 0.21–0.40, moderate = 0.41–0.60, substantial = 0.61–0.80, and almost perfect = 0.81–1.00 [28]. In Experiment 2, accordance between the two observers was assessed over all reported counts for total chews by calculating the CCC.

2.6.2. Pilot Study

The data were processed first by excluding any days in which there was inclement weather (heavy rain or snow) or days in which hay was replenished in the HAY treatment for a final dataset that included 4 days per period. The RumiWatch Converter software was used to generate hourly and daily summaries from the raw EWS output. Behavioral variables assessed using daily summaries included totals for feeding time, counts of chews, and other non-feeding jaw movements, and feeding bouts and means for chewing rate and bout duration. Data from the EWS hourly summaries were then binned into eight 3-hour time blocks to evaluate 24-hour patterns for feeding time and chewing rate: Block 1 = 0,000–0,259, Block 2 = 0,300–0,559, Block 3 = 0,600–0,859, Block 4 = 0,900–1,159; Block 5 = 1,200–1,459; Block 6 = 1,500–1,759; Block 7 = 1,800–2,059; Block 8 = 2,100–2,359. Daily summaries were also generated from GPS data for total distance traveled, mean speed, and total time spent in motion. Gross values for these parameters were evaluated in addition to values adjusted for the available area (ha) in each treatment.

For all data, normality was assessed using a Shapiro–Wilkes test. Data from daily summaries were analyzed by two-way analysis of variance (ANOVA) using the day as a repeated measure in SAS (version 9.4). The initial model included day, period, forage, and their interactions. The binned 3-hour time block data and differences between consecutive time blocks were first analyzed by two-way mixed model ANOVA with the repeated statement in SAS. The initial model included day, period, forage, time (3-hour bin time), and the forage $\times$ time block interaction. Because the effects of day and period were not significant for either daily or hourly binned data, this effect was removed, and ANOVAs were performed on the reduced model. For multiple pair-wise comparisons, Tukey's post hoc test was used to determine the differences between the main effects. The results were considered significant at $P \leq .05$; trends were considered at $P < .10$. Data are presented as means $\pm$ standard error.

For pattern analysis of 24-hour binned data, differences between consecutive time blocks were calculated (Diff A = Block 2–Block 1; Diff B = Block 3–Block 2; Diff C = Block 4–Block 3; Diff D = Block 4–Block 3; Diff E = Block 5–Block 4; Diff F = Block 6–Block 5; Diff H = Block 7–Block 6; Diff I = Block 8–Block 7; Diff J = Block 1–Block 8), and these differenced values were analyzed by ANOVA as indicated earlier for daily and hourly binned data. Finally, the binned data were also subjected to cosinor analysis for biological rhythms [29] using a SAS Macro [30] developed for single cosinor analysis using periodic regression of time series data with the period set at 24 hours. This procedure included a test for the normality of residuals (Shapiro–Wilkes test) as well as a zero-amplitude test. Based on the fitted cosine curve, the following rhythm parameters were also calculated using this procedure: the rhythm-adjusted mean (MESOR), amplitude (AMP = difference between maximum curve value and MESOR), acrophase (ACR = time of maximum curve value), and goodness of fit (R^2) for each horse in each treatment period. These parameters were then also analyzed by ANOVA.

3. Results

3.1. Validation Study

3.1.1. Interobserver Agreement

The kappa statistic generated for interobserver agreement in experiment 1 reflected almost perfect agreement, with κ = 0.96. The accordance between observers in experiment 2 was also very high, with a CCC of 0.992.

3.1.2. Experiment 1

Summary statistics for EWS and visual observations are shown in Table 1. The correlation between observed and system-recorded grazing time was very high (CCC = 0.997; R_s = 0.979; $P < .0001$), and these results were further confirmed through graphical Bland-Altman Plot analysis (Fig. 1A) showing a bias of −0.31 minutes over the 120-minute observational period. The upper and lower limits of agreement were 3.03 and −3.66, respectively. As the line of equality fell within this 95% CI, the bias was not considered significant.

3.1.3. Experiment 2

Evaluation of the EWS data output for EATUPCHEWS, EATDOWNCHEWS, and GRAZEBITES found that none of these parameters had an acceptable agreement with either manually counted PB or MC when evaluated as separate variables. However, there was high agreement between the sum of PB and MC and the sum of EATUPCHEWS and EATDOWNCHEWS (total chews) reported by the EWS (CCC = 0.979; Spearman's rho = 0.972, $P < .0001$; Bland-Altman Bias = −4.70 chews [per 5-minute period]; Fig. 1B). The upper limit of agreement for total chews over the 5-minute period was 18.69 chews, and the lower limit was −28.09 chews. As the line of equality fell within the 95% CI, there was no significant under- or over-estimation for these two sets of parameters. Summary statistics for the total chews reported by the EWS and the sum of the observed and manually counted PB and MC are also shown in Table 1.

For all negative control periods in Experiment 2, the EWS output for total chews was zero, indicating that the EWS was not reporting other activities with an oral component such as drinking or biting at flies in the chew count.

Table 1
Summary statistics of data collected during validation experiments 1 (graze time) and 2 (chew counts)[c].

Method	Minimum	Maximum	Mean	Median	Interquartile Range	Lower Quartile	Upper Quartile
Experiment 1 (graze time [min])[a]							
EWS	41.0	120.0	96.6	105.5	37.0	80.0	117.0
Visual observation	41.0	120.0	96.9	106.5	37.5	80.0	117.5
Experiment 2 (chew counts [n])[b]							
EWS	155.0	513.0	389.9	395.5	75.8	433.3	357.5
Visual observation	150.0	509.0	394.6	408.5	72.0	435.5	363.5

[a] In experiment 1, horses were monitored for 2-h periods. The 120-min maximum graze time indicates horses grazed continuously for the full 2-h observational period.
[b] Chew counts reported for experiment 2 represent the sum of prehensive bites and mastication chews recorded by visual observation and the total chews reported by the EWS output. Counts were collected over 5-min observational periods.
[c] Data are shown for data recorded by the EquiWatch System (EWS) and complementary visual observations.

3.2. Pilot Study

3.2.1. Weather Data

Mean maximum, minimum, and average temperatures for each data collection period as well as daily values for the 4 days retained for data analysis are presented in Table 2. Daily temperatures during Period 1 were near historical averages for the month of November, whereas temperatures in Period 2 were below average. Across the full duration of the study, the mean times for sunrise and sunset were 0,714 and 1,724, respectively.

3.2.2. Forage Treatments

Nutrient composition of the hay and pasture forages is shown in Table 3. Horses in the HAY treatment were offered hay at a rate of 4.3% BW DM/horse/d during period 1% and 5.43% BW DM/horse/d during Period 2. The herbage mass of the pasture forage was estimated to be 5.29% BW DM/horse/d in period 1 and 8.02% BW DM/horse/d for sections grazed in Period 2. At an efficiency rate of 50%–70% [31], the minimum available pasture forage in period 1 would have allowed consumption at a rate of 2.65% BW DM and 4.00% BW DM in period 2 (both above the standard maintenance requirement at 2%–2.5% BW DM).

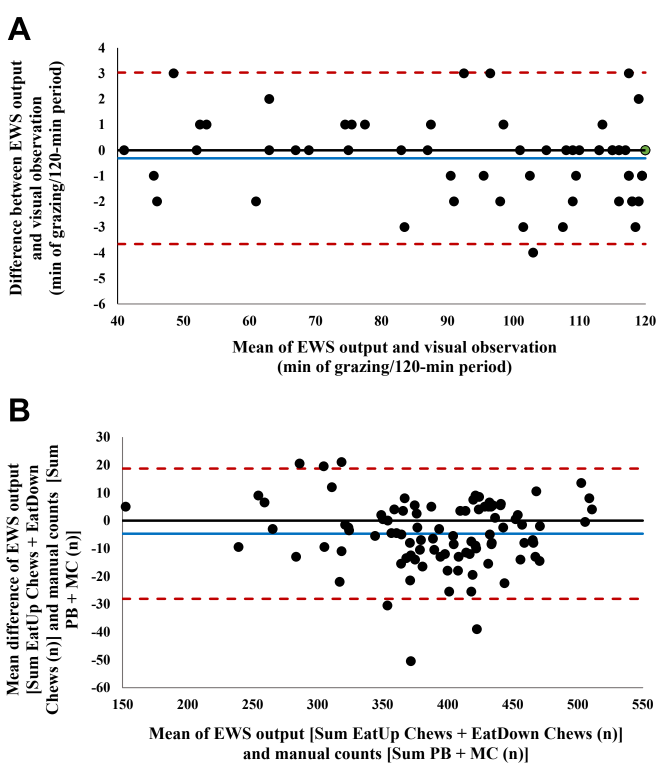

Fig. 1. Agreement of automated measurements reported by the EquiWatch System (EWS) noseband sensor measurements and complementary visual observations for (A) grazing time over 120-min observational periods and (B) total chews in 5-min periods. Total chews represent the sum of manually counted prehensive bites and mastication chews and the total chews recorded by the EWS. Agreement is displayed in Bland–Altman plots (solid blue line indicates the mean difference; solid black line indicates the line of equality; dashed red lines indicate upper and lower 95% limits of agreement).

3.2.3. Animal Movement

Parameters characterizing the daily voluntary movement of horses (quantified from GPS data) are shown in Fig. 2. When maintained on the PAS treatment, horses spent a greater total amount of time in motion (defined as a GPS-recorded speed > 0 km/hr) than when on the HAY treatment (PAS 5.81 ± 0.35; HAY 3.90 ± 0.35 hours; Fig. 2A; $P < .002$). Horses also traveled a greater total distance on PAS (5.34 ± 0.24 km) than on HAY (3.64 ± 0.24 km; Fig. 2B; $P < .0002$), but mean speed did not differ by forage treatment (PAS 1.16 ± 0.21; HAY 0.70 ± 0.21 km/hr; Fig. 2C). However, when these values were scaled to the available area for each treatment, horses on HAY traveled a greater distance per unit of area (ha; 1.11 ± 0.05 km/ha) than during the PAS treatment (0.07 ± 0.05 km/ha; Fig. 2B; $P < .0001$). Scaled speeds also differed by forage, with a greater mean speed for horses maintained on HAY (0.19 ± 0.01 km/hr/ha) than PAS (0.02 ± 0.01 km/hr per ha; Fig. 2C; $P < .0001$). Time in motion remained greater in PAS (1.76 ± 0.11 hours) compared with HAY (1.18 ± 0.11 hours) when the scaling factor was applied ($P < .002$).

Table 2
Weather data from pilot study (October–November 2018)[e].

Day	Temperature (°C)		
	Average	Daily High	Daily Low
Period 1[f]	10.35 ± 1.55[a]	18.47 ± 1.76[a]	3.33 ± 1.53[c]
Day 1	7.72	15.00	2.22
Day 2	10.56	21.11	0.56
Day 3	16.22	23.33	9.44
Day 4	6.89	14.44	1.11
Period 2	4.11 ± 1.55[b]	8.20 ± 1.76[b]	−0.14 ± 1.53[d]
Day 1	2.94	6.11	−0.56
Day 2	5.56	8.89	1.67
Day 3	3.28	6.67	−1.11
Day 4	4.66	11.11	−0.56

[a,b]Period data are presented as means ± standard error of the mean. Within columns, means followed by a common letter are not significantly different ($P < .05$).
[c,d]Differing superscripts within a column denote a trend for a difference between periods ($P < .08$).
[e] Weather data were obtained for the New Brunswick Station through the Office of the New Jersey State Climatologist website [21].
[f] Data shown include mean values from each data collection period as well as daily values from the four days of data retained for statistical analysis.

Table 3
Nutrient composition of forage treatments (unrestricted cool-season grass pasture [PAS] versus *ad libitum* orchardgrass hay [HAY])[a].

Nutrients	Forage Treatment	
	PAS	HAY
Dry matter (%)	41.70	91.40
Digestible energy (Mcal/kg)	2.49	2.00
Crude protein (%)	22.15	10.20
Acid detergent fiber (%)	28.30	42.20
Neutral detergent fiber (%)	44.25	65.80
Water-soluble carbohydrate (%)	12.90	8.10
Ethanol-soluble carbohydrate (%)	10.20	6.90
Starch (%)	2.70	1.00
Calcium (%)	0.64	0.35
Phosphorus (%)	0.40	0.29

[a] Nutrients are expressed on a 100% dry matter basis. Nutrient composition of forage samples was determined by wet chemistry analysis. Analyses were performed by Equi-Analytical Laboratories, Ithaca NY.

Table 4
Daily feeding behaviors of horses maintained on cool-season grass pasture (PAS) versus an *ad libitum* hay diet (HAY).

Feeding Behavior[c]	Forage Treatment	
	PAS	HAY
Total feeding time (hr/d)	14.79 ± 0.48^a	11.98 ± 0.48^b
Total chews (n/d)[d]	$75{,}712 \pm 2{,}223^a$	$48{,}758 \pm 2{,}223^b$
Chew rate (chews/min)[d]	83.92 ± 1.61^a	68.50 ± 1.61^b
Bouts (n/d)	9.25 ± 0.70^a	10.35 ± 0.70^a
Bout duration (min/bout)	102.4 ± 7.01^a	86.7 ± 7.01^b
Other jaw movements (n/d)	$3{,}100 \pm 979^a$	$8{,}671.50 \pm 979^b$

[a,b] Data are presented as means ± standard error of the mean. Within rows, means followed by a common letter are not significantly different ($P < .05$).
[c] Feeding behavior parameters were quantified using 24-h summaries generated with the RumiWatch Converter software from raw data collected using the Equi-Watch System (EWS; Itin + Hoch, GmbH; Liestal, Switzerland) halters.
[d] Total chew counts reported by the EWS represent the sum of prehensive bites (PB) and mastication chews (MC). The calculated chew rate was thus also based on the sum of PB and MC.

3.2.4. Feeding Behavior

Daily feeding behaviors (as evaluated using the EWS) of horses maintained on the two pilot study forage treatments (PAS and HAY) are summarized in Table 4. Horses spent a greater amount of time each day engaged in feeding behavior when maintained on PAS compared with HAY ($P = .001$). Total chews and chewing rate also differed by forage ($P < .0002$). Conversely, counts of other jaw movements classified as nonfeeding behaviors for horses on HAY exceeded those reported during the PAS treatment ($P = .002$). The duration of individual feeding bouts was longer in PAS than HAY ($P < .0001$); however, the number of feeding bouts per day did not differ by forage treatment.

For the 24-hour feeding time data, there was a significant effect of time block ($P < .0001$; Fig. 3A). There was also a significant forage × time block interaction for feeding time ($P < .005$). Feeding time was, in fact, shortest during the early morning hours of Block 2 for both HAY (14.03 ± 2.09 min/hr) and PAS (23.79 ± 2.09 min/hr; $P < .01$). However, although feeding time in PAS was lower for Block 3 (24.31 ± 2.09 min/hr) compared with all other blocks excluding Block 2 ($P < .0001$), feeding time during Block 3 for HAY (20.16 min/hr) was only lower than Block 4 (35.34 ± 2.09 min/hr), Block 6 (43.19 ± 2.09 min/hr), and Block 7 (31.67 ± 2.09 min/hr; $P < .005$). There were no differences between feeding time in Block 3 and Block 1 (24.87 ± 2.09 min/hr), Block 2, Block 5 (28.40 ± 2.09 min/hr), or Block 8 (27.45 ± 2.09 min/hr). Accordingly, differences in the feeding time between PAS and HAY were most apparent in the overnight hours, with horses on PAS spending a greater amount of time eating during Block 1 (PAS 37.59 ± 2.09; HAY 24.87 ± 2.09 min/hr), Block 2, and Block 8 (PAS 37.23 ± 2.09; HAY 27.45 ± 2.09 min/hr; $P < .04$).

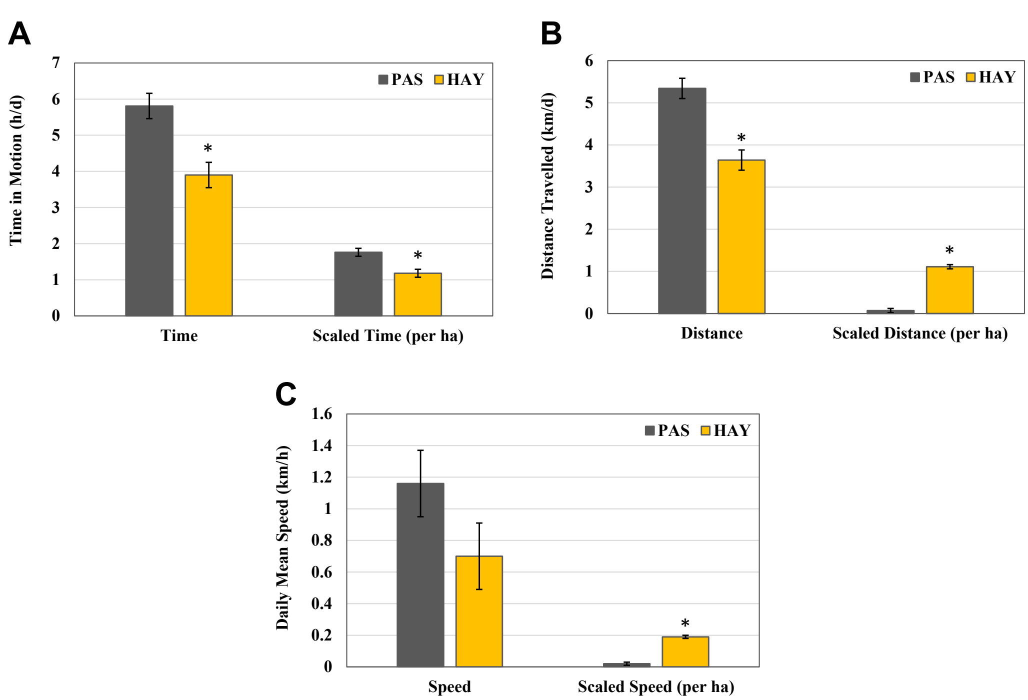

Fig. 2. Voluntary movement parameters for horses offered unrestricted access to late-fall cool-season grass pasture (PAS) versus an *ad libitum* orchardgrass hay diet (HAY). Voluntary movement was monitored using a GPS tracking device (Garmin Astro 430 Dog Tracking System, Olathe, KS). Daily averages are presented for (A) time spent in motion (H) (B) distance traveled (km), and (C) mean speed (km/hr). For each parameter evaluated, both gross measures as well as values scaled for differences in physical area between the pasture (PAS) and dry lot (HAY) are shown. Significant differences between treatments (at $P < .05$) are denoted with asterisks. Data are presented as means ± standard error of the mean.

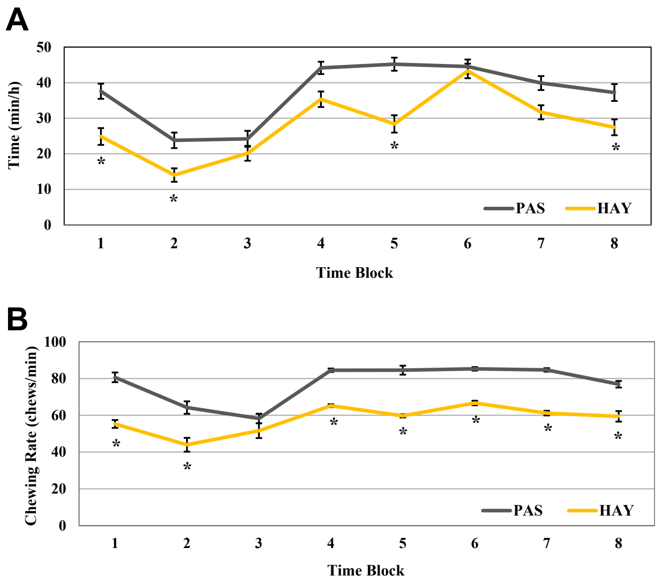

Fig. 3. Twenty-four-hour feeding patterns for (A) feeding time (min/hr) and (B) chewing rate (chews/min) in horses maintained on pasture (PAS) versus *ad libitum* hay (HAY). Chewing rate was based upon total chews reported by the EquiWatch System and represents the sum of prehensive bites and mastication chews. The 24-hr data were binned into 3-hr time blocks: 1 = 0,000–0,259, 2 = 0,300–0,559, 3 = 0,600–859, 4 = 0,900–1,159, 5 = 1,200–1,459, 6 = 1,500–1,759, 7 = 1,800–2,059, and 8 = 2,100–2,359. For both feeding time and chewing rate, an effect of forage ($P < .0001$) and time block ($P < .0001$) were observed; interactions were found for forage by time block ($P < .005$). Asterisks indicate differences between treatments at $P < .05$. Data are presented as the means ± standard error of the mean.

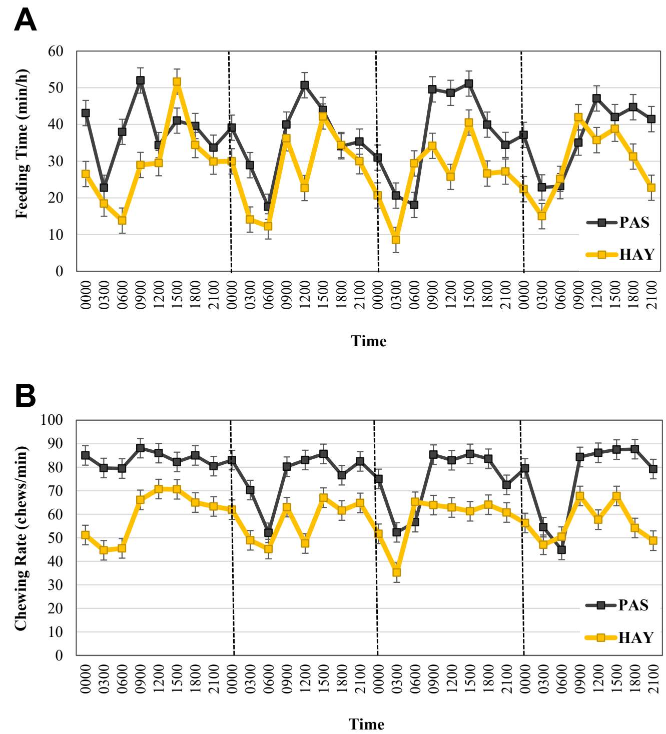

Fig. 4. Expanded view of the 24-hr variation in (A) feeding time (min/hr) and (B) chewing rate (chews/min) for horses consuming a pasture (PAS) versus *ad libitum* hay (HAY) diets. Chewing rate was based on total chews reported by the EquiWatch System and represents the sum of prehensive bites and mastication chews. Data shown include the 4 d retained in the dataset following the removal of days in which there was inclement weather or during which hay needed to be replenished in the HAY treatment. Data presented as means ± standard error of the mean.

Feeding time also differed by forage during midday hours, with feeding time greater in PAS (45.19 ± 2.09 min/hr) than HAY (28.40 ± 2.09 min/hr; $P < .0001$) during Block 5 and a similar trend for Block 4 (PAS 44.15 ± 2.09; HAY 35.34 ± 2.09 min/hr; $P = .08$).

Chewing rate also differed by time block ($P < .005$; Fig. 3B). Despite a significant forage × time block interaction for chewing rate ($P < .005$), and unlike for the feeding time variable, time-related differences were largely preserved between PAS and HAY treatments. For PAS, chewing rate was slower during Block 2 (64.20 ± 2.38 chews/min) and Block 3 (58.27 ± 2.38 chews/min) than all other time blocks ($P < .0001$) with the exception of Block 1 (80.65 ± 2.38 chews/min) where there was only a trend ($P = .06$). In HAY, horses also chewed at lower rate during Block 2 (43.97 ± 2.38 chews/min) and Block 3 (51.62 ± 2.38 chews/min) versus all other time blocks ($P < .0006$) except Block 1 (55.28 ± 2.38 chews/min). However, the chewing rate differed by forage for all time blocks other than Block 3 ($P < .0001$).

Differences between consecutive time blocks (DIFF) did not vary by forage for either feeding time or chewing rate, but there was a forage × DIFF interaction for feeding time ($P < .0001$). However, the only pair of consecutive time blocks for which the differenced value varied by forage treatment were Block 5 and Block 6 (Diff5: PAS −0.10 ± 2.44 min/hr; HAY +14.90 ± 2.44 min/hr; $P < .001$), and the DIFF for chewing rates did not vary by forage for any pairs of consecutive time blocks.

An expanded view of the 24-hour variation in feeding time and chewing rate across the 4 days of collected data is shown in Fig. 4, and descriptive parameters of 24-hour biological patterns generated by cosinor analysis are reported in Table 5. The cosinor analysis zero-amplitude test revealed a weak 24-hour rhythm for feeding time ($P < .002$), and the goodness-of-fit (R^2) did not differ between PAS and HAY. The AMP of the cosine curve for feeding time also did not vary by forage treatment. The cosinor analysis found the greatest feeding activity in the late afternoon/early evening, with ACR occurring later in PAS than when horses were maintained on HAY ($P < .0001$). In addition, the MESOR for feeding time was greater in horses when on PAS ($P < .002$). The goodness-of-fit for chewing rate (0.26 ± 0.02) was lower than the R^2 for feeding time (0.32 ± 0.02; $P < .002$). However, this weak 24-hour pattern for chewing rate was also significant as determined by the zero-amplitude test ($P < .002$). Furthermore, the R^2 values found here are similar to goodness-of-fit in previously published assessments of equine activity patterns [32]. For chewing rate, the only parameter differing between forage treatments was the MESOR, which was greater for PAS ($P < .0001$). Neither the goodness-of-fit, nor the ACR varied by forage.

4. Discussion

4.1. Validation Study

The EWS had very high agreement with complementary visual observations for grazing time (CCC > 0.99). This accuracy of reported values for grazing time is similar to published results of RWS validation in grazing cattle (CCC = 0.99; [18]). Furthermore, the EWS was accurate in assessing this parameter across a wide range of voluntary grazing times within each observational period (41–120 minutes). Although there was a slight underestimation of grazing time by the EWS, the Bland–Altman bias was less than one half-minute over the course of a 2-hour observational period. These results confirm that the EWS can be used to quantify grazing durations as well as identify specific periods during which grazing activity is occurring.

Table 5
Descriptive parameters of 24-hr biological patterns generated by cosinor analysis of feeding time data for horses in pasture (PAS) versus *ad libitum* hay (HAY) treatments.[e]

Feeding Behavior	MESOR	AMP	ARC	R^2
Feeding Time				
PAS	37.07 ± 1.39 min/hr[a]	9.38 ± 0.75 min/hr[a]	1,753 ± 15[a]	0.30 ± 0.02[a]
HAY	28.15 ± 1.39 min/hr[b]	9.66 ± 0.75 min/hr[a]	1,658 ± 15[b]	0.34 ± 0.02[a]
Chewing rate[c]				
PAS	77.37 ± 1.20 chews/min[a]	9.14 ± 1.70 chews/min[a]	1,852 ± 38[a]	0.27 ± 0.03[a]
HAY	57.89 ± 1.20 chews/min[b]	10.90 ± 1.20 chews/min[a]	1,783 ± 38[a]	0.24 ± 0.03[a]

Abbreviations: AMP, amplitude (difference between maximum curve value and MESOR); ARC, acrophase (time of maximum curve value); MESOR, rhythm-adjusted mean; R^2, goodness-of-fit.
[a,b]Data are presented as means ± standard error of the mean. For each behavior parameter (feeding time and chewing rate), means followed by a common letter within columns are not significantly different ($P < .05$).
[c] Chewing rate was based on total chews reported by the EquiWatch System and represents the sum of prehensive bites and mastication chews.
[e] Rhythm parameters were determined from analysis of a fitted cosine curve.

The accuracy of the RWS for feeding/grazing time compares favorably with published agreement values for alternative automated cattle monitoring systems [33]. As previously noted, there are few reports of continuous automated monitoring in the horse. However, in the current validation experiments, the EWS outperformed agreement values for the ETHOSYS telemetry system (mean agreement of 85% with visual observations for the detection of feeding activity) [34]. As the validation of ETHOSYS for equine monitoring was published over 20 years ago [34], it is not surprising that more than two decades of technological advancements would produce a superior tool. However, beyond the obvious potential impact of technological advancement, other factors contributing to the greater accuracy of the EWS include sensor type and placement. The ETHOSYS also combines two sensors, but the pressure is not used to detect feeding behavior signatures. Rather, the ETHOSYS incorporates an accelerometer to detect general locomotive activity and a second position detector to determine if the head is up or down; a defined pattern signature of "activity with head down" is interpreted as feeding activity [34]. The ETHOSYS sensor was housed in a collar as opposed to the halter noseband location in the EWS [34].

The second phase of the validation experiment revealed the primary limitation of the EWS as a tool for assessing equine grazing behavior—the inability of the system to distinguish between and accurately count PB and MC. In grazing cattle, the RWS can differentiate grazing bites from rumination chews [18], with Werner et al [18] reporting a high agreement between the RWS output for these parameters and manual counts (CCC = 0.98 and CCC = 1.00, respectively). This discrepancy in accuracy between the cattle and horse systems is likely because of differences in head and jaw movements characteristic of feeding behavior in the two species. Although horses obviously do not ruminate, they do exhibit differing jaw movements when ingesting (prehension) versus grinding (mastication) feed boluses, which would presumably create distinct output signatures that could be detectable by the EWS. However, the underlying algorithms for this system were originally created and optimized for application in dairy cattle. Further development of the EWS algorithms would be necessary to reliably determine PB and MC parameters from the EWS output. The value of accurately quantifying PB is illustrated by a recent study modeling feed and pasture grass intake from RWS parameters [35]. This study found that PB was singularly the most important predictor for accurately modeling feed intake [35]. Any extension and application of the EWS technology for quantifying feed intake would require equine-specific algorithm optimization. Quantifying forage intake is particularly challenging in equine pasture studies, and the potential development of the EWS for this purpose could provide an even more valuable research tool.

However, the current validation study found that the existing EWS software algorithms are sufficient to produce an accurate count of total chews (sum of PB and MC; CCC = 0.979). Moreover, the accuracy of the EWS chew counts spanned a wide range (155−513 chews). Similar to the grazing time results from Experiment 1, there was small underestimation in the total bite/chew count by the EWS. However, the Bland−Altman bias was less than five bites + chews over an observational period of 5 minutes in which the total chew count was, in some cases, in excess of 500 bites + chews. Thus, the EWS can provide an indication not only of when and for how long horses are grazing but also how vigorously they are consuming pasture forage.

4.2. Pilot Study

Feeding or grazing times reported for the EWS pilot study fall within the range of previously published values for this behavioral parameter [1−4]. However, seasonal differences in grazing activity have been documented [2,7−9]. The present study was conducted in late fall at the end of the grazing season. Although sufficient pasture forage remained to allow for adequate pasture consumption, conducting similar evaluations in the spring and summer when temperatures are warmer, duration of daylight hours is longer, and available pasture forage is more plentiful would provide greater insight into drivers and patterns of forage consumption. For example, Collas et al [5] found that horses spent a greater amount of time grazing when maintained on pastures providing a greater daily herbage allowance.

The specific research question investigated in this pilot study—the impact of forage type (HAY vs. PAS) on equine feeding behaviors—is simplistic, yet it represents a gap in the existing body of literature. Martin et al [32] examined activity levels in horses maintained on pasture versus when stalled and offered *ad libitum* hay, not surprisingly finding that horses were more active in the pasture setting. However, it is difficult to directly compare the results of Martin et al [32] to feeding activity reported in the present study. Martin et al [32] used halter-mounted accelerometers for the detection of movement, and thus "activity" counts included a range of behaviors including general voluntary movement in addition to feeding activities. In addition to treatment differences in feeding behaviors in the present study, horses maintained on PAS also had greater voluntary movement (as quantified by GPS), traveling a greater total distance and spending a greater amount of time in motion each day than hay-fed horses housed in a dry-lot setting. Furthermore, Martin et al [32] confined horses to stalls when not on the pasture treatment. In the present study, management and feeding protocols during the HAY treatment were designed to mirror those on pasture as closely as possible in an attempt to isolate forage type (hay vs. pasture) as the sole independent variable. To the authors' knowledge, no previous study has reported a comparison of hay versus pasture forage under similar management conditions. Although it is difficult to fully control environmental and management variables in a field experiment, the efforts to do so in this study, such as eliminating routine meal-feeding and offering hay on the ground dispersed across the dry lot (rather than localized in feeders), allowed us to demonstrate that varying forage type alone is sufficient to impact natural equine feeding behaviors. Horses managed on pasture spent a greater amount of time engaged in feeding behavior and chewed more vigorously than horses maintained in a dry lot on an *ad libitum* hay diet. The difference in feeding time between forage treatments was because of a longer duration of individual feeding bouts in horses on pasture, as the number of distinct feeding bouts did not differ between PAS and HAY.

A number of factors characteristic of the two forage types offered (hay and pasture) may have contributed to the observed differences in feeding behaviors. Species composition varied between the two forage treatments. The hay offered was a monoculture of orchardgrass, while the pasture contained a mix of orchardgrass, Kentucky bluegrass, and tall fescue. Pasture forage preference trials have demonstrated that orchardgrass is less preferred than Kentucky bluegrass or tall fescue [36,37]. Differences in feeding behaviors measured by the EWS may also reflect inherent differences in head and jaw movements of horses during the ingestion of hay versus pasture forage. Although ripping/tearing is necessary for prehension of living pasture grasses, similar force and range of motion are not required for prehension of dried hay. The EWS was previously validated for the detection of jaw movements in horses consuming conserved forages (dried hay and silage), and the agreement with complementary visual observations was high (>95%; [19]). Thus, differences in the prehensive characteristics likely did not affect detection of bites + chews by the EWS. These differences could have, however, influenced the rate and size of PB.

Bite size could also have potentially been affected by differences in physical properties of these two forage types (such as dry matter content or particle length). The dry matter content of pasture forage is obviously substantially lower than that of hay, and this could have contributed to the greater feeding time/chewing rate observed for horses on PAS in this study. Pastured horses are known to graze pasture forage, especially preferred patches, close to ground level [38], and it would then follow that as swards become progressively shorter, bite size could potentially decrease. Pastures used for the present study were maintained using best management practices for rotational grazing to avoid overgrazing and thus preserve long-term pasture quality. However, it is possible that horses took larger bites of hay (compared with smaller, more rapid bites in pasture), thus requiring fewer PB and lowering the total chew counts reported by the EWS. Without additional measurements to quantify particle length, bite size, and intake, it is difficult to ascertain the relative contributions of these factors. Furthermore, interpretation is limited because of the inability of the EWS to discriminate between PB and MC.

The total number of bites + chews per day was greater in horses on PAS than when maintained on HAY, whereas the counts for “other” jaw movements were greater in horses on the HAY treatment. It has previously been suggested that an inherent “ethological” drive for foraging behavior exists in the equine [39]. Ellis et al [39] conducted 24-hour observations of horses offered high- versus low-fiber diets and recorded time spent chewing the provided ration as well as time spent chewing on bedding materials. This study found that horses offered the high-fiber diet spent greater time engaged in feeding behavior (consuming the feed supplied) than horses on the low-fiber diet, whereas horses on the low-fiber diet spent a greater amount of time foraging bedding material [39]. In fact, when total combined time spent foraging either feedstuff or bedding was evaluated, there were no differences in this total foraging time between dietary treatments, suggesting that horses may compensate for low-fiber diets that can be quickly consumed by seeking other materials available for consumption [39]. Although treatment differences in “other” activity counts in the present study are of a lower magnitude and do not completely offset treatment differences in total daily counts of bites + chews, our findings do, in part, support the “ethological” drive referenced by Ellis et al [39]. However, in the Ellis study, feeding time was lower when horses were consuming the lower fiber diet [39]. In the present study, horses spent a greater amount of time engaged in feeding behavior when on PAS, despite the fact that fiber content was numerically lower in the pasture forage than in the hay diet. Thus, the results of the present study better support the negative correlation between forage neutral detergent fiber (NDF) and acid detergent fiber concentrations and forage preference of grazing horses found by Allen et al [36].

In addition to the abovementioned variation in fiber content between the two treatments, differences in other forage nutrients including crude protein (CP) and soluble carbohydrates could have, in part, driven the differences in feeding behaviors between HAY and PAS treatments. The total nonstructural carbohydrate (NSC = water-soluble carbohydrate + starch] and CP content were both numerically greater in the pasture forage than in the hay diet. Forage NSC content has been positively correlated with pasture forage preference of horses grazing cool-season grasses [36]. Edouard et al [40] reported that when offered pair-wise choices between pasture swards managed for varying height and nutritional quality, horses preferentially selected the sward in which the instantaneous intake of digestible protein was maximized. This study did not, however, measure daily intakes or grazing times in horses restricted to the individual sward types used for the pair-wise testing and was conducted using young, growing horses (2-year-old fillies), which differs from the mature mares, experimental design, and management conditions used in the present study [40]. Furthermore, Edouard et al [40] found that the impact of protein content on forage preference was greatest when protein intake was at or below daily requirements. In the present study, CP in both treatments exceeded requirements for mature horses at maintenance. Therefore, the differing CP between treatments may not have been the most influential driver of feeding behavior differences between PAS and HAY. Further studies implementing proper controls would be necessary to fully evaluate the role each of these nutrient fractions play in shaping equine feeding and grazing behaviors.

Assessment of voluntary movement using GPS tracking found that horses were more active on the PAS treatment, with horses traveling a greater total distance each day and spending a greater amount of time in motion than during the HAY treatment. Mean speed, however, was not affected by forage treatment. Parameters evaluated in the present study expand on limited data reported from previous studies using GPS monitoring of horses, where distance traveled is often the primary or even sole parameter evaluated. There is a wide range of published values for distance traveled by horses maintained in dry lot, restricted grazing, or unrestricted pasture settings. Moore et al [41] reported 0.5 km traveled daily for horses housed in dry lots. Gill [42] found that horses maintained either fully or in-part on pasture (with 3.11 ha available area) traveled an average of 2 km/d. Other studies have reported greater daily distances traveled for horses maintained on pasture, with Hampson et al [43] reporting voluntary movement at 7.2 km/d in larger 16 ha pastures. In comparison, Kenny [24] found daily distances of up to 18 km/d despite smaller available pasture areas that ranged from 0.55 to 1.60 ha. Both the available area (0.66 ha) and distances traveled for pastured horses in the present study (5.34 ± 0.24 km/d) do fall within the range of these previously reported values. However, the distance traveled by horses during the HAY treatment (3.64 ± 0.24 km/d) exceeded distances reported for horses managed either all or in-part (daily time budget was split between access to pasture and dry lot confinement) in a dry lot setting [41,42]. It is worth noting that in these studies [41,42], horses were housed individually in dry lot enclosures with an available area of approximately 45 m^2. Group management of horses in a comparatively large area (0.33 ha = 3,300 m^2) in which the hay offered was spread throughout the dry lot may explain the greater voluntary movement displayed by hay-fed horses in the present study. Furthermore, the greater voluntary movement of horses when maintained on PAS compared with HAY was expected, given the larger available area in which horses would seek forage. Depending on the specific area where horses were grazing within a pasture section, reaching the water source and shelter would require traveling greater distances than when on the HAY treatment.

Differing available areas, however, may not fully explain interstudy differences in distance traveled. Hampson et al [43] found a positive relationship between pasture size and daily distance traveled. However, Gill [42] found no differences in distance traveled between horses maintained on full pasture and those managed using a time- and area-restricted grazing protocol. Given interstudy differences in sward characteristics, pasture design and topography, season, environmental conditions, and so on, the value of direct comparisons of distance traveled is limited. However, it is worth noting that the distance traveled for unrestricted pastured-managed horses by Gill [43] was less than half that reported in the present pilot study, although the available grazing area was almost five times greater than the pasture area provided in the present study. Conversely, Kenny [24] reported distances traveled twice as large as those reported herein despite a smaller pasture area. However, the results of the present study do support an impact of pasture or lot size on voluntary movement. When recorded values for movement parameters were scaled based on the physical area available during the HAY or PAS treatments, the scaled values for distance traveled and mean speed were actually *greater* in HAY compared with PAS. Interestingly, time in motion values was not similarly impacted by scaling for lot/pasture size, as the scaled value for time in motion remained greater in PAS than HAY.

Perhaps, the most interesting findings of this pilot study are drawn from examination of the 24-hour patterns of feeding behavior. We used three complementary strategies to interrogate the patterns in feeding time and chewing rate and the potential impacts of forage type on these variables. All three sets of statistical analyses indicate that although the magnitude of these behaviors was influenced by treatment (PAS vs. HAY), the underlying daily fluctuations (patterns) in both time spent engaged in feeding behavior and vigor of feeding activity were largely preserved, regardless of forage type. There was a forage × time block interaction for feeding time and chewing rate revealed by ANOVA of time block data. However, when differences between consecutive time blocks were evaluated, the differenced values for feeding time only varied by forage type for one pair of consecutive time blocks (DIFF5). Furthermore, there was no forage × DIFF interaction for chewing rate, indicating that the abovementioned forage × time block interaction was attributable to differences in magnitude rather than differences in the daily pattern for this parameter. Finally, cosinor analysis found that although the rhythm-adjusted mean, or MESOR, varied between forage treatments for both feeding time and chewing rate, there were no treatment differences in the AMP or R^2 values. The timing of the ACR for feeding time did differ by forage type, with the peak values occurring 1 hour later in the day when horses were maintained on PAS compared with the HAY treatment. The ACR for chewing rate did not vary by treatment. Taken together, these results indicate that although while gross values for feeding behavior parameters are influenced by forage type, daily patterns of feeding behavior are robust and remain largely unaltered regardless of forage consumed.

This is particularly intriguing when one considers that the NSC content of pasture forage exhibits diurnal variation [44], whereas the nutrient content of harvested, dried hay is static. Prior studies have indicated a positive correlation between NSC content and forage preference and consumption rate [36,45]. However, if NSC content were a predominant factor influencing forage consumption, it would be expected in this study that daily patterns of feeding behavior would differ between pasture forage and hay. The similarity in patterns across forage types observed in the present study indicates a need for additional studies to clarify the relationship between soluble carbohydrates (as well as other nutritive and physical properties mentioned above) and feeding behaviors to better understand drivers of forage consumption.

In addition to expanding our current understanding of equine feeding and grazing behavior, the EWS could serve as a valuable complement to horse nutrition, health, and production/management studies. For example, in studies examining circulating glucose and insulin concentrations in the grazing horse, samples are collected at designated times in horses with *ad libitum* access to pasture forage [44,46,47]. However, little consideration is given to characterizing pasture forage consumption that may or may not have occurred immediately preceding sample collection. As meal size and consumption rate influence circulating glucose and insulin [48,49], feeding behavior assessments provided by a system such as the EWS may provide valuable insights. Furthermore, automated monitoring of feeding behaviors is also applicable in the area of equine gastrointestinal health and could be used as a novel approach for further exploring the relationships between ration composition, feeding/chewing behavior, and the development of health disorders such as colic or gastric ulcers.

5. Conclusions

A remote automated monitoring approach offers both greater capacity and accuracy in data collection when compared with traditional observational methodologies used for assessment of equine grazing behaviors. This study demonstrated that the EWS can accurately record and report equine grazing activity, with a high agreement between the EWS output and visual observations for grazing time and total bites + chews. Thus, the EWS is capable of generating data necessary for more fully characterizing feeding behaviors in horses. Data output from the EWS can be used to determine the specific timing and duration of grazing activity as well as the vigor of pasture forage consumption over a selected interval.

The EWS pilot study clearly illustrated the potential application of this technology in equine research. Furthermore, the pilot study highlighted the impact of forage type on equine feeding behaviors. Consumption of pasture forage versus an *ad libitum* hay diet did produce marked differences in gross daily feeding behavior parameters such as the total time spent engaged in feeding activity, mean chewing rate, and mean feeding bout duration over a 24-hour period. However, although the magnitude of feeding time and chewing rate did vary by forage type, the underlying patterns for these behavior parameters were largely consistent across forage treatments. These findings suggest that factors beyond forage type and nutrient composition play an important role in shaping equine feeding behaviors. Future studies implementing the EWS could provide greater understanding of biological, environmental, and nutritive factors driving grazing behavior in horses.

Financial Disclosure

This work was supported by the USDA National Institute of Food and Agriculture Hatch project 1003557 through the New Jersey Agricultural Experiment Station, United States, Hatch project NJ06170. Additional funding was provided by the Rutgers University Equine Science Center's Sustained Program Grant.

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