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**Accelerometer activity tracking in horses and the effect of pasture management on time budget**

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**Running head:** Activity tracking at pasture

**Summary**

**Background**: Accelerometry is an accepted means of quantifying human physical activity. Quantitative physical activity tracking could be beneficial for studies into equine health and disease prevention, for example, in relation to obesity management.

**Objectives**: Validate accelerometer use in grazing horses, determine between-day repeatability, and assess the effects of pasture size on time budget (i.e. duration in each activity category).

**Study design**: Proof of concept.

**Methods**: Accelerometers (ActiGraph) were positioned at the poll. Horses underwent 5 minutes of observed activity in 3 categories: standing, grazing and ambulating. Receiver operating characteristic curve analysis, used on ten second data epochs, calculated cut points between the activities. A 20-day study was then undertaken on 6 horses at pasture. Time in each category (per day) was deduced; a Mann Whitney U test was performed to compare standard versus small paddock and day versus night turn out.

**Results**: Cut off values with the optimum sensitivity (94.7-97.7%) and specificity (94.7-96.8%) were found to be <127.6 counts for standing, 127.6-702.7 counts for grazing and >702.7 counts for ambulating. Repeatability was analysed descriptively: Median (IQR) of the between-day difference in minutes standing, grazing and ambulating were 46.9 (21.3-87.9), 77.3 (40.2-124.5), and 15.6 (6.8-40.2) respectively. Median times standing and ambulating were significantly different between standard and small paddocks: standing: 8.7 versus 10.3 hours ($P<0.001$); ambulating: 55.7 versus 39.6 minutes ($P = 0.002$). There was no significant difference in the median time spent grazing. There were significant differences between day and night: standing: 32.95% versus 50.97% ($P = 0.001$), grazing: 60.81% versus 46.77% ($P<0.001$), and ambulating: 4.57% versus 2.40% ($P<0.001$).

**Main limitations**: Small sample size and lack of cross-validation of cut off points on independent, ‘unseen’ data.

**Conclusions**: Accelerometry can differentiate standing, grazing and ambulating in horses. Our proof-of-concept study demonstrates modifying pasture size influences activity budgets opening avenues into studying obesity management.

**Introduction**

Accelerometry is recognised as a reliable means of quantifying human physical activity [1-3] and it has been proposed that quantitative physical activity tracking could be a valuable tool for equine veterinary research [4]. Accelerometers are small, wearable sensors that measure accelerations in up to three orthogonal axes [5]; these measurements can be used to estimate the intensity of physical activity [6]. Studies utilising accelerometers have shown that obesity correlates with lower physical activity levels in humans [7-9] and that sedentary time is adversely associated with several cardio-metabolic biomarkers, ultimately linking physical inactivity with chronic diseases such as type-two diabetes mellitus [10-14].

In dogs, accelerometry has proven to be a valid, reliable and practical means of measuring physical activity [15-17]. It has also facilitated a number of canine studies that require an objective measurement of physical activity [18-20]. A handful of studies have explored the use of accelerometry as well as other means of activity tracking in horses [4,21,22]. Accelerometers have been validated for use in horses exercised in-hand [4,23], with the optimal location for correctly identifying grazing behaviour being at the poll [23]. Although it is suggested that a lack of physical activity is a contributing factor in equine obesity, the exact effects are as yet unknown [24]. Therefore, harnessing this technology for use in horses would be valuable for future studies into the effect of physical inactivity on equine health.

This study aims to validate the use of tri-axial accelerometers in grazing horses. Furthermore, our proof of concept study aims to analyse between-day repeatability and investigate the effect of pasture management on time budget (i.e. duration of time spent in each physical activity category – standing, grazing and ambulating). We hypothesised that, by restricting space and managing horses in a smaller paddock, horses would spend more time standing and less time ambulating when compared to management within a larger paddock. We also hypothesised that, when compared to day-time, during the night horses would spend proportionally more time standing and less time ambulating.

## Materials and Methods

### Accelerometers

ActiGraph's wGT3X-BT 3-axis accelerometers[a] were securely attached to field safe head collars at the position of each subject's poll. All data collected were downloaded as ten second epochs using the accompanying ActiLife[a] software package. In all analyses the vector magnitude ('the square root of the sum of the squares of each axis' [25]) was used as the measurement for physical activity intensity.

### Participants

Six horses of different age, breed and practical use were selected to use in the study (Table 1). All horses were situated in a privately-run livery yard in rural Nottinghamshire. All subjects completed the study except subject 4 who was withdrawn after day 5 of the 20 day study for reasons unrelated to this study.

### Determining accelerometer cut points

### Validation

Each subject performed five minutes of controlled physical activity in each of the following categories:

- *Standing* – Subject was tied loosely on the yard, allowing free movement of the head
- *Grazing* – Subject was turned out in their paddock and observed to be continuously grazing. This includes the usual small steps taken when a horse is grazing.
- *Ambulating* – Subject was walked in-hand

Data analysis

Data was highly skewed, so the non-parametric Kruskal-Wallis test was used for analysis of statistical significance between the accelerometer outputs of each of the three physical activity categories and the Dunn's multiple comparisons test was used to locate these differences.

To establish accelerometer cut off points, receiver-operating characteristic (ROC) curves were produced using the validation data set described above. One ROC curve was produced for standing vs. grazing and another was produced for grazing vs. ambulating to determine the cut off points for each category. The cut off points that produced the highest combined sensitivity (probability of correctly categorising the subject's activity e.g. periods of time when the horse is standing actually being recorded as standing) and specificity (probability that the subjects activity level is not incorrectly categorised e.g. when the horse is not standing, it is recorded as not standing) were selected to use.

**Proof of Concept Study**

Subjects wore the accelerometers continuously for 20 days. The subjects were turned out in equally sized paddocks twenty-four hours a day. For the initial ten days, the paddocks were ~40 x 60 m ('standard paddock'); for the following ten days, the paddocks were ~10 x 60 m ('small paddock'). The small paddock data was only used for the comparison of grazing systems, all other analyses used standard turn-out data only. Data was exported into Microsoft Excel; sorted into twenty-four hour periods (commencing at 20:00:00 GMT and ending 19:59:50 GMT); and non-wear times, as reported by owners, were deleted. Any days with more than four hours of non-wear time were excluded from the study. Each ten-second epoch was categorised as standing, grazing or ambulating using the group cut points determined from ROC analyses and time spent in each category was calculated.

**Data analysis**

**Repeatability**

The difference in time spent in each physical activity category between all the days for each subject were calculated. These data were not normally distributed; the median (Mdn) and interquartile ranges (IQR) were calculated to assess the size of the observed between-day differences of each physical activity category.

**Small versus Standard Paddock**

Initially a Shapiro-Wilk normality test was used to determine whether both sets of data (standard and small paddock) were normally distributed within each activity category. As at least one data set proved to be skewed in each category, a Mann-Whitney U test was performed to determine significant differences between the data sets.

**Day-time versus Night-time Turnout**

In order to investigate differences in time budgets between day-time and night-time turnout, 24-hour periods were split into day and night. During the study, sunrise varied from 0443-0517 and sunset varied from 2051-2122. Standardised hours of 0500-2100 were used to analyse day-time turnout (and the remaining hours used for night-time turnout analysis). As the lengths of day and night were not equal, percentage time spent in each activity category was calculated, rather than hours spent.

A Shapiro-Wilk normality test was used to determine whether the data for each activity category was normally distributed. As at least one data set proved to be skewed in each category, a Mann-Whitney U test was performed to test for differences.

All data analyses were carried out using GraphPad Prism 7[b] software. P values <0.05 were considered to be significant.

## Results

**Validation**

Accelerometer output differed significantly (P<0.001) across the three activity categories when the subjects undertook five-minute periods of observed, controlled physical activity (Fig 1).

**Cut off point establishment**

Using the same data, ROC curve analyses were performed to determine the accelerometer cut points that defined each of the physical activity categories (Table 2). Cut off values with the highest combined sensitivity and specificity were found to be <127.6 counts for standing, 127.6-702.7 counts for grazing and >702.7 counts for ambulating. The discrimination between the different activities was performed with high sensitivity and specificity.

**Repeatability**

In total, 178 between day differences were available from the 6 horses over the 20 days after excluding unsuccessful data recording days. Figure 2 illustrates the Mdn (IQR) of the difference in time spent between days in each physical activity category; these are displayed as absolute values. Mdn (IQR) of the difference in time spent standing, grazing and ambulating between days were 46.9 (21.3-87.9) minutes; 77.3 (40.2-124.5) minutes; 15.6 (6.8-40.2) minutes respectively.

**Comparison of Standard and Small Paddocks**

Time spent standing and ambulating was significantly different when comparing the two paddock sizes (Fig 3). Standing contributed to a significantly (P<0.001) larger proportion of the time budget when the horses were turned out in the smaller paddocks (Fig 3A); horses in standard turnout paddocks spent a significantly (P = 0.001) greater amount of time ambulating (Fig 3C). However, there was no significant difference (P = 0.3) in the time spent grazing between the paddock sizes (Fig 3B).

**Comparison of Day-Time and Night-Time Turnout**

Time spent in each activity category was significantly different when comparing day-time and night-time turnout. Analysis showed that horses spent a significantly different amount of time (P<0.0001) standing during day-time turnout when compared with night-time turnout (Fig 4A). During the day, horses spent a Mdn (IQR) of 33.0 (27.5-37.1) % standing, in comparison with night where they spent 51.0 (47.1-55.2) % standing. Significant differences (P<0.001) were also seen in the amount of time horses spent grazing (Fig 4B) with 60.8 (58.2-65.4) % grazing during the day and a lower percentage of 46.8 (43.3-50.2) % at night. Finally, a significant difference (P<0.001) in time spent ambulating between day-time and night-time turnout was seen (Fig 3C) with a larger percentage of time spent ambulating during the day, 4.6 (3.7-6.9) %, in comparison with night-time turnout, 2.4 (0.8-3.4) %.

**Discussion**

Accelerometry has many potential applications for equine veterinary research. Although accelerometers have been validated for use in horses exercised in-hand, it was yet to be established whether these devices can discriminate between grazing and other activities [4]. Our validation results suggest that accelerometry can distinguish between standing, grazing and ambulating and therefore may be able to be used to monitor the physical activity of horses in their habitual environment. Our accelerometer cut off points differentiated between activities with high sensitivity, specificity, and area under the ROC curve in our limited dataset. Additional studies are required to test these cut off points on 'unseen' data (i.e. data not used in the calculation of the cut off points) to establish whether the determined points are of general validity or need to be tailored to horse characteristics such as size, breed, age etc. It is encouraging that our findings are in line with those of Morrison *et al*. (2015) which set a range of 0-707 counts for sedentary behaviour (compared to our cutoff point of 702.7 counts). Our investigation added an additional cut point for distinguishing between standing and grazing.

The between-day differences of time spent in each category showed median values of 46.9 minutes for standing, 77.3 minutes for grazing and 15.6 minutes for ambulating. Without studies in larger number of horses, it is impossible to ascertain that this is normal variation. The advantage of accelerometer based devices, such as the ones used in this study, is that they can be used for a considerable number of days without the need to download the data or charge the batteries hence easily resulting in data sets containing multiple days or even weeks of data for each horse.

Wild horses have been observed to spend 46.4 ± 5.9% of their time grazing and 7.4 ± 1.0% of their time ambulating [26]. In comparison, in our standard paddock, our subjects spent 67.7% of their time grazing and 5.2% of their time ambulating, with the remainder of time being categorised as standing. Our three categories are somewhat of a simplification and do not take into account other equine behaviours such as drinking and grooming (which would most likely be categorised as grazing in our study). This might account for why our percentage of grazing is somewhat higher and future studies should aim to address the recognition of additional behaviours. Nevertheless, our subjects spent less time ambulating compared to these wild horses. There are a number of variables that may help with explaining this: our subjects were restricted to smaller paddocks, and area restriction has been shown to reduce activity [27]; weather [28] and presence of lameness [29] can also influence an animal's time budget.

The results of this study have shown that paddock size significantly alters the proportion of time spent standing and ambulating, but not the amount of time spent grazing. The difference of 1.6 hours of standing between the standard and small paddocks exceeds the between-day variation values of 0.78 hours (46.9 minutes). Horses kept in a small paddock spent considerably more time standing than when managed in a standard paddock. This information may be of use for rehabilitation programmes where movement needs to be restricted, for example when recovering from injury [30]. This may provide a suitable alternative or adjuvant to permanent stabling which is often time consuming and dependent on the facilities available. In addition, ambulating was found to be significantly higher in the standard paddock compared with the small paddock. The management of horses suffering from osteoarthritis often involves short amounts of regular gentle exercise to assist with joint mobility; therefore, standard sized paddocks may be advisable for horses with such conditions [31].

Interestingly, there was no significant difference in the time spent grazing between the two systems. Previously it had been thought that space limitation would decrease the food intake of horses and help to prevent nutritional disorders such as pasture associated laminitis [32]. However, our research suggests that space restriction alone will not significantly alter the amount of time spent grazing, suggesting that other management strategies hold more importance.

The differences between day and night-time turnout (differences for all categories exceeding the documented between-day differences) may also be useful knowledge in the context of managing horses with particular dietary and/or exercise requirements. The proportion of time spent standing significantly increased during night-time turnout when compared with during day-time turnout, which may be useful knowledge in the context of horses requiring restricted exercise. As the proportion of time spent grazing was increased during day-time turnout, this could be of interest to owners wishing to maximise or minimise their horse's calorie intake during turnout. However this study was undertaken on horses turned out twenty-four hours a day, results might be different if horses are stabled during the day and only turned out at night or vice versa.

In the present study accelerometers were attached to field-safe head collars at the position of the subject's poll. However, compared to poll placement, Morrison *et al*. (2015) found that withers placement was more accurate for horses exercised in hand. Studies in dogs have found the best placement to be on the collar, near the trunk [33]. It may be argued that at the level of the withers, changes in head position due to grazing behaviour may not be detected as easily. As suggested by Morrison *et al*. (2015), the best way to overcome this may be to use both sites of attachment simultaneously, poll and withers, in future studies.

The sample size of the present proof-of-concept study (n = 5) is comparatively small. Previous studies validating the use of accelerometers both in humans and animals have had sample sizes of 20-30 [4,15,34]. It is encouraging that the cut off point between grazing and ambulation found here is very similar to the previously identified cut point for sedentary behaviour in a larger group of horses (Morrison *et al*. 2015) and that receiver operating curves showed that the chosen cut points had high sensitivity and specificity for the horses in this study. Nevertheless, we would recommend investigating the generalisability of these cut points. Our study subjects were not all of the same breed and varied in age and use. It would appear to be important to investigate whether cut points with higher sensitivity and specificity can be found when adapting the cut points to individual horse characteristics.

In addition, it should be acknowledged that some data loss occurred: subject 4 was withdrawn on day 5 of the study and on 8/105 days, the trackers or head collars became detached resulting in data having to be discounted. Furthermore, we relied on owners to report non-wear times so there is likely to be an element of recall bias in our data. This should be taken into account in the design of future studies ideally incorporating an easy means of marking events (e.g. via a smartphone app) or automatically based on location from global positioning system loggers. Finally, the time our subjects spent out of the paddock and the work they did was variable with some subjects doing no work and others being schooled in medium level dressage. When horses are not exercised they may spend more time walking around the paddock [28]. Ideally, the work each subject undertook would have been standardised.

Lameness in dairy cattle has been shown to decrease activity [29] and as our subjects did not undergo a full clinical lameness examination (but all were considered non-lame by their owners), we cannot comment on whether this had an effect on our results. Weather also affects time budget with horses being more agitated and walking significantly more on rainy and windy days compared with warmer, drier days [28]. During this study, weather was highly variable, with some hot, dry days and other days with constant heavy rain, therefore this might have affected our results, in particular the between-day differences. It should also be noted that the study began with all horses turned out in larger paddocks, therefore it cannot be guaranteed that our results are the effect of changing paddock size and not influenced by the horses becoming habituated to the change in paddock size over time. However, 4 of the subjects had been turned out for 24-hours a day for two months prior to commencement of the study, making the effect of time less likely to be influencing the results.

**Conclusion**

Our limited validation data suggests that accelerometry can distinguish between standing, grazing and ambulating with high sensitivity and specificity. Further investigations should be conducted in horses with more defined characteristics (breed, age, use, sex, etc.) to establish more robust estimates of between-variability of activity time budgets.

Paddock size can affect physical activity levels in horses. In line with our hypothesis, horses in a small paddock showed significantly increased amount of time spent standing compared with a standard grazing system, however, time spent grazing was not significantly altered. Our day-time vs. night-time results showed significant differences, with the proportion of time spent grazing higher during day-time compared to at night in horses turned out 24 h a day. This may be of use in the management of nutritional disorders linked to obesity and in the rehabilitation of horses recovering from injury when movement needs to be restricted.

**Authors' declaration of interests**

No competing interests have been declared.

**Ethical animal research**

The Clinical Research and Ethical Review Board at the Royal Veterinary College granted ethics approval for this study (URN: 2017 U109);

**Owner informed consent**

Horse owners gave written informed consent prior to the commencement of the study.

**Sources of funding**

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**Authorship**

R. Weller, T. Pfau, N. Menzies-Gow and P. Harris designed the study. I. Maisonpierre and M. Sutton performed data collection and processing. Data analysis by I. Maisonpierre, M. Sutton, T. Pfau and R. Weller. All authors contributed to data interpretation, writing of the manuscript and approved the final draft of the manuscript.

**Manufacturers' addressess**

[A]ActiGraph LLC, Pensacola, Florida, USA.

[B]GraphPad Software, La Jolla, California, USA.

**Tables**

**Table 1:** Subject details. A horse description (breed, sex [**G -** Gelding; **M** – Mare], age, height, use and additional information) was obtained from each owner. BCS was assessed using the Carroll and Huntingdon 5-point scale [35] and approximate body mass was acquired using an equine weigh tape.

| Subject No. | Breed | Sex | Age (years) | Height (hands) | Body Condition Score (BCS) | Approximate Body Mass (kg) | Use | Additional Information |
|---|---|---|---|---|---|---|---|---|
| **1** | Welsh Section D | G | 22 | 15 | 3/5 | 450 | Hacking | Arthritis of hocks and fetlocks |
| **2** | Thoroughbred X Warmblood | M | 11 | 15.2 | 4/5 | 525 | Hacking Schooling Jumping | |
| **3** | Warmblood | G | 4 | 16.3 | 3/5 | 600 | Dressage | |
| **4** | Welsh Section D | G | 11 | 14.2 | 3/5 | 450 | Showing Dressage Hunting | |
| **5** | Cob | M | 22 | 16.1 | 4/5 | 600 | Retired | Arthritis of fetlocks |
| **6** | Cob | G | 15 | 16 | 3/5 | 575 | Dressage | |

**Table 2:** Sensitivity, specificity and area under the receiver operating characteristic (ROC) curve for the whole group accelerometer cut points used in this study.

| Physical activity Category | Sensitivity (%) | Specificity (%) | Area under ROC curve (95% CI Interval) | Accelerometer cut point (Vector Magnitude) |
|---|---|---|---|---|
| **Standing** | 97.7 | 94.7 | 0.973 (0.953 to 0.992) | <127.6 |
| **Grazing** | | | | 127.6-702.7 |
| **Ambulating** | 94.7 | 96.8 | 0.986 (0.975 to 0.997) | >702.7 |

## Figure legends

**Fig 1:** Accelerometer output (vector magnitude) in 10 second epochs during five-minute periods of observed physical activity. Mdn (IQR) - Standing: 0 (0-3), n = 187; Grazing: 356.4 (285.9-448.7), n = 187; Ambulating: 1237 (1044-1526), n = 187. There is significant difference across physical activity categories as well as between each individual category. $^{***}$P<0.0001

**Fig 2:** Mdn (IQR) of the difference in time spent in each physical activity category. n = 178. Standing = 46.9 (21.3-87.9) minutes; Grazing 77.3 (40.2-124.5) minutes; Ambulating 15.6 (6.8-40.2) minutes

**Fig 3:** Time budgets of horses managed in standard paddocks compared with small paddocks **(A) Standing* -** Standard paddock: Mdn(IQR) time spent 8.7 (8.0-9.4) hours, n = 48. Small paddock: Mdn (IQR) time spent = 10.3 (8.8-11.3) hours, n = 38. **(B) Grazing -** Standard paddock: Mdn (IQR) time spent = 12.2 (11.5-13.2) hours, n = 48. Small paddock: Mdn (IQR) time spent = 11.7 (10.3-13.6) hours, n = 38. **(C) Ambulating* -** Standard paddock: Mdn (IQR) time spent = 55.7 (42.4-84.8) minutes, n = 48. Small paddock: Mdn (IQR) time spent= 39.6 (34.83-62.7) minutes, n= 38.

**Fig 4:** Time budgets of horses during the day compared with the night (standard paddock). **(A) Standing* -** Day: Mdn (IQR) time spent (%) = 33.0 (27.5-37.1), n = 44. Night: 50.9 (44.3-58.1), n = 51. **(B) Grazing* -** Day: 60.8 (58.2-65.4), n = 44. Night: 46.8 (43.3-50.2), n = 51. **(C) Ambulating* -** Day: 4.6 (3.7-6.9), n = 44. Night: 2.4 (0.8-3.4), n = 51. All numbers in percent.

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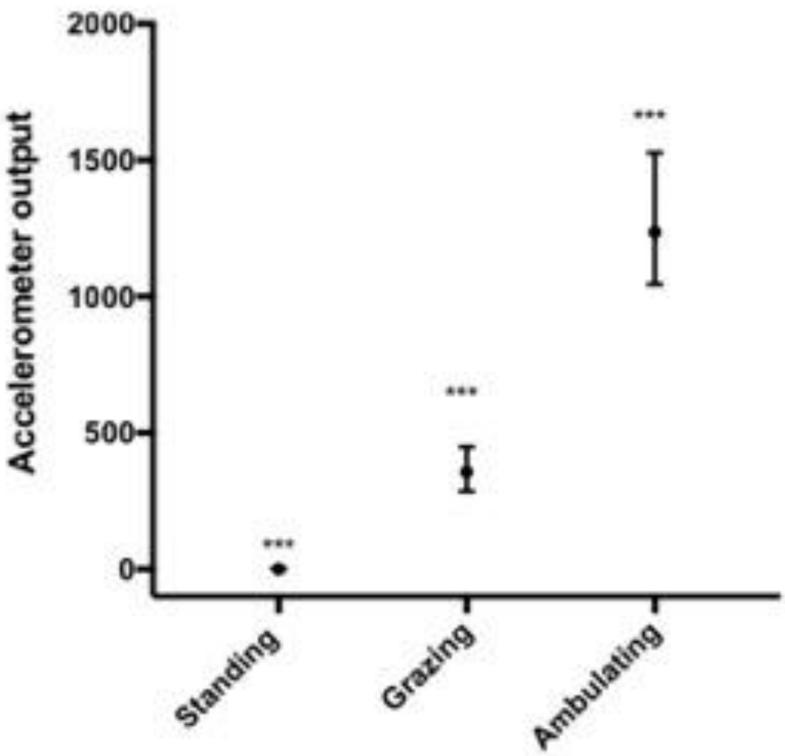

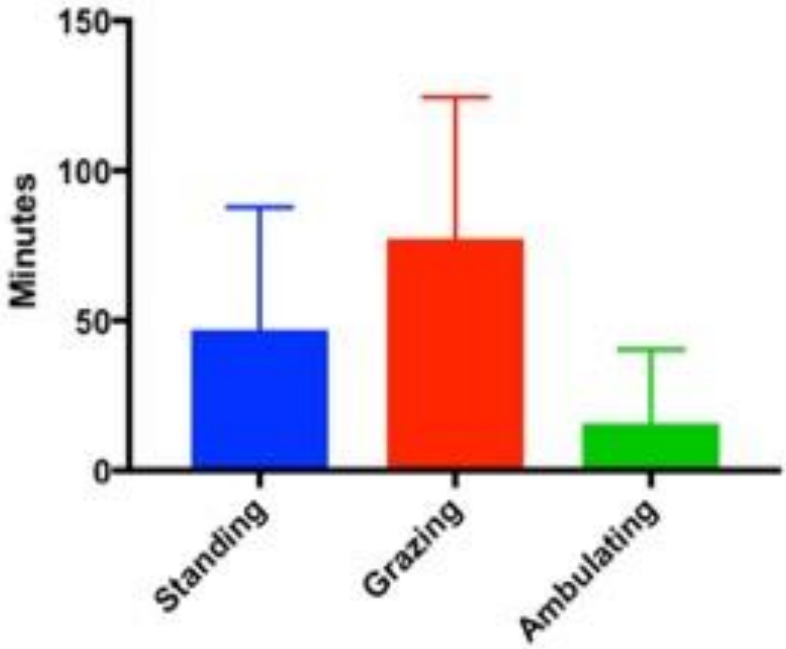
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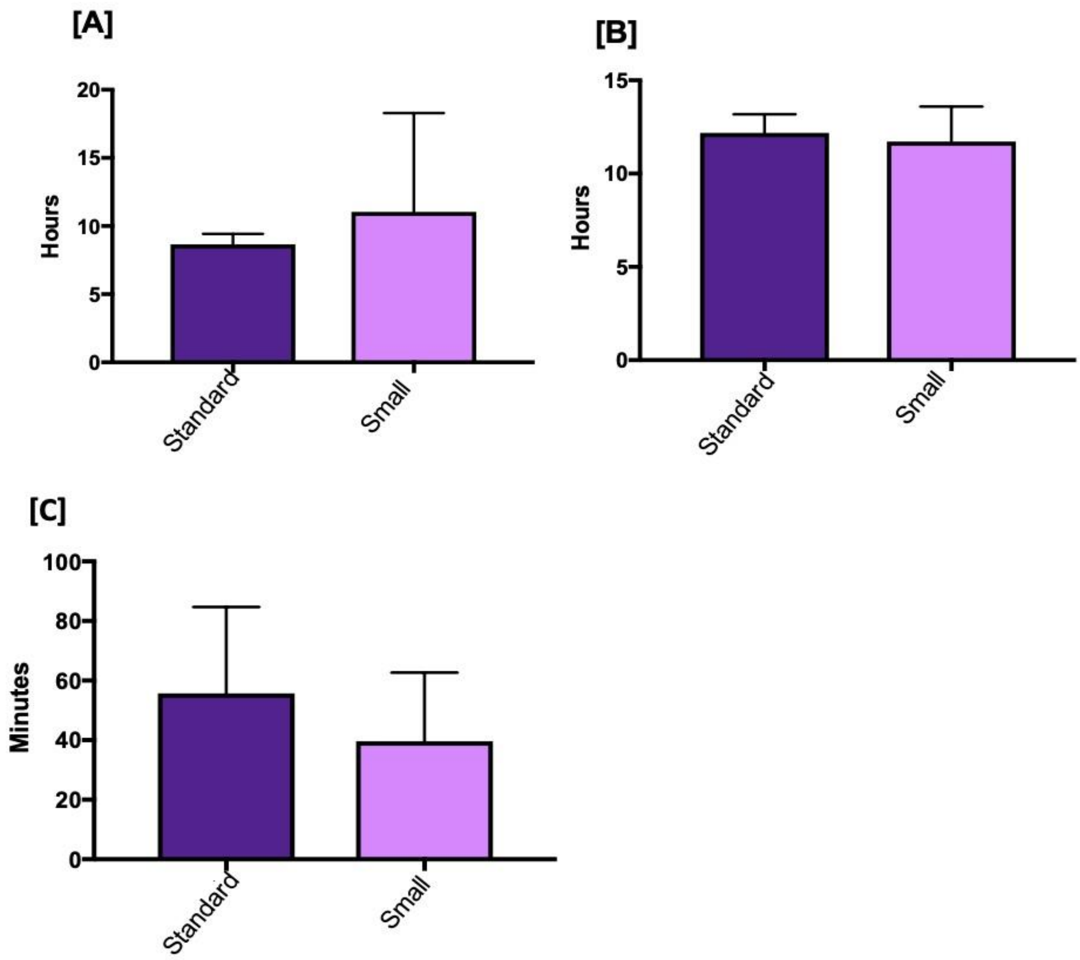
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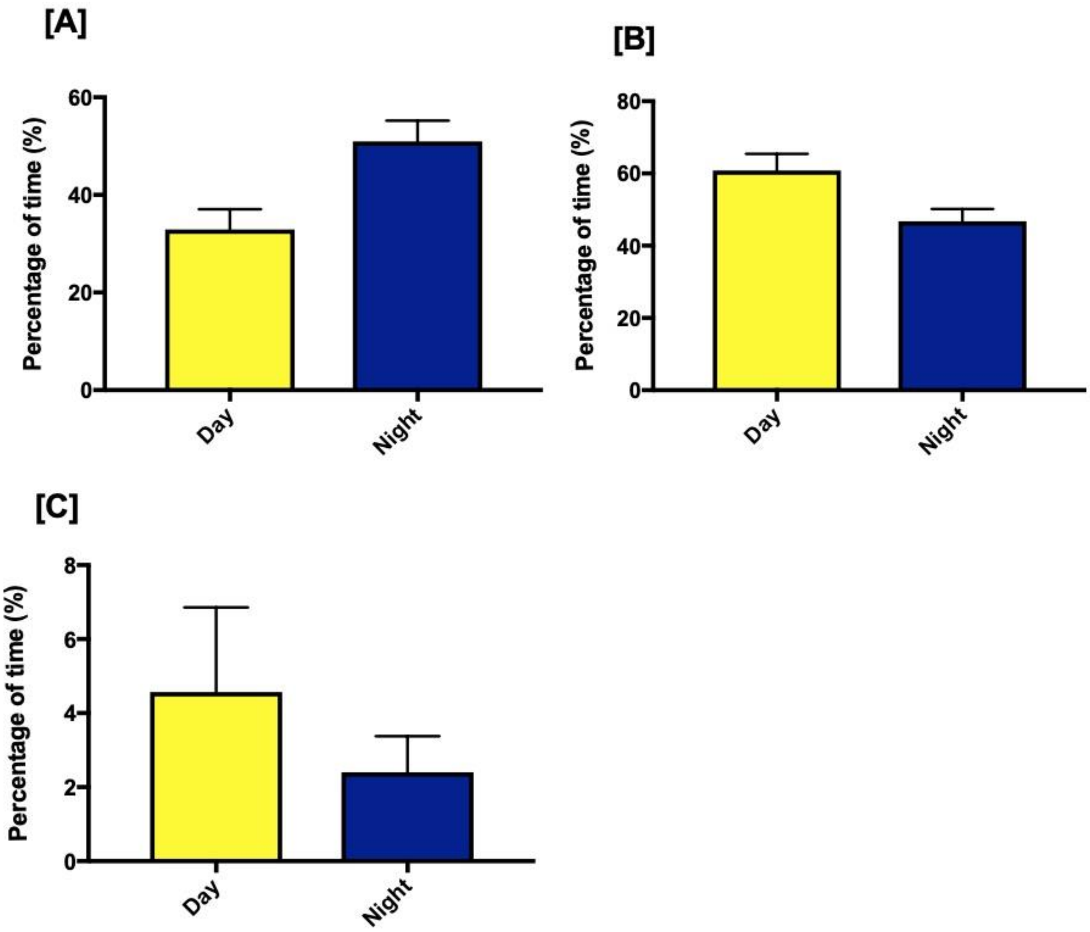

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