



Canine Research

An actigraphy-based comparison of shelter dog and owned dog activity patterns

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ABSTRACT

Animal shelters tend to be stressful environments for dogs because of the sights, sounds, odors, and schedules that characterize shelter living. Levels of activity, including the amount of time spent resting or engaging in sedentary behaviors, may provide insights into overall welfare, especially when comparing shelter dogs' activity patterns to those of dogs in a home setting. The goal of this study was to compare the intensity and consistency of shelter dogs' and owned dogs' activity levels using three distinct methods for analyzing actigraphy data. Activity levels were measured for 19 owned dogs and 19 shelter dogs using triaxial accelerometers affixed to nylon collars on each dog's neck. Shelter dogs were more active than owned dogs during the first three quarters of the day, whereas owned dogs were more active than shelter dogs during the final quarter. Comparisons of shelter dogs' and owned dogs' ten consecutive hours of greatest activity also indicated that shelter dogs were more active earlier in the day than owned dogs. Furthermore, shelter dogs exhibited higher activity levels than owned dogs during this period of greatest activity. During the five consecutive hours of least activity, shelter dogs were more active than owned dogs. Finally, individual shelter dogs' activity patterns were more consistent day to day than owned dogs'. Our findings suggest that the shelter environment may inhibit dogs from resting. Further research is needed to assess the impacts of activity patterns on the health of shelter-housed dogs and to determine how quickly these dogs adjust to their owner' schedules after adoption.

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Introduction

Regardless of whether a dog enters an animal shelter after having been accustomed to living in a home, in a yard, or roaming freely, the dog's transition to the shelter environment is likely to be stressful. On entering a shelter, a dog will experience new sights, sounds, and odors, as well as prolonged periods of confinement and a different routine. Numerous studies have reported elevated cortisol levels in dogs when they are kenneled at a boarding facility, training facility, or animal shelter (Hennessy et al., 1997; Rooney et al., 2007; Hennessy, 2013; Part et al., 2014). Furthermore, dogs commonly engage in more activity in the kennel environment than the home environment (Part et al., 2014), and high levels of activity

in a shelter, as measured by accelerometers, have been linked to elevated cortisol levels (Jones et al., 2014).

Although dogs commonly show heightened activity levels in a shelter environment, some dogs may respond to having little stimulation or control in their kennel by exhibiting behaviors associated with social withdrawal. For instance, some dogs remain in the back of their kennel, where they may feel more secure, and ignore prospective adopters who are trying to view them (Wells and Hepper, 1992; Protopopova et al., 2014). Whether a dog's activity levels increase or decrease in a shelter, such changes may be indicative of stress and are likely to alter the timing, duration, and quality of resting behavior.

Studies of humans have identified that sleep deprivation and changes in sleep-wake cycles are associated with numerous psychosocial and health-related problems, including cognitive impairment (Randazzo et al., 1998; Anderson et al., 2014), depression (Roberts et al., 2009; Anderson et al., 2014), and heightened susceptibility to disease (Meier-Ewert et al., 2004; Ensrud et al., 2012; Smagula et al., 2016). Due to physiological similarities

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between dogs and humans, it is likely that measures of shelter dog activity levels and daily activity patterns may provide information about their overall welfare in the shelter environment, particularly when compared to dogs living in homes.

Activity levels of owned dogs are dependent on numerous factors, including their owner's routine and lifestyle (Piccione et al., 2014). Sleep habits of owned dogs are also influenced by their owner's sleep habits, as dogs and their owners display synchrony in sleep timing, and dogs wake up earlier on the days their owners go to work (Randler et al., 2018). Activity of owned dogs can be highly variable from day to day, depending on the owner's schedule and presence in the home (Piccione et al., 2014). Furthermore, some owners may arrange for their dogs to attend dog daycare or go for outings with a dog walker during working hours.

The aim of this study was to compare the activity patterns of shelter dogs and owned dogs using three distinct approaches. The first approach used activity cut points established by Morrison et al. (2013) to determine whether shelter dogs and owned dogs differed in the amount of time they engaged in sedentary, light-to-moderate, and vigorous activity. The second approach applied the Low Movement Recumbency (LMR) algorithm (Ladha and Hoffman, 2018) to compare the amount of time shelter dogs and owned dogs spent resting. The third approach compared rest-activity rhythms in shelter dogs and owned dogs using a nonparametric method initially developed for the study of human activity patterns (Witting et al., 1990). This approach assessed the consistency of dogs' activity patterns within and across days and characterized the intensity of activity levels during the most active ten-hour period (M10) and the least active five-hour period (L5) of each dog's day. M10 scores are influenced by daytime napping, whereas L5 scores indicate movement and arousal during nighttime hours (Witting et al., 1990). We hypothesized that activity patterns would differ between shelter dogs and owned dogs and that, compared to owned dogs, shelter dogs would display consistently higher activity levels throughout the day and less variation in activity patterns across days.

Methods

Participants

Dogs residing at home with their owners and dogs residing in an animal shelter participated in this study. Owned dogs lived within twenty-five miles of Buffalo, NY, and did not share their home with another dog or a cat. Data collection for owned dogs occurred between October 2016 and May 2017 and between February 2018 and March 2018. We used social media and word of mouth to locate individuals who were willing to have their dogs participate in the study. Before delivering the study materials to participants' homes, we conducted a phone interview to screen out any aggressive or fearful dogs. We also screened out dogs whose owners engaged in shift work.

Shelter dog data were collected between October 2017 and April 2018, at an open-admission animal shelter located in Upstate New York. This shelter houses all stray and seized dogs from the local community, in addition to dogs surrendered by their owners from the surrounding area. This facility also occasionally transfers dogs in from other shelters. With the exception of litters of puppies and small dogs from the same family, dogs are housed individually. The shelter has a maximum capacity of 36 dogs, although it normally does not house more than 25 dogs at any given time. When dogs arrive at the shelter, they are initially housed in a holding area with 10 kennels in the center, which are each separated from smaller kennels by guillotine doors. This room is not accessible to the public. Dogs are generally kept on the longer side (1.3 m wide ×

2.4 m long × 1.6 m tall, with fencing up to the ceiling), except during cleaning hours when they are typically moved to the short side. Each kennel contains an elevated bed, blanket, one hard toy, one soft toy, and a water bowl. Shelter employees are usually onsite between 07:00 and 18:00 and give each dog two walks per day. One walk occurs between 08:00 and 09:00, and the other occurs between 14:00 and 17:00.

As per shelter protocol, each dog that enters the shelter undergoes an intake examination, which evaluates the dog's health and general behavior. Dogs are also vaccinated as part of the shelter's intake protocol. Only dogs that were easy to handle and judged to be healthy during the examination participated in this study. Dogs that displayed aggressive behaviors, such as growling or attempting to bite, were excluded from the study. In addition, dogs that showed extreme fear (e.g., displayed a tucked tail during the entire examination) and/or appeared to be shut down or failed to engage with the intake staff were excluded from participating.

Measures

VetSens triaxial accelerometer sensors (VetSens, Newcastle, United Kingdom) were used to measure activity. These devices simultaneously monitored measurements from three perpendicular axes to collect precise movements, while incorporating a real-time clock for accurate time determinations of movements. The accelerometers recorded at 100 Hz and had a battery life of 14 days, allowing devices to remain on dogs for the entire data collection period. VetSens devices were small (23 × 32.5 × 7.6 mm, 11 g) and were attached to each dog's collar. Data from VetSens devices were uploaded to and processed through VetSens (<https://vetsens.co.uk>), which provides analysis for research on dog movement via the ActivityScope program (VetSens, Newcastle, United Kingdom). Among other metrics, VetSens provides a minute-by-minute summary of the intensity of physical activity.

Procedure

VetSens devices were affixed to each dog's collar with Gorilla tape (Gorilla Glue Company, Cincinnati, OH USA) such that the device was entirely covered and protected by the tape. Collars were fitted snugly to the dog's neck, allowing two to three fingers to fit between the dog's neck and collar. This ensured that the collar could not slip off, get caught on an object, or be chewed.

The VetSens devices were delivered to owned dogs' homes. During the home visit, a member of the study team fitted a collar to the dog and attached the VetSens device to that collar. The devices were programmed to begin recording data at 20:00 on the day the devices were dropped off and to continue recording for two weeks. Owners were asked to allow the dog to wear the collar continuously during the study period, but they were allowed to remove the collar during any periods when they felt wearing the collar might pose a risk to the dog (e.g., when playing off-leash with other dogs).

Shelter dogs were fitted with nylon collars and VetSens devices during their intake examination. The device immediately started recording the dog's movements as soon as it was affixed to the dog's collar, and data collection continued until the dog moved from the holding area to the adoption floor.

Data analysis

For all dogs, data analysis focused on data collected beginning at the first midnight the dog wore the instrumented collar and ending 144 hours later for owned dogs and at 23:59 on the last full day shelter dogs were in the holding area. Data analyses were conducted in R (Version 3.4.1; R Core Team, 2017) and IBM SPSS

Statistics for Windows (Version 24.0; IBM Corp, 2016). As recommended by Morrison et al. (2013), we reported movement counts as the composite vector magnitude (VM3) of the anteroposterior, mediolateral, and vertical axes. VM3 values at or below 1351 counts per minute (cpm) are characteristic of sedentary movements (i.e., no movement of the trunk, such as when lying or standing still or sleeping); VM3 values between 1,352 and 5,695 cpm are characteristic of light-to-moderate activity (slow to moderate movement of the trunk, such as when walking on a leash) and values at or above 5,696 cpm are characteristic of vigorous activity (i.e., rapid movement of the trunk, such as when running outdoors off-leash) (Morrison et al., 2013). Yam et al. (2011) demonstrated that the Actigraph GT3X triaxial accelerometer is a valid and reliable tool for assessing physical activity volume and intensity across a range of dog breeds, ages, and sizes, and Westgarth and Ladha (2017) concluded that activity counts generated by the VetSens hardware correspond strongly with counts generated by the Actigraph GT3X accelerometer used by Yam et al. (2011) and Morrison et al. (2013) (Pearson's $r^2 = 0.96$).

In addition to examining activity levels according to cut points, we applied the LMR algorithm (Ladha and Hoffman, 2018) to identify the number of minutes per day and per quarter of the day that owned dogs and shelter dogs were resting. To validate this algorithm, Ladha and Hoffman (2018) coded video data collected on owned dogs to distinguish periods of rest from activity. Rest behavior (i.e., nonactive behavior) was defined as no movement of any body part while lying or sitting. During rest periods, the dog's head may have been fully relaxed or supported by neck muscles. A dog was considered not resting if standing or moving the head or trunk for more than one second. The algorithm distinguished rest from active behavior with a mean accuracy of 0.86.

We ran Levene's tests to determine whether the variation in the proportion of time in sedentary, light-to-moderate, and vigorous activity differed between owned dogs and shelter dogs. The P values reported for these Levene's tests reflect a Bonferroni correction because we ran a separate test for each of the three activity categories. We also ran Levene's test to compare variation in the proportion of time owned dogs and shelter dogs spent resting, as assessed by the LMR algorithm. We used beta regression models, controlling for sex, age, and weight, to determine whether owned dogs and shelter dogs differed in the proportion of time they engaged in sedentary, light-to-moderate, and vigorous activity over a 24-hour period, and to determine whether owned dogs and shelter dogs differed in the proportion of time they engaged in resting behavior over a 24-hour period.

To compare the number of minutes dogs were sedentary during each quarter of the day (0:00–05:59; 06:00–11:59; 12:00–17:59; 18:00–23:59), we used multilevel modeling. Dog ID was treated as a random factor; quarter of the day, group (i.e., shelter dog or owned dog), and sex of dog were fixed factors; and dog age and weight were covariates. We examined whether there was an interaction between quarter of day and group. We treated the first quarter of the day as the reference group in planned contrasts to determine whether shelter dogs or owned dogs showed a greater difference in sedentary activity between the quarter of least activity (i.e., the first quarter) and each of the other three quarters. We ran the same analysis on the rest data that were derived from the LMR algorithm.

Nonparametric activity measures that identified rest-activity rhythms were calculated in R (R Core Team, 2017) using the nonparACT package (Blume et al., 2016). Interdaily stability (IS) measures how consistent activity rhythms are across days, whereas intradaily variability (IV) assesses how variable activity patterns are across a 24-hour period. M10 is the average activity level across the ten consecutive hours of maximal activity, whereas L5 is the average activity level across the five consecutive hours of minimal

activity. Relative amplitude (RA) examines the difference between an individual's most active 10-hour period (M10) and least active 5-hour period (L5). L5 and M10 were positively skewed and so were log-transformed before the analysis. We used general linear models to assess the impact of group on IV, L5, and M10 while controlling for dog sex, age, and weight. Because all possible IS and RA values ranged between 0 and 1, we used beta regression models to see if the group impacted these measures.

Results

On average, we collected 14.8 days ($SD = 0.5$, min = 14, max = 16) of actigraphy data from 19 owned dogs and 5.1 days ($SD = 2.7$, min = 2, max = 12) from 43 shelter dogs. We restricted analyses of data from shelter dogs to 19 individuals for whom we had a minimum of three consecutive days (i.e., 72 hours) of data, starting at the first midnight after placement of the accelerometer on the dog upon shelter intake. For these dogs, which included 9 males and 10 females that ranged from 1 year to 9 years ($M = 3.7$, $SD = 2.0$), we had an average of 5.7 full days ($SD = 1.8$, min = 3, max = 10) of data. Length of stay ranged from 7 to 278 days ($M = 42.47$, $SD = 63.24$). Five of these dogs were surrendered to the shelter by their owners, and 14 arrived at the shelter as strays. A Welch's two-sample t -test indicated that shelter dogs' average daily activity scores, which were calculated by adding together their average hourly VM3 scores, did not differ according to intake type ($t = 1.05$, $df = 4.41$, $P = 0.35$), and so stray and owner-surrendered dogs were combined in analyses comparing shelter dogs with owned dogs.

The owned dogs included 11 males and 8 females that ranged in age from 0.7 years to 13 years ($M = 5.4$, $SD = 3.9$) and had lived with their owners between 0.5 years and 12 years ($M = 5.3$, $SD = 4.0$). The ages of the owned dogs and shelter dogs did not differ significantly ($t = -1.60$, $df = 36$, $P = 0.12$). Shelter dogs ranged in weight from 5.5 kg to 34.0 kg ($M = 24.8$, $SD = 6.7$), and owned dogs ranged in weight from 3.9 kg to 35.0 kg ($M = 17.7$, $SD = 10.1$). This difference was significant ($t = 2.56$, $df = 36$, $P = 0.02$). The VetSens device recorded data continuously during the data collection period for all 19 shelter dogs; data for owned dogs over the time period assessed are complete, with the exception of one dog that did not wear the collar for one hour during the study period.

Comparison based on cut point thresholds

Both shelter dogs and owned dogs spent more than two-thirds of their day engaging in sedentary behavior (Table 1). Levene's tests identified that shelter dogs exhibited significantly greater variation than owned dogs in the proportion of time they spent engaging in sedentary activity ($F(1, 36) = 9.132$, $P = 0.015$) and light-to-moderate activity ($F(1, 36) = 6.748$, $P = 0.042$), but the variation in the proportion of time that shelter dogs and owned dogs engaged in vigorous activity did not differ ($F(1, 36) = 4.061$, $P = 0.154$; Figure 1). Beta regression models indicated that neither group, nor sex, nor age, nor weight impacted the proportion of time dogs engaged in sedentary, light-to-moderate, or vigorous activity (Table 2).

There were significant main effects of quarter of day on number of minutes spent in sedentary activity (quarter: $\chi^2(3) = 115.890$, $P < 0.001$). However, there were no significant main effects of group ($\chi^2(1) = 2.630$, $P = 0.105$), sex ($\chi^2(1) = 0.323$, $P = 0.570$), age ($\chi^2(1) = 0.008$, $P = 0.928$), or weight ($\chi^2(1) = 0.524$, $P = 0.469$). The interaction between quarter of day and group was significant ($\chi^2(3) = 113.811$, $P < 0.001$). The decrease in sedentary activity from quarter 1 to quarter 2 was greater for shelter dogs than for owned dogs ($b = -0.202$, $t(108) = -5.954$, $P < 0.001$); the same was true for the decrease in sedentary activity from quarter 1 to quarter 3

Table 1
Descriptive statistics for shelter dogs and owned dogs based on cut points, the LMR algorithm, and nonparametric activity measures

Measure	Shelter dogs	Owned dogs
	Mean (95% CI)	Mean (95% CI)
Sedentary	68.0% (62.0%–74.1%)	73.5% (70.2%–76.8%)
Light to moderate	27.8% (22.3%–33.1%)	23.9% (21.3%–26.6%)
Vigorous	4.3% (1.1%–7.4%)	2.6% (1.7%–3.5%)
Minutes resting	1045.1 minutes (965.3–1125.0)	1148.31 minutes (1111.8–1184.8)
Counts per minute during most active 10 hours	2299.8 (1730.8–2868.7)	1545.6 (1364.6–1726.6)
Counts per minute during least active 5 hours	423.4 (259.9–586.9)	243.6 (196.1–291.2)
Interdaily stability (IS)	0.65 (0.59–0.71)	0.46 (0.42–0.51)
Intradaily variability (IV)	0.90 (0.79–1.01)	1.03 (0.97–1.09)
Relative amplitude (RA)	0.69 (0.65–0.74)	0.73 (0.69–0.77)

LMR, low movement recumbency.

($b = -0.084$, $t(108) = -2.488$, $P = 0.014$). The decrease in sedentary activity from quarter 1 to quarter 4, however, was greater for owned dogs than for shelter dogs ($b = 0.239$, $t(108) = 7.034$, $P < 0.001$).

Comparison based on minutes resting

Levene's test indicated that shelter dogs exhibited significantly greater variation than owned dogs in the proportion of time spent resting, as assessed using the LMR algorithm ($F(1, 36) = 11.484$, $P = 0.002$). Neither sex, nor age, nor weight impacted the proportion of time dogs spent resting across a 24-hour period, but group did (Table 2). Across a 24-hour period, shelter dogs engaged in approximately 100 fewer minutes of resting behavior compared with owned dogs (Table 1).

There were significant main effects of quarter of day and group on the number of minutes spent resting (quarter: $\chi^2(3) = 106.24$, $P < 0.001$; group: $\chi^2(1) = 5.943$, $P < 0.015$). However, there were no significant main effects of sex ($\chi^2(1) = 0.428$, $P = 0.513$), age ($\chi^2(1) = 0.0063$, $P = 0.937$), or weight ($\chi^2(1) = 1.032$, $P = 0.310$). The interaction between quarter of day and group was significant ($\chi^2(3) = 92.503$, $P < 0.001$). The decrease in resting behavior from quarter 1 to quarter 2 was greater for shelter dogs than for owned dogs ($b = -63.37$, $t(108) = -5.44$, $P < 0.001$); the same was true for the decrease in resting behavior from quarter 1 to quarter 3 ($b = -25.14$, $t(108) = -2.16$, $P = 0.033$; Figure 2). The decrease in resting behavior from quarter 1 to quarter 4, however, was greater for owned dogs than for shelter dogs ($b = 66.65$, $t(108) = 5.72$, $P < 0.001$).

Nonparametric measures of activity

Shelter dogs and owned dogs differed regarding how much their activity patterns fluctuated across and within days (Table 1). IS was significantly greater for shelter dogs than owned dogs, suggesting greater consistency in activity across shelter dogs' days than owned dogs' days; however, neither age nor weight impacted IS (Table 2). IV was significantly lower for shelter dogs than owned dogs, indicating that owned dogs transitioned between rest and activity more often than shelter dogs (Table 3). Neither sex, nor age, nor weight impacted IV.

Owned dogs' and shelter dogs' average hourly VM3 scores differed substantially across much of the day (Figure 3). Owned dogs and shelter dogs differed in the timing of their most active periods and in the intensity of their movements during these periods. The 10-hour period (M10) during which shelter dogs were most active began at 07:20 (95% CI = 07:09–07:30), whereas this active period for owned dogs began at 11:16 (95% CI = 10:24–12:06). This difference was significant ($F(1, 33) = 62.222$, $P < 0.001$), even when including dog sex, age, and weight in the model (Table 3). In addition, shelter dogs were significantly more active during this 10-hour window than were owned dogs ($F(1, 33) = 5.613$, $P = 0.024$), whereas neither age, nor sex, nor weight impacted activity intensity during this window (Table 3).

Regarding the onset of owned dogs' and shelter dogs' least active five hours (L5), the period during which shelter dogs were least active began at 23:16 (95% CI = 22:07–00:24), and it began for owned dogs at 00:19 (95% CI = 23:49–00:49). However, neither group, nor sex, nor age, nor weight was associated with the onset of the least active five-hour period (Table 3). Shelter dogs had higher average activity levels during this period than owned dogs ($F(1, 33) = 4.805$, $P = 0.036$), but sex, age, and weight did not impact activity levels during this period (Table 3). RA was slightly higher for owned dogs than for shelter dogs, but neither group, nor sex, nor age, nor weight significantly impacted RA (Table 2).

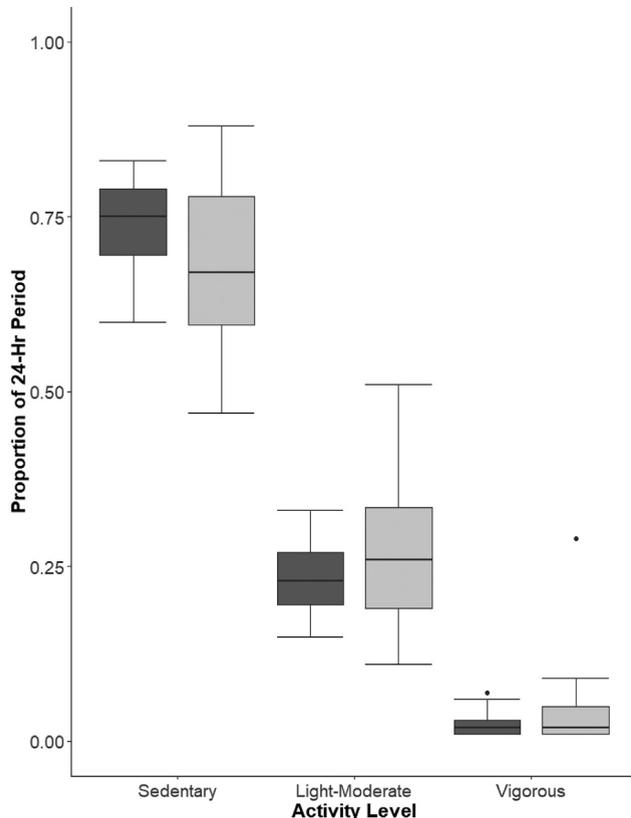


Figure 1. Box plot depicting the proportion of time owned and shelter dogs engaged in sedentary, light-to-moderate, and vigorous activities. Dark-gray bars represent owned dogs, and light-gray bars represent shelter dogs.

Table 2

Results from beta regression models comparing the proportion of the day shelter dogs and owned dogs spent in sedentary, light-to-moderate, and vigorous activity; the proportion of the day they engaged in resting behavior; and interdaily stability and relative amplitude for shelter dogs and owned dogs

Characteristic	Estimate	Std. error	z value	Pr (> z)
Sedentary				
Intercept	0.968	0.248	3.903	<0.001
Group	-0.274	0.168	-1.632	0.103
Sex	-0.136	0.150	-0.907	0.364
Age	0.000	0.025	-0.010	0.992
Weight	0.006	0.009	0.657	0.511
Light to moderate				
Intercept	-1.262	0.225	-5.615	<0.001
Group	0.244	0.153	1.594	0.111
Sex	0.194	0.136	1.428	0.153
Age	0.018	0.022	0.806	0.420
Weight	-0.005	0.008	-0.557	0.578
Vigorous				
Intercept	-3.074	0.408	-7.533	<0.001
Group	-0.036	0.267	-0.135	0.893
Sex	0.038	0.241	0.158	0.874
Age	-0.068	0.042	-1.637	0.102
Weight	0.002	0.015	0.153	0.879
Resting				
Intercept	1.124	0.244	4.605	<0.001
Group	-0.391	0.163	-2.391	0.017
Sex	0.082	0.146	0.563	0.574
Age	0.001	0.024	0.053	0.957
Weight	0.009	0.009	1.000	0.317
Interdaily stability				
Intercept	-0.245	0.241	-1.017	0.309
Group	0.846	0.163	5.201	<0.001
Sex	0.154	0.146	1.054	0.292
Age	0.014	0.023	0.585	0.559
Weight	-0.003	0.009	-0.380	0.704
Relative amplitude				
Intercept	1.112	0.231	4.818	<0.001
Group	-0.077	0.153	-0.502	0.615
Sex	0.070	0.138	0.510	0.610
Age	-0.006	0.023	-0.281	0.778
Weight	-0.009	0.008	-1.037	0.300

Bold indicates $P < 0.05$.

Table 3

Results from general linear models comparing shelter dogs and owned dogs on nonparametric activity measures

Characteristic	F	df (num, den)	P
Intradaily variability			
Group	4.755	1, 33	0.036
Sex	0.079	1, 33	0.780
Age	0.101	1, 33	0.753
Weight	0.750	1, 33	0.393
M10 start time			
Group	62.222	1, 33	< 0.001
Sex	0.205	1, 33	0.653
Age	0.057	1, 33	0.813
Weight	1.375	1, 33	0.249
Counts per minute during M10			
Group	5.613	1, 33	0.024
Sex	0.144	1, 33	0.707
Age	0.285	1, 33	0.597
Weight	0.472	1, 33	0.497
L5 start time			
Group	2.230	1, 33	0.145
Sex	0.868	1, 33	0.358
Age	0.857	1, 33	0.361
Weight	0.317	1, 33	0.577
Counts per minute during L5			
Group	4.805	1, 33	0.036
Sex	0.029	1, 33	0.866
Age	0.046	1, 33	0.832
Weight	0.107	1, 33	0.746

M10, most active ten-hour period; L5, least active five-hour period.

Bold indicates $P < 0.05$.

Discussion

We analyzed accelerometer data collected from owned dogs and shelter dogs in three distinct ways, each of which indicated that dogs' physical activity levels and daily activity patterns differ based on whether they are in a home environment or an animal shelter. We did not detect a difference in the proportions of the day shelter dogs and owned dogs engaged in sedentary, light-to-moderate, or vigorous activity levels. However, when we used the LMR algorithm

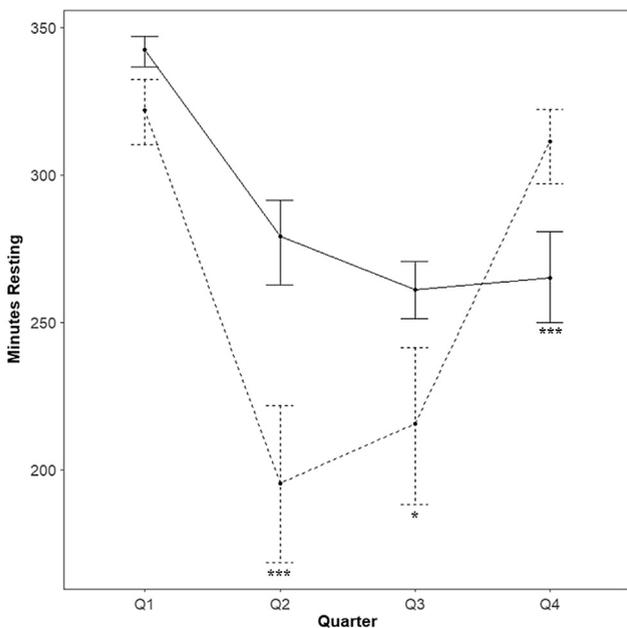


Figure 2. Minutes resting during each quarter of the day. The solid line represents owned dogs, and the dashed line represents shelter dogs. Asterisks are placed by the group that showed the greatest change from Q1 to Q2, from Q1 to Q3, and from Q1 to Q4. * $P < 0.05$, *** $P < 0.001$.

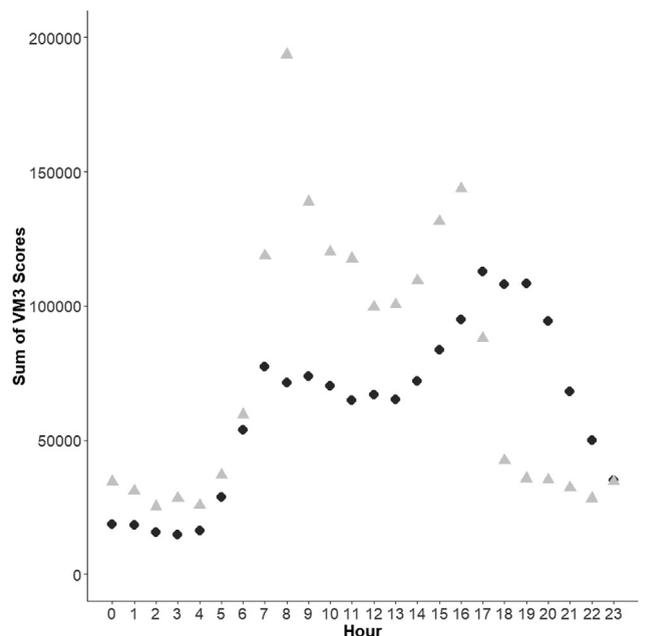


Figure 3. Average hourly sum of VM3 scores for owned and shelter dogs across a 24-hour period. Black circles represent owned dogs, and gray triangles represent shelter dogs. VM3, vector magnitude.

(Ladha and Hoffman, 2018) to examine the proportion of time dogs engaged in resting behavior, we found that shelter dogs spent significantly less time resting than owned dogs. This suggests that comparisons based on the LMR algorithm may be more sensitive to differences in activity levels than comparisons based on cut points. Also of note, IS was greater for shelter dogs than owned dogs, meaning that individual shelter dogs' activity patterns were more consistent day to day than owned dogs'. This may be due to the shelter's relatively consistent operating schedule and the long hours of confinement within a kennel.

Periods of greatest activity for shelter dogs were concentrated earlier in the day than owned dogs' and largely coincided with the hours during which shelter staff were on-site. Similar to findings from Owczarczak-Garstecka and Burman (2016), dogs were least active during hours when the shelter was closed. Shelter dogs showed a marked decrease in activity during late afternoon and evening hours, whereas this was the time period when owned dogs' activity levels tended to increase. In addition, shelter dogs displayed higher levels of activity than owned dogs during both their most active ten hours of the day (M10) and their least active five hours (L5). These findings are consistent with findings from a previous study that showed that dogs in kennels are more active than dogs residing in homes (Part et al., 2014).

Shelter dogs spent significantly less time resting than owned dogs, indicating that the shelter environment may inhibit dogs from resting. Compared with owned dogs, shelter dogs' activity levels during their least active five-hour period (L5) and the number of minutes they spent resting during the first quarter of the day suggest they are moving more, and thus likely sleeping less, at night. If dogs accumulate a resting deficit while in the shelter, they may need time to recover from this deficit and acclimate to a new routine on leaving the shelter. Prior research supports this idea. Shelter dogs displayed longer periods of rest when they were removed from the shelter and placed in a temporary foster home for sleepovers (Gunter et al., 2019). In addition, these dogs also showed significant reductions in cortisol while in a foster home.

Given associations between sleep quality and physical and psychological well-being (McEwen, 2006), the heightened activity levels seen in shelter-housed dogs compared with owned dogs indicate that the shelter may adversely impact shelter dogs' health and even their attractiveness as adoption candidates. Prior research has identified a negative association between the amount of time dogs rest with their head on their paws or the ground and their cortisol levels (Gunter, 2018; Hekman et al., 2012) and has demonstrated a positive relationship between shelter dogs' activity levels and cortisol levels (Jones et al., 2014). Furthermore, adopters commonly report desiring dogs who display calm behaviors (Wells and Hepper, 1992; Marston et al., 2005), but our findings suggest it may be more difficult for dogs to display calm behaviors in the shelter compared with when at home.

Shelter dogs exhibited more interindividual variability than owned dogs regarding the proportions of time they spent engaging in sedentary and light-to-moderate activities. Although many shelter dogs did exhibit more activity than owned dogs, there were also shelter dogs that were less active than owned dogs. Follow-up research is needed to determine what information interindividual variation can provide about shelter dog welfare and whether individual differences in activity are predictive of shelter dog outcomes (e.g., length of time on the adoption floor, likelihood of being returned). Given the variability observed in shelter dog activity and previously reported associations between activity levels and cortisol (Jones et al., 2014), actigraphy may provide a noninvasive, economical way to identify dogs at risk for poor shelter outcomes and to determine appropriate types of enrichment based on the activity level of the dog.

Although our study identified differences between owned dogs' and shelter dogs' activity levels, additional data are needed to determine whether M10 and L5 thresholds, which were derived from assessments of human activity patterns (Witting et al., 1990), are ideal for assessing dog activity levels and patterns, and to evaluate the impact that shelter housing has on dogs' activity patterns. Our study involved a relatively small number of owned dogs and shelter dogs. Furthermore, the between-subject nature of our study design did not enable us to rule out the possibility that some shelter dogs may have displayed hyperactive or boisterous behaviors before entering the shelter. Owners who relinquish their dogs to shelters commonly report behavioral problems, including hyperactivity, as reasons for relinquishment (New et al., 2000; Diesel et al., 2010). Thus, a within-subject design, ideally implemented across multiple shelters, that tracks the activity of individual dogs in their original home environment and in the shelter is necessary to capture the degree to which the shelter environment impacts dogs' activity patterns.

Actigraphy data might also provide insights into how well dogs handle the transition from the shelter to an adoptive home. Dogs that have become accustomed to a shelter's routine may show increased activity at times when owners are commonly away at work. If this is the case, a lack of stimulation during these hours after adoption may contribute to anxious, hyperactive, or destructive behavior. Such behaviors are highly cited as reasons for returned adoptions (Shore, 2005), and dogs returned within the first month after adoption are commonly reported to exhibit problematic behaviors (Diesel et al., 2008). It remains to be determined how quickly dogs acclimate to a new owner's routine and whether behavioral problems are likely to arise because of the dog having adjusted to a shelter routine.

There is also more to investigate regarding how housing conditions within the shelter impact activity. Our assessment of shelter dogs' activity levels and patterns only provided information about the first days of a dog's shelter stay, during which time they were housed in an area of the shelter that was inaccessible to members of the public. Previous shelter studies have found that human traffic in the kennel area increases standing, barking, and moving to the front of the kennel (Wells and Hepper, 2000), whereas reducing human visitor activity in the kennel area is associated with decreases in dogs' vocalizations and repetitive behaviors and increases in the amount of time dogs are sedentary (Hewison et al., 2014). Therefore, we hypothesize that most dogs would exhibit even higher activity levels when on the adoption floor than they did in the holding area because of greater human traffic in the adoption area.

Finally, owned dogs in this study did not live with another dog. Although the shelter dogs in this study could not physically interact with other dogs in the kennels, they could still see and hear other dogs. Thus, the impact that dogs' opportunities to interact with conspecifics have on activity levels in the shelter or at home is another variable future studies might explore.

Conclusions

Owned dogs and shelter dogs exhibited marked differences in their activity levels and daily activity patterns, with shelter dogs showing greater activity than owned dogs during the first three quarters of the day and owned dogs showing more activity during the last quarter of the day. It is notable that the hours during which shelter dogs were most active corresponded closely to the shelter's operating hours. This suggests that the timing of human presence in the shelter may influence shelter dog activity patterns. Positive shelter-related outcomes depend on dogs successfully transitioning from a shelter environment to a home environment, and so follow-up work is needed to determine how quickly dogs adjust to their

new owner's schedule. Furthermore, the interindividual differences observed in the shelter dogs' activity patterns indicate that actigraphy may provide a noninvasive, affordable way to identify which dogs are experiencing compromised welfare in the shelter environment and for assessing how various interventions may impact the well-being of these dogs.

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Ethical considerations

All procedures performed were in accordance with the ethical standards set by the Institutional Animal Care and Use Committee at Canisius College.

Conflict of interest

Christy L. Hoffman and Sabrina Wilcox have no competing interests. Cassim Ladha is engaged in development of the VetSens product.

References

Anderson, K.N., Catt, M., Collerton, J., Davies, K., von Zglinicki, T., Kirkwood, T.B., Jagger, C., 2014. Assessment of sleep and circadian rhythm disorders in the very old: the Newcastle 85+ Cohort Study. *Age Ageing* 43, 57–63.

Blume, C., Santhi, N., Schabus, M., 2016. 'nparACT' package for R: A free software tool for the non-parametric analysis of actigraphy data. *MethodsX* 3, 430–435.

Diesel, G., Brodbelt, D., Pfeiffer, D.U., 2010. Characteristics of relinquished dogs and their owners at 14 rehoming centers in the United Kingdom. *J. Appl. Anim. Welf. Sci.* 13, 15–30.

Diesel, G., Pfeiffer, D.U., Brodbelt, D., 2008. Factors affecting the success of rehoming dogs in the UK during 2005. *Prev. Vet. Med.* 84, 228–241.

Ensrud, K.E., Blackwell, T.L., Ancoli-Israel, S., Redline, S., Cawthon, P.M., Paudel, M.L., Dam, T.T.L., Stone, K.L., 2012. Sleep disturbances and risk of frailty and mortality in older men. *Sleep Med* 13, 1217–1225.

Gunter, L., 2018. Understanding the Impacts of Breed Identity, Post-Adoption and Fostering Interventions, & Behavioral Welfare of Shelter Dogs (PhD Thesis). Arizona State University, Tempe, AZ.

Gunter, L.M., Feuerbacher, E.N., Gilchrist, R.J., Wynne, C.D., 2019. Evaluating the effects of a temporary fostering program on shelter dog welfare. *PeerJ* 7, e6620.

Hekman, J.P., Karas, A.Z., Dreschel, N.A., 2012. Salivary cortisol concentrations and behavior in a population of healthy dogs hospitalized for elective procedures. *Appl. Anim. Behav. Sci.* 141, 149–157.

Hennessy, M.B., 2013. Using hypothalamic–pituitary–adrenal measures for assessing and reducing the stress of dogs in shelters: A review. *Appl. Anim. Behav. Sci.* 149, 1–12.

Hennessy, M.B., Davis, H.N., Williams, M.T., Mellott, C., Douglas, C.W., 1997. Plasma cortisol levels of dogs at a county animal shelter. *Physiol. Behav.* 62, 485–490.

Hewison, L.F., Wright, H.F., Zulch, H.E., Ellis, S.L.H., 2014. Short term consequences of preventing visitor access to kennels on noise and the behaviour and physiology of dogs housed in a rescue shelter. *Physiol. Behav.* 133, 1–7.

IBM Corp., 2016. SPSS for Windows. IBM Corp, Armonk, NY.

Jones, S., Dowling-Guyer, S., Patronek, G.J., Marder, A.R., Segurson D'Arpino, S., McCobb, E., 2014. Use of accelerometers to measure stress levels in shelter dogs. *J. Appl. Anim. Welf. Sci.* 17, 18–28.

Ladha, C., Hoffman, C., 2018. A combined approach to predicting rest in dogs using accelerometers. *Sensors (Basel)* 18, 2649.

Marston, L.C., Bennett, P.C., Coleman, G.J., 2005. Adopting shelter dogs: owner experiences of the first month post-adoption. *Anthrozoös* 18, 358–378.

McEwen, B.S., 2006. Sleep deprivation as a neurobiologic and physiologic stressor: allostasis and allostatic load. *Metabolism* 55, S20–S23.

Meier-Ewert, H.K., Ridker, P.M., Rifai, N., Regan, M.M., Price, N.J., Dinges, D.F., Mullington, J.M., 2004. Effect of sleep loss on C-Reactive protein, an inflammatory marker of cardiovascular risk. *J. Am. Coll. Cardiol.* 43, 678–683.

Morrison, R., Penpraze, V., Beber, A., Reilly, J.J., Yam, P.S., 2013. Associations between obesity and physical activity in dogs: A preliminary investigation. *J. Small Anim. Pract.* 54, 570–574.

New, J.C., Salman, M.D., King, M., Scarlett, J.M., Kass, P.H., Hutchison, J.M., 2000. Characteristics of shelter-relinquished animals and their owners compared with animals and their owners in U.S. pet-owning households. *J. Appl. Anim. Welf. Sci.* 3, 179–201.

Owczarczak-Garstecka, S.C., Burman, O.H., 2016. Can sleep and resting behaviours be used as indicators of welfare in shelter dogs (*Canis lupus familiaris*)? *PLoS One* 11, e0163620.

Part, C.E., Kiddie, J.L., Hayes, W.A., Mills, D.S., Neville, R.F., Morton, D.B., Collins, L.M., 2014. Physiological, physical and behavioural changes in dogs (*Canis familiaris*) when kennelled: testing the validity of stress parameters. *Physiol. Behav.* 133, 260–271.

Piccione, G., Marafioti, S., Giannetto, C., Di Pietro, S., Quartuccio, M., Fazio, F., 2014. Comparison of daily distribution of rest/activity in companion cats and dogs. *Biol. Rhythm Res.* 45, 615–623.

Protopopova, A., Mehrkam, L.R., Boggess, M.M., Wynne, C.D.L., 2014. In-kennel behavior predicts length of stay in shelter dogs. *PLoS One* 9, e114319.

R Core Team, 2017. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.

Randazzo, A.C., Muehlbach, M.J., Schweitzer, P.K., Walsh, J.K., 1998. Cognitive function following acute sleep restriction in children ages 10–14. *Sleep* 21, 861–868.

Randler, C., Díaz-Morales, J.F., Jankowski, K.S., 2018. Synchrony in chronotype and social jetlag between dogs and humans across Europe. *Time Soc* 27, 223–238.

Roberts, R.E., Roberts, C.R., Duong, H.T., 2009. Sleepless in adolescence: Prospective data on sleep deprivation, health and functioning. *J. Adolesc.* 32, 1045–1057.

Rooney, N.J., Gaines, S.A., Bradshaw, J.W.S., 2007. Behavioural and glucocorticoid responses of dogs (*Canis familiaris*) to kennelling: Investigating mitigation of stress by prior habituation. *Physiol. Behav.* 92, 847–854.

Shore, E.R., 2005. Returning a recently adopted companion animal: adopters' reasons for and reactions to the failed adoption experience. *J. Appl. Anim. Welf. Sci.* 8, 187–198.

Smagula, S.F., Stone, K.L., Redline, S., Ancoli-Israel, S., Barrett-Connor, E., Lane, N.E., Orwoll, E., Cauley, J.A., 2016. Actigraphy and polysomnography measured sleep disturbances, inflammation, and mortality among older men. *Psychosom. Med.* 78, 686.

Wells, D., Hepper, P.G., 1992. The behaviour of dogs in a rescue shelter. *Anim. Welf.* 1, 171–186.

Wells, D.L., Hepper, P.G., 2000. The influence of environmental change on the behaviour of sheltered dogs. *Appl. Anim. Behav. Sci.* 68, 151–162.

Westgarth, C., Ladha, C., 2017. Evaluation of an open source method for calculating physical activity in dogs from harness and collar based sensors. *BMC Vet. Res.* 13, 322.

Witting, W., Kwa, I.H., Eikelenboom, P., Mirmiran, M., Swaab, D.F., 1990. Alterations in the circadian rest-activity rhythm in aging and Alzheimer's disease. *Biol. Psychiatry* 27, 563–572.

Yam, P.S., Penpraze, V., Young, D., Todd, M.S., Cloney, A.D., Houston-Callaghan, K.A., Reilly, J.J., 2011. Validity, practical utility and reliability of Actigraph accelerometry for the measurement of habitual physical activity in dogs. *J. Small Anim. Pract.* 52, 86–91.