THESIS

OBJECTIVELY MEASURED FREE-LIVING PHYSICAL ACTIVITY IN PET DOGS: RELATIONSHIP TO BODY CONDITION SCORE AND OWNER-PET ACTIVITY

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ABSTRACT

OBJECTIVELY MEASURED FREE-LIVING PHYSICAL ACTIVITY IN PET DOGS: RELATIONSHIP TO BODY CONDITION SCORE AND OWNER-PET ACTIVITY

The prevalence of canine obesity continues to increase and is due, in part, to inadequate levels of physical activity (PA). Accelerometers have emerged as a useful tool to objectively quantify levels of physical activity in humans, as well as companion pets, but there is little data on the levels/patterns of free-living physical activity in pet dogs and how it relates to body condition score (BCS) and owner physical activity. **PURPOSE:** To quantify free-living physical activity levels of healthy pet dogs using a collar-mounted accelerometer and to relate this to BCS and owner-reported dog walking behavior. **MATERIALS AND METHODS:** We recorded anthropometric data, BCS and five consecutive days of free-living physical activity via accelerometry in 74 dogs. Four consecutive days of one-minute accelerometer count epochs were summed to generate a measure of hourly and total daily physical activity levels. We also recorded step counts in 49 owners who were instructed to wear a hip-mounted pedometer while walking their dog and record the number of steps following each walk. **RESULTS:** Mean (SE) accelerometer counts/day were 202,859(5,806). Dogs with a BCS of three were significantly more active than those with a BCS of four (p= 0.047). Dogs were more physically active in the morning and evening hours, presumably because their owners were present. Dogs appeared to engage in distinct periods of PA such that 40% or more of total daily activity occurred during three hours or ~12% of each day. We analyzed 169 days of owner walks. Mean (SE) accelerometer counts recorded during a walk and corresponding pedometer counts were 95,905(5,637) and 4,558(305) respectively. There was a significant positive relationship between accelerometry counts and steps (r^2 0.63, $p<0.001$). **DISCUSSION:** These data support the use of accelerometry to assess free-living physical activity in dogs and show that physical activity levels of dogs are inversely related to their adiposity. The strong relationship between dog physical activity and owner dog-walking suggests that interventions aimed to increase walking in dogs may benefit both the dogs and their owners. Accelerometers may be useful in a clinical setting to measure the effects of such interventions.

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PREFACE

This thesis was written as a manuscript and therefore is formatted as per the guidelines of the journal to which it was submitted. The first chapter contains the introduction taken from the manuscript including the statement of purpose and hypotheses. The second chapter contains a literature review. Chapters III – V contain methods, results and discussion taken directly from the manuscript

CHAPTER I

INTRODUCTION

In 1970 it was estimated that 20-30% of all dogs were obese [1]. Current estimates suggest anywhere from 24% - 40% of all dogs are overweight or obese [2]. Not surprisingly, the increasing prevalence of overweight and obese dogs has come during a time of increasing numbers of overweight and obese humans[3, 4]. Canine obesity is defined using a Body Condition Score (BCS) scale. The BCS is assessed by a Doctor of Veterinary Medicine (DVM) by palpation and visual inspection of the dog[19]. A five point BCS scale ranks dogs from very thin (1), to obese (5), with three being the ideal score. Canine obesity can be attributed to several factors, but is typically a result of a positive energy balance due to a combination of overfeeding and a lack of physical activity (PA)[6, 7]. Canine obesity is associated with several chronic diseases including some forms of cancer, diabetes, high blood pressure and heart disease, osteoarthritis, and decreased lifespan[7]. Given the health risks associated with canine obesity, steps to prevent and treat excess adiposity are clearly needed. A common recommendation to prevent/treat canine obesity is to reduce caloric intake and increase daily PA[8]. Caloric intake can be easily controlled, although objective levels of PA in dogs have not yet been established. To be successful with weight management, veterinarians and owners must have an objective, relatively simple method to quantify their pets' free-living PA.

Accelerometers have been increasingly used to measure PA and estimate energy expenditure (EE) in humans. While these devices have limitations, they are unobtrusive and have been validated in humans as a useful tool for objectively monitoring free-living PA and energy expenditure[9,10]. Surprisingly, only two studies have validated the use of accelerometry to quantify PA in dogs in a laboratory setting[11,12]. Hansen et al. used 5 accelerometers, attached at 8 locations on four individual dogs and compared the measured activity levels against direct observation using video. Hansen et al. reported that the most accurate and convenient location to reliably measure PA on a dog was the ventral location on the collar[11]. Wearing the accelerometer around the neck served to minimize false readings, for example, when a dog wagged its tail. In addition, this location was found to leave the dogs unencumbered, as opposed to mounting the device on the leg, or around the hips[11]. Yamada and Tokuriki studied 10 beagle dogs housed in a cage for two hours each. Their results suggest that an accelerometer could be used to measure free-living PA in dogs as long as the sensitivity of the accelerometer was appropriate for the size of the dog.[12]

Accelerometers have also been validated as a method to measure free-living PA in dogs [13,14]. Dow et al. used the Actical accelerometer to quantify the optimal sampling interval for dogs, i.e. how many hours, days or weeks of data acquisition was required to gain the most valid and comprehensive measure of activity. They concluded that the least variable sampling period was 7 full days (10% variability in counts), however, consecutive weekdays also displayed low variability (12% variability in counts). Dow et al. also showed in a representative dog that their activity appeared to correlate with owner presence, with low levels of PA during owner absence, and higher spike of PA during owner facilitated activity.   Brown et al. focused on examining the differences in activity before and after an osteoarthritis medication was administered. Dogs receiving the treatment showed a 20% increase in post treatment Actical accelerometer counts, while dogs receiving the placebo showed no change in baseline counts. Findings from these two studies appear to indicate that dogs participate in similar levels of PA as a group, while variability between dogs is quite common. Surprisingly, no studies have objectively quantified the relationship between free-living PA and BCS in dogs. Such information may help to design effective interventions for canine weight management, including the establishment of target levels of PA in healthy and overweight/obese dogs.

Dog owners have been shown to be more active than non-dog owners. A recent study conducted by Brown and Rhodes[15] reported that pet owners tend to be more active than non pet owners. Similarly, Johnson and Meadows[16] found that dog owners were more likely to continue a regular walking routine than those who did not own a dog. However, we do not know the relationship between owner and dog PA. This information could be used to provide insights into whether dogs engage in PA when their owners are not present. If dogs do not engage in PA when owners are not present, successful weight management interventions may require owner-facilitated PA.

Statement of purpose

This study had two aims: 1) to describe quantity of physical activity of dogs using accelerometry and relate these measures of PA to BCS and 2) to describe the temporal characteristics of canine physical activity patterns (what time of the day they are active) relative to owner activity.

Hypotheses

1) Physical activity levels in free-living dogs are inversely related to Body Condition Score (BCS).

2) Free-living dogs are most active when they are with their owners and there is a positive relationship between owner dog-walking and levels of PA in dogs.

CHAPTER II

LITERATURE REVIEW

This study requires a comprehensive understanding of the literature in the following five areas: 1. Canine obesity, 2. Tools for quantifying physical activity 3. Quantifying physical activity in dogs, 4. Relationship between physical activity and energy expenditure in dogs, and 5. Canine/human physical activity relationship.

Canine obesity:

Companion pets suffer from obesity along with a number of other concurrent diseases associated with being overweight or obese. In 1970 it was estimated by owner report and veterinary direct observation that 20-30% of all dogs were overweight[1] and current estimates from veterinary records suggest anywhere from 24% - 40% of all dogs are overweight or obese[2]. The canine lifestyle, which leads to obesity, is quite similar to the human lifestyle that leads to obesity. With the exception of hypothyroidism and hyperadrenocortism, obesity is caused by an energy imbalance. Either the dog's energy intake is excessive, and/or the dog's physical activity patterns are too low. Additional criteria affecting increased incidence of obesity in dogs includes neutering, regular snacking, and living in a single-dog household[17]. Often, a mixture of the two aforementioned conditions applies, which leads to development of excess adipose tissue[7]. Obesity in dogs is often observed in clinical practices and can lead to co-morbidities such as cardiovascular, musculoskeletal, and metabolic diseases which affect not only the lifespan, but quality of life of the dog[17]. Relationships have also been shown between canine obesity and hypertension and immune dysfunction[18]. These diseases are not necessarily caused directly by obesity, but they have been shown to be less prevalent in non obese dogs[7] therefore, obesity is seen as a health risk.

Canine obesity is defined using a Body Condition Score (BCS) scale. The BCS is assessed by a Doctor of Veterinary Medicine (DVM) by palpation and visual inspection of the dog[19]. A number of different scoring systems have been developed including five point, six point, seven point and nine point scales[17,20-23]. The 5, 6 and 9 point scales each require a trained DVM to administer, however the seven point scale was developed for owners to asses body condition in their own dog. The five point scale ranks dogs from very thin (1), to obese (5), with three being the ideal score. The ribs and tail base are palpated, and the side and overhead views are observed, in order to assign the final score. Dogs with easily felt ribs under a slight fat cover, and smooth contoured tail base with bones felt under a thin layer of fat who have an abdominal tuck and well proportioned lumbar waist are considered ideal[17]. The nine point scale has been reputed to be the most accurate and practical scale as it strongly correlates with and has been validated by Dual-emission X-ray absorptiometry (DEXA). A score of five is considered to be ideal with an increasing or decreasing score corresponding to a 10% increased or decreased body weight. Inter-scorer reliability has also been shown to be quite high in this assessment scale[20]. The lack of a standard, objective method to quantify obesity in dogs suggests that accurate estimates of obesity prevalence may be difficult to obtain.

The optimal weight loss strategy for pet dogs is quite controversial. Typically, protein, fat, and fiber content are modified in dog food when weight loss is the ultimate goal. It has been shown that high fiber caloric restriction diets cause weight loss in obese humans[24], however several studies[25-27] in dogs have failed to discover a benefit to increased dietary fiber, while others[28-30] have found significant differences in weight loss between dogs fed high vs. low fiber diets. Other studies have shown that modifying diet alone is not enough to combat canine obesity.[31]

Physical activity is considered to be a key part of weight loss and weight maintenance in canines. A study conducted in Western Australia reported that each hour of weekly exercise decreased the odds of obesity (OR = 0.9)[32]. This study suggested that decreased caloric intake, along with increased physical activity has the greatest effect on weight loss/maintenance in dogs. A study conducted by the Ralston Purina Company employed a caloric restriction intervention followed by 26 weeks of ad-libitum feeding after the dog reached their optimal weight. Similar to observations in humans, the researchers discovered that the dogs regained all the weight they had lost and reverted to the former behavior patterns[33]. This phenomenon has also been examined by Brown, who asserts that when dealing with obese animals, it is important to remember that the animal's condition is the product of a "lifestyle", and the lifestyle must be changed if the animal is to achieve and maintain a normal weight[34].

Tools for quantifying physical activity:

Researchers have used both subjective and objective measures to quantify physical activity in humans. Subjective measures, such as physical activity recalls and surveys, while valid, can only provide a general estimate of physical activity[35]. However, individuals tend to overestimate the time spent in physical activity[35]. Importantly, the use of a direct subjective measure in dogs, such as a survey or self report, is not possible.

Pedometers, or step counters, are easy to use and can be purchased at a low cost, making them convenient PA monitoring tools. To most people, step counts, or steps per day, is a logical measurement which makes pedometers good tools for quantifying the amount of walking that has been done in a day. Pedometers are also useful tools for encouraging movement [36,37]. While pedometers have been used to quantify PA in dogs, they are not able to distinguish between walking, trotting or galloping. Therefore, they are not as accurate at measuring the intensity of PA as other devices like accelerometers[38].

A conventional pedometer can be used to estimate EE via step counts or the time that the foot is in contact with the ground [39]. However, pedometers have limited accuracy in their ability to estimate free-living EE[40]. Kumahara et al. studied 71 subjects wearing 2 different types of hip based accelerometers, one which measured accelerations and the other step counts, for 24 hours in a respiratory chamber[40]. Accelerometry signals and step counts were recorded along with 24 hour EE. Researchers concluded that since the main determinant of 24 hour EE was body mass (explaining 75% of variance); step counts were not highly associated with EE. Therefore, measuring step counts is not an accurate method to predict EE[40].

Accelerometers are typically composed of a seismic mass mounted to a piezoelectric element housed in an enclosure[10]. When accelerations are imposed on the device, the seismic mass is caused to move, thus altering the current produced by the piezoelectric element. This alteration allows an increased charge to accumulate on one end of the sensor and this charge is translated into an output voltage which corresponds to the amount of acceleration experienced by the device. Accelerometers can be used to measure the acceleration of up to three planes of motion[10]. Accelerometers can accurately detect each step a dog takes, and because the magnitude of the acceleration is registered, the intensity of the movement can be estimated[41]. Additional studies on validity and reliability of pedometer vs. accelerometer measures are discussed in the following section.

Quantifying physical activity in dogs:

Self-report of canine PA is not an option, therefore researchers rely on owner reporting as a subjective measure of PA. Several studies have reported physical activity in dogs via owner reporting[42], however, the validity and accuracy of this method has been questioned[42]. Limitations of owner reported canine activity include the inability of the owner to accurately recall time, intensity, and duration of PA. Also, owners are often not physically with their dog for 24 hours of the day, therefore, large portions of time in which dogs could have been active may be under reported.

Given the limitations of owner-reported PA assessment, objective measures of canine physical activity have been developed. Pedometers and accelerometers have both been used to objectively measure PA in dogs.

Pedometers have been used to measure PA in dogs in one study[43]. Chan et al. recruited 26 dogs and their owners. Leashed dogs, wearing pedometers were led on multiple trials over a 30 meter field in which their owners walked, trotted, or ran with them while researchers visually counted the number of strides taken by the dog. Upon completion of each trial, researchers recorded the observed stride number along with the recorded pedometer counts. Findings indicate that in large and medium dogs, counts were over estimated in pedometers by 17% and in small dogs, counts were underestimated by 7%. This could be due to step-count threshold levels being set too low for large dogs, and too high for small dogs.

Accelerometers have been increasingly used to measure PA and estimate energy expenditure (EE) in humans[44-60]. While these devices have limitations, they are unobtrusive and have been validated in humans as a useful tool for objectively monitoring free-living energy expenditure[9,10]. To date, very few studies have been conducted to validate accelerometry as an objective measure of canine physical activity[11,12,43].

Two studies have validated the use of accelerometry to quantify PA in dogs[11, 12]. Yamada and Tokuriki studied 10 beagle dogs housed in a cage for two hours each in order to classify activity (standing, head turning, whole body movement, lying down) based on several different thresholds (0.02G, 0.05G, and 0.1G). They found that with a higher threshold, whole body movement was identified; however, smaller movements like head turning did not register counts, while with a lower threshold, those less intense activities were classified, but whole body movement was over reported. Yamada and Tokuriki suggest that an accelerometer could be used to measure free-living PA in dogs as long as the threshold and amount of acceleration was adequately set to reflect the size and movement patterns of the dog. Threshold can be set to register movement at a range of accelerations, and for a small dog, the threshold needs to be lower than that of a large dog, as movement in small dogs doesn't generate accelerations like that in large dogs. Hansen et al. used 5 accelerometers, mounted to 8 locations on four individual dogs and compared the measured activity levels against direct observation using video. Hansen et al. reported that the most accurate and convenient location to reliably measure PA on a dog was the ventral location on the collar[11], with r^2 values of 0.78, 0.78 and 0.77 for measures of distance traveled, periods of inactivity, and periods of activity respectively. With the ventral location, they found a strong correlation when they combined distance traveled (measured using video analysis that tracked the dogs center of mass) and periods of inactivity (r^2=0.89). While correlation coefficients for all five locations ranged from 0.71 to 0.93, the collar was chosen because it was strongly related to activity/inactivity and was the most convenient location to mount an accelerometer. Wearing the accelerometer around the neck also served to minimize false readings, for example, when a dog wagged its tail. In addition, this location was found to leave the dogs unencumbered, as opposed to mounting the device on the leg, or around the hips[11]. These studies concluded that accelerometry is a valid method for measuring PA in dogs.

Only two studies have been conducted in which accelerometers were used to measure free-living PA in dogs[13,14]. Dow et al. used an Actical accelerometer to quantify the optimal sampling interval for dogs, i.e. how many hours, days or weeks of data acquisition was required to gain the most valid and comprehensive measure of activity. The highest variability (% change in total counts per day) within dogs was in weekend days with median differences at 21% variability (total counts per day) and a range of 0% - 154%. Weekday within dog variability had a median difference of 10% and ranged from 0% - 75%. Weekdays tended to be more structured, and less variable. Thus, they concluded that since the weekend days seem to be the most variable, it is necessary to sample for a full 7 days to minimize variability and achieve valid estimates of PA. Dow et al. also showed in a representative dog that their activity appeared to correlate with owner presence, with low levels of PA during owner absence, and higher spike of PA during owner facilitated activity. The representative dog showed spikes in activity counts between 7am and 8:30am, again at 1pm and then from 6pm-10pm with almost no activity at other times. The owner indicated she left her house to work from 8:30am - 5:30pm, but came home briefly for lunch in the middle of the day, thus her pet's activity increased in correlation with her presence. Brown et al. focused on examining the differences in activity before and after an osteoarthritis medication was administered. Seventy dogs were randomly split into two groups of 35. The treatment group received an osteoarthritis medication while the control group received a placebo, on days 8 - 21 of a 21 day study. Dogs receiving the treatment showed a 20% increase in post treatment Actical accelerometer counts (measured days 15-21), while dogs receiving the placebo showed no change in baseline counts. Mean total counts over seven days in the Brown et al. study were almost identical to mean total counts measured by Dow et al. (~200,000 per day), although the range was considerably higher in Dow et al. (~52,000 – 833,000), presumably because their dogs were not suffering from osteoarthritis. Findings from these two studies appear to indicate that dogs participate in similar levels of PA as a group; however, variability between dogs is quite common. We are unaware of any published studies comparing an objective measure of PA in dogs to BCS, weight, BMI or any other measure of body composition.

Relationship between physical activity and energy expenditure in dogs:

In the previous section I outlined the fact that obesity and overweight were due to a positive energy balance (i.e. increased calorie ingestion or lack of physical activity). In order to understand how to manipulate energy balance, we must understand some basic principles of energy expenditure.

Daily energy expenditure includes three general components, 1) resting metabolic rate (RMR), 2) thermogenic effect of food, and 3) energy expended during physical activity[61]. RMR refers to the required energy in order to maintain physiologic functions. The thermogenic effect of food refers to the energy released in the form of heat during the digestion of food. Physical activity EE is the amount of energy used for any form of PA or movement.

Aerobic energy expenditure (EE), which composes the majority of EE for typical low intensity movements, can be quantified based on rates of oxygen consumption (VO_2) and carbon dioxide production. By measuring VO_2 and body mass, scientists can quantify EE and calculate energy expenditure per kilogram of body weight. Indirect calorimetry, a method of estimating EE by using known volumes and flow rates of inhaled oxygen and exhaled carbon dioxide, has been validated in dogs[62]. Doubly labeled water (DLW), another method of estimating EE, works by means of labeling the hydrogen and oxygen atoms in water with non-radioactive isotopes. This method can be used to estimate EE by using assumptions based on the ratio of oxygen to carbon dioxide measured after 5-20 days following the initial dose of DLW[63]. DLW measurement has been validated in dogs[64], as well as used to estimate EE in dogs in the field[65,66]. More recently, activity counts registered by accelerometers have been used to estimate EE and have been validated using both DLW and indirect calorimetry in people[67-69]. However, EE estimation via accelerometry has not been validated in dogs.

Several factors influence energy expenditure. Scientists have been examining the relationship between body weight, physical activity, and energy expenditure since the late 1800's. In 1883 Max Rubner published a paper on resting metabolic rate in dogs, stating that smaller dogs had a higher metabolic rate per kilogram of body mass than larger dogs, where metabolic rate was proportional to body surface area of the dog, whether large or small[70].

It is important to understand the impact that physical activity has upon total energy expenditure. Several groups have conducted studies of energy metabolism in sled dogs. Sled dogs are a good model to study as RMR is quite easy to determine due to the fact that in the summer, sled dogs are fed every three to four days and are chained to rocks. TEF is also quite simple to determine, as metabolic rate can be measured post feeding for at least 24 hours to determine the increase in metabolism due to feeding, without PA as a confounding factor. In most other models, researchers do not have the luxury of a 24 hour window in which to detect specific changes in metabolism due to food. In 2010, Gerth and colleagues found that TEF contributed 9.5% of total daily EE and RMR contributed approximately 65%, leaving 25% due to PA[71]. They also found that when the same group of dogs was put to work in the winter, their total daily EE increased 8 fold over summer daily EE and PAEE contributed approximately 60% to total daily EE[71]. This suggests that PAEE can vary significantly in dogs, depending on their lifestyle.

Energy expenditure can be determined from metabolic rate (W/kg). Taylor et al. have published several papers regarding metabolic rate (W/kg), metabolic cost of transport (J/kg/m), and speed and gait changes in quadrupeds[72-78]. There are several mechanical determinants of locomotor metabolic rate (and thus, EE) and they vary based on gait, i.e. walk, trot or gallop. These determinants include support of body weight, acceleration of the limbs during the swing phase, and work done to move the center of mass forward. Mechanical energy is also conserved via stored elastic energy in muscles, tendons and ligaments during some forms of locomotion, thereby reducing the metabolic rate. Each of these determinants will be addressed, as they influence each gait, in the following paragraphs.

Models have been developed for walking, trotting, and galloping gaits in quadrupeds and bipeds alike. Cavagna et al. have modeled walking in humans as an inverted pendulum, where energy is conserved by the exchange between gravitational potential energy and kinetic energy during a step[79]. Gait studies in dogs reveal a walking pattern similar to humans. For each stride, the dogs' center of gravity rises and falls twice, as the fore and hind limbs perform identically to two separate bipeds[80]. This conservation of energy reduces the need for work to be done by the musculoskeletal system, reducing the metabolic cost of walking[79]. However, work must still be performed by muscles during walking and this work requires metabolic energy. While movement and support of body weight are the major determinants of the metabolic cost of walking (74%), Marsh et al. reported that, at a constant speed, leg swing utilizes 26% of the energy used for bipedal locomotion in birds[81]. Grabowski et al. report that work done to move the center of mass comprised 45% of walking metabolic rate in humans[82].

They also showed that metabolic rate of muscle forces generated to support body weight accounted for 28% of walking metabolic rate. Thus, the total metabolic rate associated with body center of mass progression and weight support amounts to ~73% which is quite similar to the 74% suggested by Marsh et al. Thus, forward progression of the center of mass, support of weight, and acceleration of the limbs through swing accounts for ~45%, ~28% and ~26% respectively[81,82] of the metabolic cost of walking.

As dogs increase locomotor speed, they transition from walking to trotting to galloping. The trotting and galloping gaits are modeled differently than walking. Rather than an inverted pendulum, a spring-mass model has been used to describe the mechanics of trotting and galloping. These “bouncing” gaits utilize stored elastic energy to conserve mechanical work and reduce metabolic cost (J/kg/m). As an animal trots or gallops, elastic energy is stored in tendons/ligaments and then returned, resulting in a linear relationship between speed and metabolic rate. The spring stiffness in the spring-mass model is proportional to body mass, $k_{leg} \propto M^{0.67}$ [83]. Thus, larger animals have stiffer leg springs.

As noted above, there is a relationship between an animal’s size and metabolic cost for locomotion. Taylor reported a decreased energetic cost (J/kg/m) of locomotion as animal size increased[78]. If we look specifically at dogs, this means that it is more costly per kilogram of body mass for small dogs to trot or gallop than it is for larger dogs to trot or gallop the same distance. This cost to size relationship was shown to be in direct proportionality to the mass supported. Dogs trotted and galloped on a treadmill, carrying weights from 7 – 27% of their body mass. When the load was 10% of their mass, O_2 consumption increased by 10%, and when the load was 20% of their mass, O_2

consumption increased by 20%. This highlights the relationship between metabolic rate and support of mass, showing that mass support is directly related to oxygen consumption. Since it costs small dogs more energy per kilogram of body mass to move, a daily walk of 30 minutes at a given speed for a small dog would cost proportionally more energy than the same walk for a larger dog.

Work by Kram and Taylor highlight the fact that the primary determinant of metabolic cost is the cost of producing muscle force[84]. Metabolic rate (W/kg) was found to be inversely proportional to the time of contact during running. This has been shown to scale with body mass from a kangaroo rat (30g) to a dog (27kg) to a small pony (141kg). Kram and Taylor observed that in smaller animals trotting or galloping at constant speed, time of contact was greatly reduced, which caused a need for increased rate of force production in skeletal muscles used in locomotion. They explained that typical aerobic muscle fibers used by large animals could not contract at a fast enough rate in small animals due to the decreased time of contact, therefore, fast twitch muscles, which utilize greater amounts of ATP at greater rates were recruited. Thus, energy utilized for locomotion was greater in smaller animals[85], meaning that EE is greater per kilogram of body mass in small dogs, than it is in large dogs.

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Canine/human physical activity relationship

While dog owners have been shown to be more active than non-dog owners, there is little objective data on PA levels of dogs. A recent study conducted by Brown and Rhodes[15] reported that pet owners tend to be more active than non pet owners. Similarly, Johnson and Meadows[16] found that dog owners were more likely to continue a regular walking routine than those who did not own a dog. It is well known that obese humans are less physically active than non-obese individuals[86]. However, we do not know the relationship between owner and dog PA.

A recent study from the Netherlands found that the degree to which dogs were overweight correlated with the BMI of their owner[87]. This group examined 47 dog/owner pairs and took into account the duration of ownership, time spent on daily walks, gender, education level and age of both dog and owner and concluded that individuals with a higher BMI owned dogs that weighed more than individuals with a lower BMI. Several studies have reported increased walking in dog owners vs. non dog owners, although the degree to which walking increases is highly variable. In 2001, Bauman et al utilizing owner self report, found that dog walkers walked 18 minutes longer each week than non dog walkers[88]. Another study used direct observation to determine differences between walking time in dog walkers and non dog walkers[89]. Results showed that dog walkers spent an average 5 minutes longer per walk, when walking their dog than non dog owners. However, the author recognized that dog owners may not have actually walked further, but rather spent 5 minutes more because of frequent stops made by the dog, or distracted sniffing or interaction with other dogs. Another observational study, carried out in 1991 found that after 10 months of dog ownership, owners increased their weekly walk time from one hour to five hours[90]. The author noted that the subject population might not be indicative of a broader population, as individuals were recruited upon adopting a dog from an animal shelter. Additionally, the author noted that there was no significant increase in health of the owners aside from increased walk time. Again, this study was based on owner report, and therefore may not be as valid as a direct measure.

CHAPTER III

MATERIALS AND METHODS

Experimental Design: This cross-sectional study was conducted in 10 veterinary clinics throughout the U.S. We instructed the veterinarians on all the protocols of the study, and each veterinarian was then responsible for relaying the information to the dog owners enrolled in the study. Veterinarians invited owners of dogs to participate in the study. Owners who agreed to participate in the study completed pre- and post-test canine PA surveys as well as daily activity logs during the duration of the data collection. Free-living PA of the dogs was measured via accelerometry during a six day period.

Subjects: The owners of 76 dogs of varying breeds were recruited. Informed consent was obtained from the dogs' owners. Prior to the study, veterinarians asked owners to fill out a survey in order to gather data (age, sex, breed) on each dog. Dogs height (from shoulder to ground) and weight were measured and a body condition score (BCS) classification was assigned (scale of 1 – 5 where 1 is thin, and 5 is obese) by a qualified veterinarian[20]. See Table 1 for a summary of the physical characteristics of the dogs.

Table 1. Physical characteristics of the dogs (N=74)

	Mean	SD	Range
Age (yrs)	3.78	2.19	1 - 7
Weight (kg)	23.94	14.89	2.44-55.52
Height (cm)	48.5	15.2	19.1- 83.8
BCS(1-5)	3.53	0.7	2 - 5

Table 1 – Physical characteristics for 74 dogs enrolled in a study to measure free-living physical activity via accelerometry. Age is based on owner report and rounded to nearest year. Dogs over seven years were excluded from the study. Weight, height, and BCS were measured by a licensed DVM. BCS was scored on the 1-5 scale.

Protocol: The veterinarian attached a custom-designed collar with accelerometer to the dogs' necks. Owners were instructed not to alter their PA in any way. There was no incentive for owners to "create" opportunities for their dogs to exercise. The study was designed to record PA of the dog as it behaved in its normal environment. Data were recorded for 6 days (Sunday morning until the following Friday afternoon) On Friday afternoon, owners were instructed to remove the collar and return it to the veterinarian along with a record they were instructed to keep during the week (table 2), detailing hours they were with their pet, and specific time periods that they facilitated exercise for their pet. These records were used as a guide so that we could have an idea when accelerometry counts were due to owner led PA or spontaneous activity by the dog. Forty-nine dog owners were also given pedometers and instructed to wear them when they took their dog for a walk. Following the walk, the owners were instructed to record the step counts registered by the pedometer

Table 2: A sample of the data collection sheet given to every participating dog owner.

Monday Activities	0700	0900	1100	1300	1500	1700	1900	2100	2300
1..Pet ate meal.									
2. Played with pet									
3. Walked with pet.									
4. Ran with pet.									
5. Pet rested beside me while I: read, watched TV or did household duties.					X	X			
6. Pet riding in car.									
7. Pet asleep.	X	X	X						
8. Other: outside				X					

Measurement device: We used the Actiband ™ (Cambridge Neurotechnology Ltd., Cambridge, UK) uni-axial accelerometer to measure PA in dogs. The Actiband contains a piezoelectric element which measures vertical accelerations. The device measures 3.6(L) x 1.8(W) x 0.8(D) cm and weighs 5 grams. The Actiband samples data at 32Hz and uses an 8bit A/D chip to convert analog voltage to a digital value counts which are summed to one minute epochs. Researchers attached the device to the ventral location on a custom-designed collar, which was then fastened around the dog's neck. This placement insured that the counts registered by the device would best reflect the activity of the dog, and has been previously validated[11]. Counts were recorded using one minute epochs, summed to hourly totals for five consecutive days.

Data Analysis: To quantify levels of physical activity, we determined mean total, daily and hourly accelerometry counts for each dog by summing the count/min values over the appropriate time period. We also normalized accelerometry counts by dog height to account for differences in body size. Data from Sunday – Thursday were analyzed, however, Sunday's data were only used to compare a weekend day to the mean weekday counts. This precautionary step was taken in order to minimize the possibility of the "Hawthorne effect[91]," as owners may have been inclined to see that their pet was exercising more than usual on the first day of data collection. The final day (Friday) was not used, as owners removed the collar at varying times. Results from owner reported surveys were also recorded and cross referenced for their corresponding dog.

In order to quantify distinct periods of activity we ranked activity counts from least to greatest for each dog for each day. We then added together the counts from the three hours representing the greatest number of counts, and divided these three hours of activity counts by the total activity counts of that specific day to calculate a percentage of total/day.

Forty-nine dog owners reported pedometer step results during daily dog walks. These pedometer counts were then plotted against canine accelerometry counts corresponding to the walk as well as the day the walk occurred. We analyzed 83 specific walks where owners reported both the time and pedometer counts. In these cases we plotted canine accelerometer counts measured during the walk against owner pedometer counts during the walk. We also analyzed 169 walks where owners reported pedometer counts but not the exact walk time. In these cases we plotted owner pedometer walk counts against daily accelerometer counts for the day the walk took place.

Statistics: Statistical analysis was performed using Sigma Plot (version 11.0). Linear regression was used to determine the relationship between total accelerometry counts and body mass (kg). A one-way ANOVA was used to determine the relationship between mean total counts, BCS, and BCS normalized by height. A Kruskal-Wallis One Way Analysis of Variance on Ranks was used to analyze the means of custom time intervals (6am – 7:59am, 8am – 5:59pm, and 6pm – 10:59pm) to determine if there were significant differences in the temporal characteristic of canine PA, i.e. what time the dogs were most active as opposed to least active. We also used linear regression to determine the relationship between daily and hourly accelerometer and owner pedometer counts. Significance was defined as $p < 0.05$.

CHAPTER IV

RESULTS

We analyzed four days of data for 74 dogs (38 males and 36 females), totaling 296 days of activity data. Two accelerometers appeared to malfunction and record extremely high counts for 2 of the dogs, so that data was not used. As a result, of the 7296 hours of data collected from Monday to Thursday, we were able to analyze 7104 hours or 97% of the data. Of the 74 dogs, we studied 7 herding, 7 hound, 3 non-working, 21 sporting, 9 terrier, 12 toy, 11 working, and 4 mixed based on US Kennel club groupings. Mean (SE) total accelerometer counts were 977,323 (50,574) and ranged from 255,425 - 2,473,805. Mean (SE) daily accelerometer counts for Monday – Thursday were 202,859 (5,806) and ranged from 46,262 – 561,863. Mean (SE) accelerometry counts for Sunday were 171,244 (10,754).

There were no significant sex differences (p=0.327) in PA. BCS was inversely correlated with PA. Dogs with a BCS of 3 were significantly (p=0.047, Figure 1a) more active than those with a BCS of 4 and normalizing PA data by leg length (to account for height differences between dogs) did not change this inverse relationship between BCS and PA (Figure 1b). There were no significant differences in activity between heavier and lighter dogs (p=0.135).

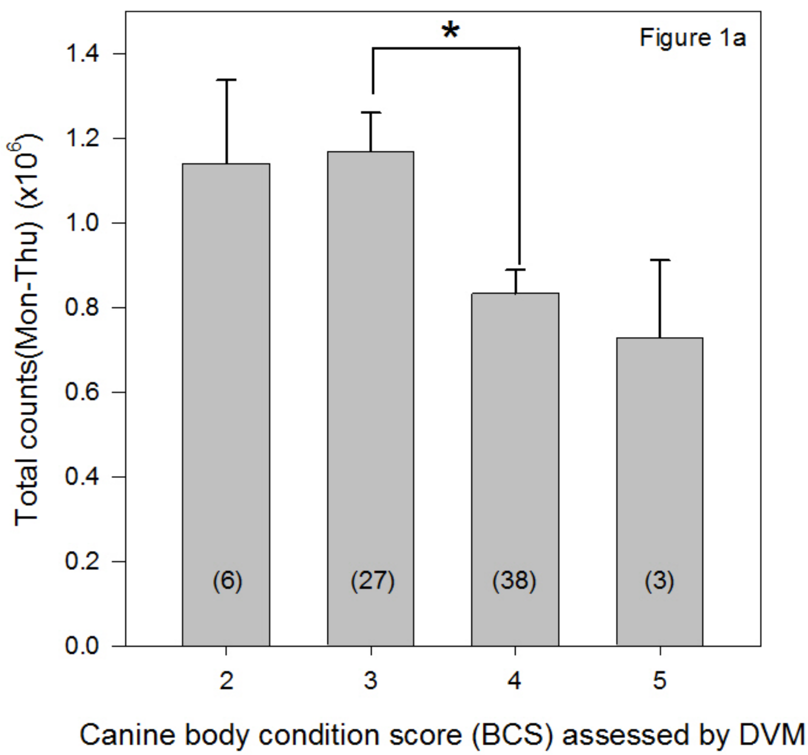


Figure 1a
Total counts(Mon-Thu) (x10^6)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
*
(6)
(27)
(38)
(3)
2
3
4
5
Canine body condition score (BCS) assessed by DVM

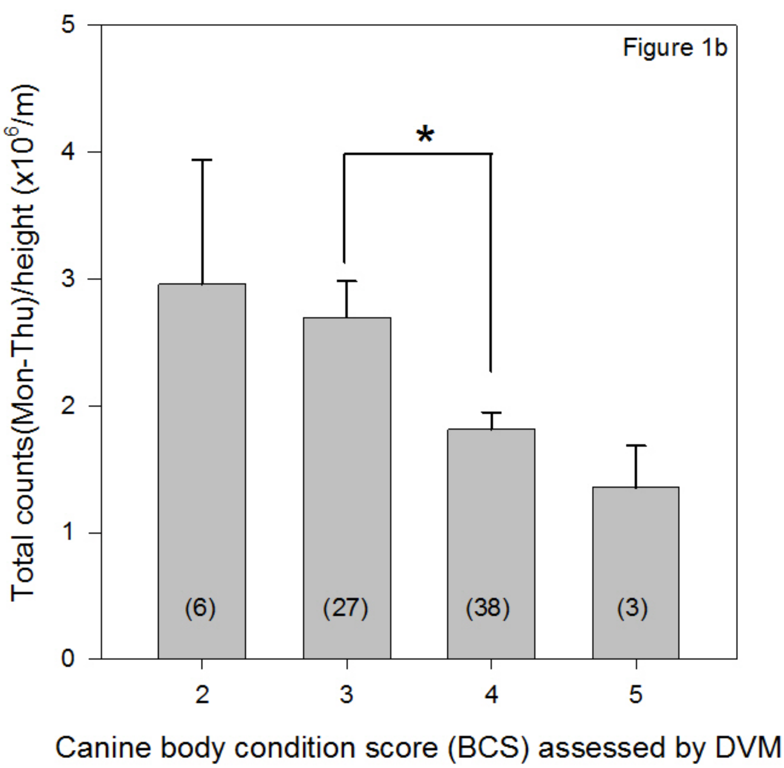


Figure 1b
Total counts(Mon-Thu)/height (x10^6/m)
5
4
3
2
1
0
*
(6)
(27)
(38)
(3)
2
3
4
5
Canine body condition score (BCS) assessed by DVM

Figure 1 – (a) mean (SE) total (four days) counts for each BCS classification. (b) mean (SE) total counts (four days) normalized to leg length for each BCS classification.
* significant ($p<0.05$) different in acc counts.

Dogs were more active during the mid-morning and evening hours compared to mid-day and at night (Figure 2a, 2b) but there was considerable variability in the PA patterns between dogs. There were significant differences in levels of PA between early morning hours (6am – 7:59am) day time hours (8am – 5:59pm) and evening hours (6pm – 10:59pm) (Figure 2c). Dogs were significantly ($p <0.001$) more active during the evening hours, presumably when their owners were home.

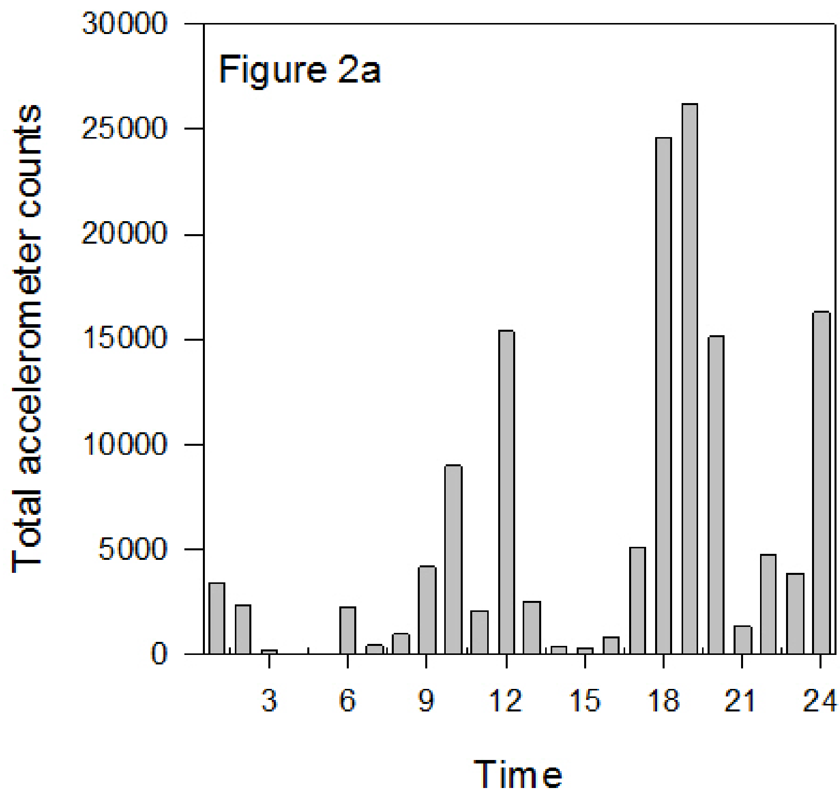


Figure 2a
Total accelerometer counts
30000
25000
20000
15000
10000
5000
0
3
6
9
12
15
18
21
24
Time

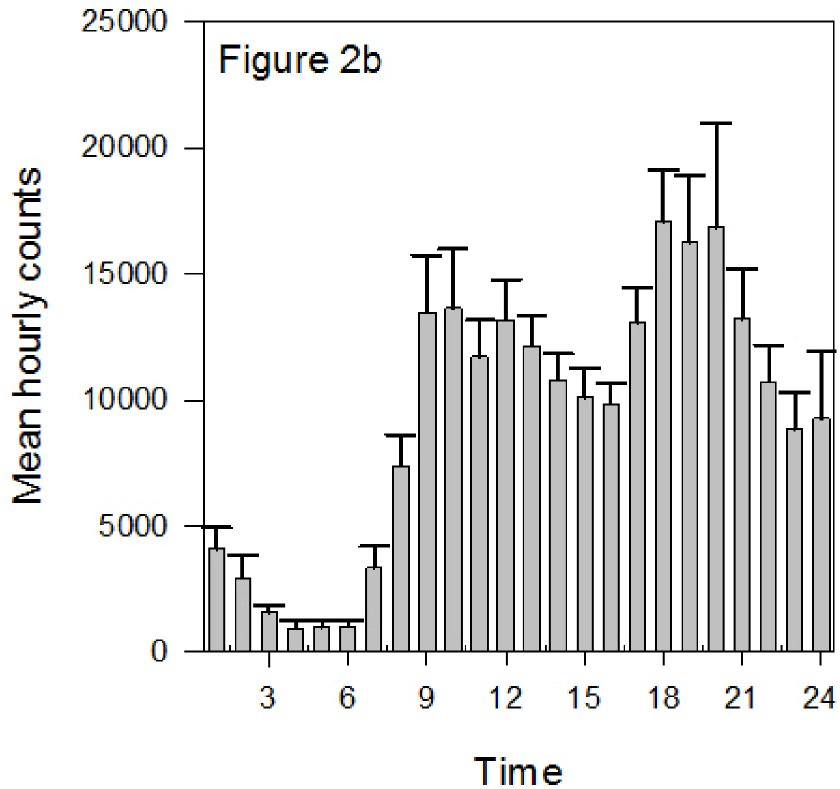


Figure 2b
Mean hourly counts
25000
20000
15000
10000
5000
0
3
6
9
12
15
18
21
24
Time

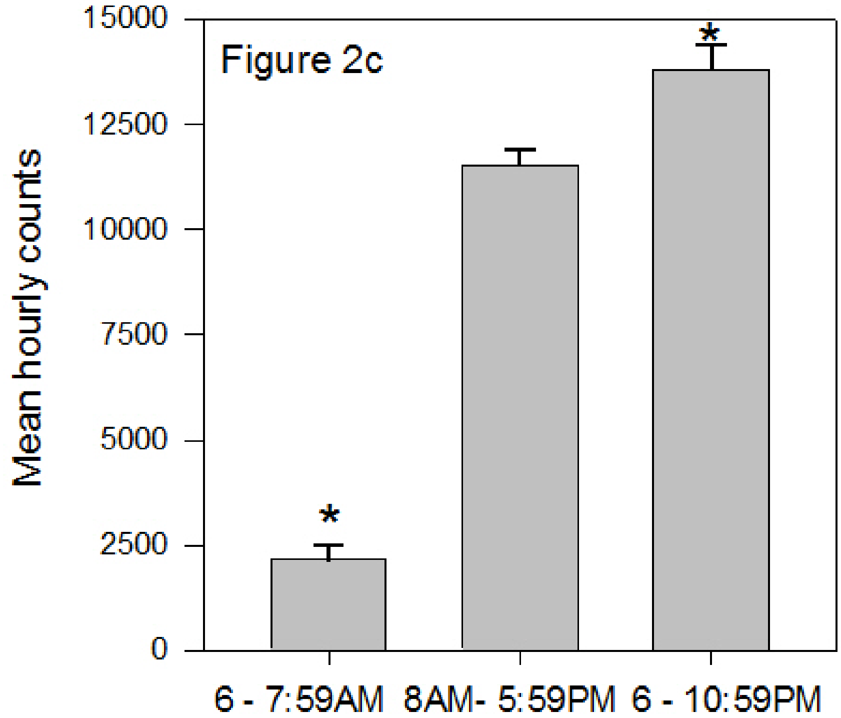
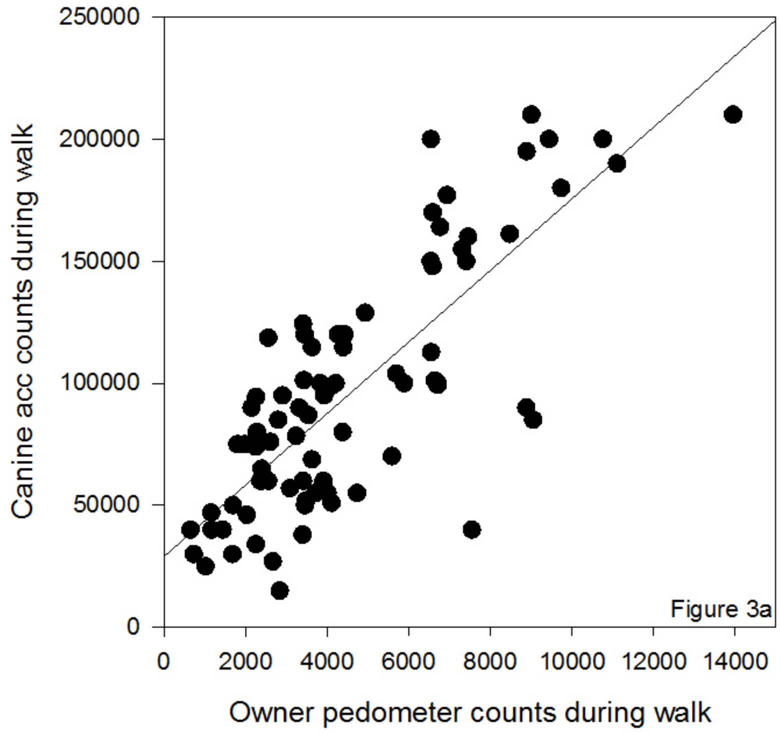


Figure 2 – (a) Hourly accelerometer counts for a representative dog. (b) Mean total counts (four days) for all dogs by hour. The number 3 represents counts from 3-4am and 24 represents counts from midnight – 1am. (c) – Mean counts per hour for all dogs for all days. * significant (p<0.001) differences in counts compared to 8am-5:59pm time period.

In order to quantify activity in distinct periods of time, we analyzed hourly activity for 296 days. In 255 of those days, or 86% of the total days analyzed, we found activity counts in a three hour window accounted for greater than 40% and up to 82% of total daily activity. To put this into perspective, a three hour window constitutes only 12.5% of a 24 hour day, or 18.75% of a 16 hour day with 8 hours of inactivity accounted for as sleep.

We analyzed pet accelerometer counts measured during an owner facilitated walk in 83 different walks. We also quantified total daily accelerometer counts vs. owner pedometer counts measured during a walk (169 days). We found that counts recorded during walks, taken as a percentage of total daily activity made up 30% or more of dogs' activity in 80% of the cases. Dogs were more active when their owners walked with them. Of the 49 dogs taken for walks, 12 were not walked every day. In each of these dogs, daily counts on non walk days were ~50% lower than daily counts on walk days regardless of the walk distance (estimated based on pedometer step count). There was a significant positive relationship ($p<0.001$) between accelerometer counts and step counts recorded during a walk (figure 3a). Mean (SE) step counts and daily accelerometer counts were 3676 (201.6) and 210,096 (7697) respectively. There was a significant positive relationship ($p<0.001$) between step counts and daily accelerometry counts (figure 3b).


250000
200000
150000
100000
50000
0
Canine acc counts during walk
Figure 3a
0 2000 4000 6000 8000 10000 12000 14000
Owner pedometer counts during walk

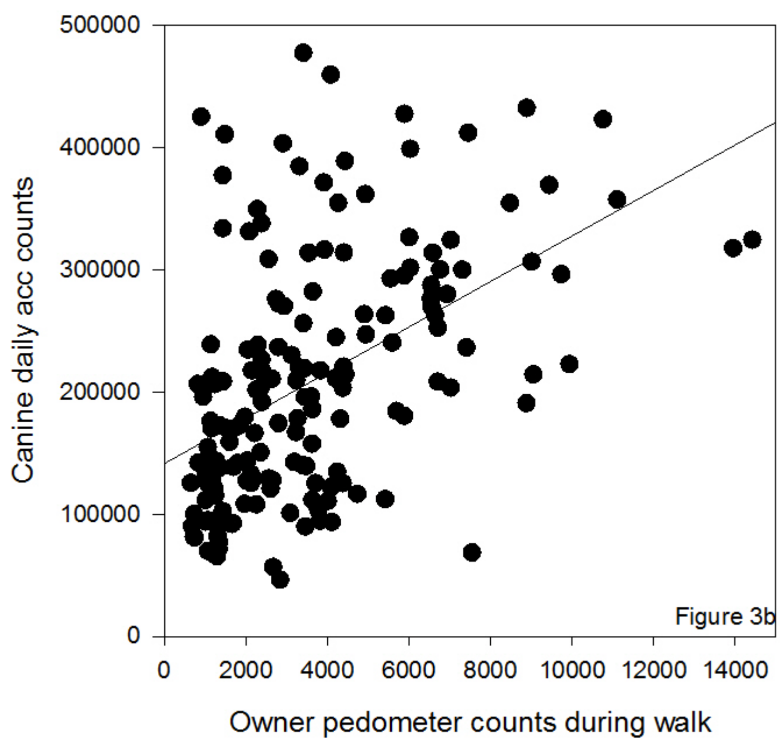

500000
400000
300000
200000
100000
0
Canine daily acc counts
Figure 3b
0 2000 4000 6000 8000 10000 12000 14000
Owner pedometer counts during walk

Figure 3 – (a) pedometer counts recorded during walks(x) plotted against dog accelerometer counts(y) corresponding to walk time. Regression line: y = 14.654x + 29103.754, R^2 = 0.630. (b) Owner pedometer counts recorded during walks(x) plotted against daily dog accelerometer counts(y). Regression line: y = 18.612x + 141682.962, R^2= 0.238.

CHAPTER V

DISCUSSION

In this study we have shown that an accelerometer can be used to measure free-living PA in dogs. We accept our hypothesis that physical activity in free-living dogs is inversely related to body condition score (BCS). We also accept our hypothesis that free-living dogs are most active when they are with their owners and there is a positive relationship between owner dog-walking and levels of PA in dogs.

The use of accelerometry has benefits over owner reported activity questionnaires. In particular, accelerometry can provide PA data while the owners are not home, or sleeping, which suggests it is a useful tool for objectively measuring PA in individual dogs. As expected, dogs with a greater BCS engaged in less PA and PA was greater when owners were typically present. We found that counts between dogs were quite variable, however, counts during the week were less variable within dogs than between dogs, as has been reported by Dow et al.[14]. It was not possible to make direct comparisons in counts between Dow et al. and our study, as we used different accelerometer models. For this reason, we propose that future work in the field of activity monitoring should use raw accelerometer output to allow comparisons between investigations.

Only one previous study has directly measured PA in dogs and compared it to BCS[43] however, accelerometry was not used for this comparison. Chan et al. reported an inverse correlation between BCS and pedometer counts in 26 dogs ($r = -0.554$), however, they note that step counts were overestimated in larger dogs, and underestimated in small dogs, most likely due to the fixed sensitivity of pedometer measures. With a fixed threshold, some counts are not registered in small dogs, while in large dogs, counts can be registered even when a step is not taken. We felt it was important to also account for possible differences in counts between large and small dogs and therefore normalized total counts between BCS classifications to height in order to account for any measurement differences due to the size of the dog. The normalization showed no significant differences from non-normalized counts. Thus, we provide further evidence that BCS is inversely related to PA in dogs. This finding is similar to reported relationships between BMI and PA in humans, which clearly shows an inverse relationship in children and adults alike[92]. These results suggest that greater PA in dogs may be important to maintain or achieve an optimal body composition score.

To our knowledge, this is the first study of its kind to report temporal characteristics of dogs measured directly by accelerometry, although previous studies have been conducted utilizing owner report[5]. The temporal characteristics reported in our study are consistent with previous studies reporting that companion pet activity increases when owners are present[5], (e.g. during evening hours). We were able to classify basic overall trends, showing dogs to be more active in the evening than morning or mid-day (figures 2a, b). When comparing owner reported walks with corresponding canine accelerometer counts we saw spikes in counts, which accounted for the majority of PA during the day. In 80% of days dogs went for walks, the walk accounted for 30% or more of their total activity that day. This suggests that companion pets may get a large percentage of their activity during owner initiated PA, i.e. walks. This observation has important implications for future research on increasing PA in companion pets and owners alike. This ability to examine activity patterns and temporal characteristics of individual dogs is a tool that DVM's could use to quantify free-living activity in pets that have been prescribed a new medication for a condition such as osteoarthritis, or recently undergone surgery. It can also be used to show pet owners how active, or – as our results suggest –how inactive their dogs are while the owners are not home.

While there are no other studies that report free-living PA using the same device, the owner pedometer data can be used to provide insights into our results. Using a conversion of ~2000 steps/mile[93] and accelerometry and step data from selected walks, we can compute approximate distances traveled from our regression equation in figure 3a (y=14.654x + 29103.754, where y is accelerometer counts and x is pedometer counts). Thus, the dogs in this study walked/ran ~1-16 miles/day, which is reasonable given reported levels of activity in dogs[42]. This relationship was quite strong, with an r^2 value of 0.63 and showed that the average walk was 4558 pedometer counts, equating to ~2 miles. This seems reasonable as owner reporting suggests that a typical walk with a dog is ~30 minutes[94].

Our results suggest an increase in pet PA on days of owner facilitated walks vs. non-walking days and our BCS data suggest the importance of PA for optimum canine weight. Although owner PA was not our outcome measure, we can make a case that if the pet's PA increased during walk days, so did the owners. The literature suggesting positive human health behaviors, i.e. increased PA associated with dog ownership[95-97], supports this assertion. These data also allow consideration of target PA values for dogs. The range of daily counts for our subject population, was <50,000 counts of PA per day to >500,000 counts of PA per day. Dogs on the lower range, ~50,000 – 100,000, tended to have greater BCS, while dogs higher on the range, ~300,000 – 500,000 tended to have a lower BCS. It may be possible for future studies to set threshold levels of PA based on these findings. The intercept of the step count to accelerometer count data (figure 3b) is ~150,000 counts/day. This suggests that the baseline level of activity for these dogs was ~150,000 counts/day. It should be noted that the BCS distribution of dogs taken for walks was similar to that of all 74 dogs. We can compare this to our BCS data from figure 1a, which shows that dogs with a BCS of 3 had ~300,000 counts/day, while those with a BCS of 4 had ~220,000 counts/day. Three-hundred-thousand counts appears to be a good target for daily PA, with 150,000 counts due to ~4 miles of PA/day or a ~1 hour walk.

There are no currently published recommendations for canine PA; however, there are guidelines for humans. The current ACSM recommendation[98] for human PA is 60-90 minutes of moderate to vigorous exercise per day to lose weight or maintain weight loss, which equates to approximately 4 miles of walking. Our data suggests there is a relationship between dogs that get the recommended 4 miles of walking per day (the same as humans) and a BCS of 3. These findings have interesting implications for future public health initiatives. Our comparison of daily pet accelerometer counts to owner pedometer counts suggests that owners' who engage in PA with their pets (i.e. walking) positively influence daily activity in those pets. DVM's may be able to use this information when recommending physical activity to the owners of overweight dogs. It is conceivable if we use this novel approach of encouraging PA in pet owners for their pets' sake, we may be able to increase levels of PA in pets as well as owners, helping owners achieve recommended levels of PA.

Upon closer examination of dog walk counts we found no difference in mean total walking counts between dogs with a BCS of 3 and 4. However, in dogs with a BCS of 3, walking counts accounted for 39% of daily activity, while in dogs with a BCS of 4 walking counts accounted for 46% of daily activity. This relationship shows that overweight dogs may engage in slightly less spontaneous PA than their normal weight counterparts.

Interpretation and extrapolation of this study's findings should take into account limitations inherent to its design. Although veterinary clinics were recruited from various areas in the US, they were not randomly selected. This indicates a slight possibility of sample bias. The weather may have been a confounding factor, as our study was conducted from December 9 – 27th and included northern U.S. areas which are usually cold during that time of the year. Cold weather could have precluded dogs from being active outdoors, thereby underestimating levels of PA. Another possible limitation is the height normalization we used. In order to account for levels of PA being size dependent, we normalized activity counts to height. We were able to compare the height normalized counts by BCS, to the total counts (not normalized) by BCS. There was no significant change in results between BCS, which leads us to believe that no confounding factor due to height exists; however, future studies should be conducted to measure possible accelerometer count differences by size of dog.

Further research using accelerometers along with measures of energy expenditure to develop relationships between counts and activity intensity would allow the development of a daily PA threshold, moderate to vigorous PA cutpoints and EE estimates. Such studies have been performed in humans[68] and could be replicated in the canine population using methods similar to those used in this study[99]. With a greater subject population, we could attempt to set cut points for differing dog breeds. These cut points could then be used in the clinical setting where DVM's could send pet owners home with an accelerometer for 1 week, collect data, and gain valuable insight into the weekly amount and intensity of PA of the individual dog, in order to make an educated recommendation for the health of the dog. Also, it would be interesting to conduct a longitudinal study to measure whether PA changes with feedback from this initial study. Finally, this study may encourage research into ways to increase PA of dogs throughout the day, as it appears that their activity is at its lowest in the morning and during the middle of the day, presumably, when their owners are at work.

In conclusion, we have shown that canine PA is inversely related to BCS. Owner facilitated walks seem to play a role in increasing dog PA counts throughout the day. Dogs appear to be more active during hours that their owners are typically home, either in the early morning 6am – 8am, or the night 6pm – 11pm. It is conceivable that by increasing owner facilitated walks, we can increase PA in both owners and pets alike.

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