Feeding frequency, but not dietary water content, affects voluntary physical activity in young lean adult female cats

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ABSTRACT: The objective of this study was to investigate whether increased dietary water content and feeding frequency increased voluntary physical activity of young, lean adult female cats. A replicated 4 × 4 Latin square design with a 2 × 2 factorial treatment arrangement (feeding frequency and water content) was used. The 4 treatments consisted of 1 meal daily dry pet food without added water (1D; 12% moisture as is), 1 meal daily dry pet food with added water (1W; 70% total water content), 4 meals daily dry pet food without added water (4D; 12% moisture as is), and 4 meals daily dry pet food with added water (4W; 70% total water content). Eight healthy adult, lean, intact, young, female domestic shorthair cats were used in this experiment. Voluntary physical activity was evaluated using Actical activity monitors placed on collars and worn around the cats’ necks for the last 7 d of each experimental period of 14 d. Food anticipatory activity (FAA) was calculated based on 2 h prior to feeding periods and expressed as a percentage of total daily voluntary physical activity. Increased feeding frequency (4 vs. 1 meal daily) resulted in greater average daily activity ($P = 0.0147$), activity during the light period ($P = 0.0023$), and light:dark activity ratio ($P = 0.0002$). In contrast, physical activity during the dark period was not altered by feeding frequency ($P > 0.05$). Cats fed 4 meals daily had increased afternoon FAA ($P = 0.0029$) compared with cats fed once daily. Dietary water content did not affect any measure of voluntary physical activity. Increased feeding frequency is an effective strategy to increase the voluntary physical activity of cats. Thus, it may assist in the prevention and management of obesity.

Key words: feline, meal frequency, moisture content, obesity

INTRODUCTION

Obesity is the most common form of malnutrition in the pet population in western countries (Sloth, 1992). In 2012, approximately 58% of cats were considered overweight or obese (Calabash, 2013), translating to a total of 43.2 million overweight or obese cats in the United States. It is imperative that in conjunction with the development of effective strategies to manage obesity, preventive measurements for this disease are also exploited. A possible strategy is to increase the physical activity of cats without relying on the owners to follow an “exercise/play time” regimen with their cats. Objective measures (i.e., activity collars) are needed to validate this strategy. Multiple-meal feeding vs. single-meal feeding has been suggested by veterinarians to pet owners (German and Martin, 2008) but without published evidence of its efficiency.

Our laboratory recently tested whether increased feeding frequency could stimulate voluntary physical activity in cats. In that study, cats fed 4 meals vs. 1 meal daily had increased (~18%) voluntary physical activity (Deng et al., 2014). In addition to feeding frequency, increasing dietary water content has also been shown to be effective in increasing voluntary physical activity in cats (Deng et al., 2014; Cameron et al., 2011). However, the potential synergistic effects of increasing dietary water content and feeding frequency on voluntary physical activity of domestic cats have not been evaluated. Therefore, the objective of this study was to investigate the effects of increased dietary water content and feeding frequency...
on the voluntary physical activity of young, lean adult female cats. We hypothesized that cats fed more often and greater dietary water content would have greater voluntary physical activity than cats fed once a day or a diet containing low water content.

MATERIALS AND METHODS

Animals and Diets

All animal care procedures were conducted under a research protocol approved by the Institutional Animal Care and Use Committee, University of Illinois, Urbana. Eight healthy, lean, young, adult, intact, female domestic shorthair cats (approximately 1.5 yr old; 3.3 kg BW; 4.5 to 5.5 BCS on a 9-point scale [Laflamme, 1997]) were used in this experiment. Cats were group-housed in 2 rooms (n = 4 per room) most of the day but individually housed in cages (0.61 by 0.61 by 0.61 m) to access diets in the animal facility of the Edward R. Madigan Laboratory at the University of Illinois (Urbana). The rooms were environmentally controlled (20°C) with a 16-h light:8-h dark cycle. Cats in both rooms had access to comparable toys and scratching poles for behavioral enrichment and to encourage play in similar fashion.

Cats were fed a commercial dry kibble diet (Whiskas Adult Meaty Selection, Chicken & Turkey Flavors; Mars, Inc., Franklin, TN) at amounts to maintain ideal BW and BCS throughout the study. Before the experiment, food intake to maintain BW was determined by calculating the daily energy requirement using previous feeding records. Food refusals were collected and weighed daily. If the food refusals had additional water added, they were dried in a 55°C oven, weighed once dried, and cooled down to room temperature. Cats were weighed and assessed for BCS weekly. Water was available ad libitum throughout the experiment and during feeding times.

Experimental Design

This study aimed to determine the voluntary physical activity of adult cats fed 1 or 4 times daily and with (70% moisture content) or without (12% moisture as is) water added to their diet. A 2 × 2 factorial treatment arrangement was used in a replicated 4 × 4 Latin square design consisting of 4 periods of 14 d. Each period included a 7-d adaption phase followed by a 7-d measurement of voluntary physical activity. The 4 treatments consisted of 1) 100% of the daily intake without added water offered at 0815 h (1D); 2) 100% of the daily intake with added water (70% total water content) offered at 0815 h (1W); 3) 25% of the daily intake without added water offered at 0815, 1215, 1615, and 2015 h (4D); and 4) 25% of the daily intake with added water (70% total water content) offered at 0815, 1215, 1615, and 2015 h (4W). Cats were housed in 1 of 2 rooms, depending on their allotted treatment. One room housed the cats fed once daily, while the other housed the cats fed 4 times a day. Each room had a total of 4 cats per experimental period, and all cats and treatments rotated between the 2 rooms.

All cats were maintained on a strict housing schedule. Cats fed once a day were individually housed in cages for access to diet from 0815 to 0915 h each day. For the other 23 h, cats were group-housed in the room to allow for voluntary physical activity without human interference. In contrast, cats fed 4 meals daily were individually housed in cages for access to diet from 0815 to 0915 h, 1215 to 1315 h, 1615 to 1715 h, and 2015 to 2115 h each day. For the other 20 h, cats were group-housed in the room to allow for voluntary physical activity without human interference. Even though cats fed once a day had a longer daily period for social interaction and fewer hours of individual housing, this schedule was chosen to avoid artifacts that could potentially disturb the physical activity pattern of cats fed once daily (e.g., human interaction aside from their morning feeding time).

Voluntary Physical Activity Assessment

Voluntary physical activity was evaluated using activity monitors (Actical monitor; Mini Mitter, Bend, OR), which were placed on collars and worn around the cats’ necks for 7 consecutive days. The use of the activity monitors, which have been validated by Lascelles et al. (2008) and used in our laboratory (Belsito et al., 2009; Vester et al., 2009), allowed us to objectively measure the physical activity of the cats without human interference. The monitors contain omnidirectional sensors capable of accurately incorporating both intensity and duration of movement. Commercial software (Actical software; Mini Mitter) analyzed the data compiled by the monitor and converted it into arbitrary numbers referred to as “activity counts.” Physical activity was expressed as activity counts per epoch (epoch length = 15 s). Values represent the mean epoch activity count over the 7-d period, during the selected hours (light hours, dark hours, and average daily activity). Cats wore the same monitor among the experimental periods to control for device variability. One device malfunctioned during the last experimental period; thus, the data from 1 cat was unavailable for analysis.

Food Anticipatory Activity

Food anticipatory activity (FAA), which was measured in all cats, was calculated as the activity in the 2-h period before the scheduled feeding times (based on the
Effect of meal frequency in cats

4 meal daily schedule) divided by the total daily voluntary physical activity and expressed as a percentage. Total daily FAA was the sum of the FAA of each feeding time.

Statistical Analyses

All data were analyzed using the Mixed procedure of a commercial software (SAS version 9.3; SAS Inst. Inc., Cary, NC). Data normality was analyzed using PROC UNIVARIATE. The experimental design was a replicated 4 × 4 Latin square with a 2 × 2 factorial treatment arrangement of feeding frequency and water content. Cat and period were included in the model as random effects. The fixed effect of feed frequency, water content, and their interaction were tested in the model. The random effects of cat, period, and room were also tested. Treatment least squares means were compared to each other, and Tukey adjustment was used to control for experiment-wise error. Results are presented as means with their SEM. A probability of \( P \leq 0.05 \) was considered significant.

RESULTS

Daily Food Intake and Weekly Body Weight

A significant interaction between feeding frequency and dietary water content was observed for daily food intake and weekly BW (Table 1). Cats fed 1W had lower \( (P = 0.012) \) daily food intake compared with cats fed 1D, 4D, or 4W. Weekly BW was slightly greater (0.1 kg; \( P = 0.037 \)) in cats fed 1W compared with cats fed 1D, 4D, or 4W.

Voluntary Physical Activity

A similar average daily activity pattern was observed among all 4 dietary treatments (Fig. 1). Despite the similar patterns, the activity counts of cats fed 4 times daily were numerically higher than those fed only once a day for the majority of the light period.

The interaction of feeding frequency and dietary water content was not statistically significant \( (P > 0.05) \) for average total daily activity, activity during light and dark periods, or light:dark activity ratio (Table 2).

Table 1. Effect of feeding frequency (FF) and dietary water content (WC) on daily food intake and BW in young, lean adult female cats

<table>
<thead>
<tr>
<th>Item</th>
<th>Treatment</th>
<th>SEM</th>
<th>FF</th>
<th>WC</th>
<th>FF*WC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily food intake, g DM basis</td>
<td>1D</td>
<td>49.6a</td>
<td>43.6b</td>
<td>51.0a</td>
<td>50.2a</td>
</tr>
<tr>
<td>BW, kg</td>
<td></td>
<td>3.3a</td>
<td>3.4b</td>
<td>3.3a</td>
<td>3.3a</td>
</tr>
</tbody>
</table>

\( a,b \) Within a row, means without a common superscript differ \( P < 0.05 \).

\( 1 \) 1D = 1 meal daily dry pet food without added water, 1W = 1 meal daily dry pet food with added water (70% total water content), 4D = 4 meals daily dry pet food without added water, and 4W = 4 meals daily dry pet food with added water (70% total water content).

However, increased feeding frequency (4 vs. 1 meals daily), but not dietary water content, resulted in greater total average daily activity \( (P = 0.015) \), activity during the light period \( (P = 0.002) \), and light:dark activity ratio \( (P < 0.001) \). Physical activity during the dark period was not altered by feeding frequency \( (P > 0.05) \).

Food Anticipatory Activity

Similar to the voluntary physical activity data, no significant interaction \( (P > 0.05) \) between feeding frequency and dietary water content was observed for morning (0815 to 0915 h), noon (1215 to 1315 h), afternoon (1615 to 1715 h), evening (2015 to 2115 h), and total daily FAA. Cats fed 4 meals per day had greater afternoon FAA \( (P = 0.003) \) than cats fed once daily (Fig. 2). Water content did not affect total daily FAA \( (P > 0.05) \).

DISCUSSION

This study was the first to investigate the effects of feeding frequency and dietary water content on voluntary physical activity of adult cats using quantitative measurements. Throughout the study, cats were fed the same diet at amounts to maintain BW and BCS to eliminate potential confounding factors (e.g., changes in physical activity due to weight gain or loss [or meal size], changes in dietary thermic effects due
to variation in nutrient composition, etc.). Despite our attempt to keep energy intake consistent throughout the study, cats fed 1W consumed less food than the cats fed the other 3 treatments. The addition of 70% water increased the food volume, which could have intensified gut fill in cats fed this treatment, leading to an inhibitory effect on food intake. The distention of the gastric wall activates stretch receptors and mechanoreceptors inhibiting the ingestion of food (Havel, 2001). In addition, the cats fed once daily had only 1 h to consume their food. This time restriction may have posed a challenge for the cats fed 1W to ingest the larger food volume. It has been previously reported that dietary water content decreases food intake in cats (Kane et al., 1981). Although cats fed 1W had decreased daily food intake, they had a greater BW (3%) compared with the other dietary treatments. This change in BW, however, did not modify the BCS of the cats, which was unaltered from baseline for all cats during the experimental period (data not shown).

In contrast to our hypothesis, no interaction between feeding frequency and dietary water content was observed for voluntary physical activity. However, a significant effect of feeding frequency was observed, with cats fed 4 times daily having greater physical activity, especially during the light period, when compared to cats fed once a day. The greater activity during the light period coincides with the feeding schedule of the current study, in which all the feeding times took place during the light period. Three previous studies conducted in our laboratory have reported similar findings (Belsito et al., 2009; Deng et al., 2011; Deng et al., 2014).

Deng et al. (2011) reported numerically greater average daily activity and ratio of light:dark period activity for cats fed multiple meals in comparison with cats fed once a day. Because of limitations with the design of that study, no statistical analyses were performed for that particular comparison. In another study, cats fed 4 meals or a random number of meals daily (1, 2, or 4 meals/d) had greater average total daily activity, activity during the light period, and light:dark activity ratio compared to cats fed once a day (Deng et al., 2014). In the current study, the activity counts/epoch for average total, light period, and dark period activity levels were within ranges reported in previous studies (Belsito et al., 2009; Deng et al., 2011; Deng et al., 2014).

The daily activity pattern was similar among the dietary treatments but seemed to peak close to feeding times, with the 4-meal treatments having activity counts above the 1-meal treatments for most of the 24-h period. This finding is in agreement with previous results from our laboratory (Deng et al., 2011; Deng et al., 2014) except for the activity pattern immediately before the morning feeding period. Although 4-meal fed cats had a greater peak at the morning meal in this study, 1-meal fed cats had a greater peak than multiple-meal fed cats in the previous study (Deng et al., 2014). The previous studies used neutered male cats while the current study used intact females. The neutered male cats had an average daily food intake of 50.7 g dry matter basis (DMB) and a ME intake of 42.9 kcal DMB/kg BW, whereas the female cats in this study had an average daily food intake of 58.6 g DMB and a ME intake of 57.4 kcal DMB/kg BW. Because the neutered cats in those studies required a lower (~25%) amount of food and energy per kilogram BW, a greater feeling of hunger or search for food may have occurred in those animals. The lower food intake of those male cats vs. the female cats used in this study may also explain the discrepancies in the FAA findings between these studies.

### Table 2. Effect of feeding frequency (FF) and dietary water content (WC) on voluntary physical activity counts in young, lean adult female cats

<table>
<thead>
<tr>
<th>Item</th>
<th>Activity counts/epoch (15 s)</th>
<th>SEM</th>
<th>FF</th>
<th>WC</th>
<th>FF*WC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total activity</td>
<td>15.8</td>
<td>1.72</td>
<td>0.0147</td>
<td>0.4732</td>
<td>0.5559</td>
</tr>
<tr>
<td>Light activity</td>
<td>17.1</td>
<td>2.44</td>
<td>0.0023</td>
<td>0.4656</td>
<td>0.7090</td>
</tr>
<tr>
<td>Dark activity</td>
<td>14.6</td>
<td>1.47</td>
<td>0.6703</td>
<td>0.6312</td>
<td>0.4493</td>
</tr>
<tr>
<td>Light-dark ratio</td>
<td>1.2</td>
<td>0.14</td>
<td>0.0002</td>
<td>0.6001</td>
<td>0.7507</td>
</tr>
</tbody>
</table>

1D = 1 meal daily dry pet food without added water, 1W = 1 meal daily dry pet food with added water (70% total water content), 4D = 4 meals daily dry pet food without added water, and 4W = 4 meals daily dry pet food with added water (70% total water content).

**Figure 2.** Effect of feeding frequency and dietary water content on food anticipatory activity (FAA) in young, lean adult female cats. *Feeding frequency differed (P = 0.0029) between cats fed 1 meal vs. 4 meals daily. 1D = 1 meal daily dry pet food without added water, 1W = 1 meal daily dry pet food with added water (70% total water content), 4D = 4 meals daily dry pet food without added water, and 4W = 4 meals daily dry pet food with added water (70% total water content).
The mechanisms by which dietary water intake impacts individual cats (because several cats played with their water bowls or drank water from their paws after dipping them in the water, accurately estimating drinking water and total water intake was not possible) and 2) the inability to separate the effect of feeding frequency from human interaction during feeding times. It would be interesting to evaluate if feeding frequency is still a valuable strategy to increase physical activity when using automated feeders in the absence of humans. The authors believe that automated feeders have the potential to be effective, mainly if placed in a room where the cat does not spend most of its time, or if multiple feeders are used in different rooms of the house, forcing the cat to exercise to gain access to the food. However, future studies should be performed to validate this hypothesis.

Overall, few studies have shown that feeding frequency is an effective strategy to increase the physical activity of cats of different ages and neuter status, whereas less consistent results have been observed for increased dietary water content. Because of the high prevalence of obesity in the feline population, it is imperative that veterinarians and pet food professionals continue to educate pet owners about feline nutrition and effective means to maintain ideal BW and BCS or to achieve weight loss safely and successfully. Increased feeding frequency is a strategy that should be considered in this regard.

LITERATURE CITED


