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Comparison of Frequency and Stay Time between Normal and Abnormal Elimination Behavior of Cats Using a Litter Box with Automatic Sensor

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Abstract Changes in elimination behavior, including urination and defecation, are common clinical signs of numerous disorders in cats. Therefore, this study attempted to automatically measure the elimination behavior of cats using the litter box and develop an early warning system for the guardian in case of abnormalities. To construct an early warning system for abnormal changes through cat elimination behavior, it consisted of a litter box, an automatic sensor for data collection and data wifi transmission, a server for data analysis, and a mobile phone app for result transmission and early warning. To establish the reference interval (RI), the elimination behavior was monitored for more than 2 weeks using a motion sensor within a litter box in 37 healthy cats and 19 diseased cats. The data were expressed as daily total visits, daily total stay duration, average stay duration per elimination, weekly total visits, and weekly total stay duration. Healthy cats showed median daily total visits of 3 times/day (RI 1.0-7.0) and daily total stay duration of 192 s/day (RI 8.0-452.0). For weekly data, the median total visits were 20 times/week (RI 3.0-35.25) and the median total stay duration was 1,147 s/week (RI 80.0-2,249.5). The average stay duration per elimination was 59 s/elimination (RI 4.67-132.0). Diseased cats showed more frequent elimination behavior than healthy cats ($p < 0.001$). Otherwise, for each elimination, diseased cats had shorter stay durations than healthy cats ($p < 0.001$). This study established the RIs of elimination behavior parameters (frequency and duration) in healthy cats. The present study might help guardians and veterinarians detect changes in elimination behaviors in diseased cats at an early stage.

Key words elimination behavior, urination, feline lower urinary tract disease, chronic kidney disease, cat litter box.

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Introduction

Chronic kidney disease (CKD) and feline idiopathic cystitis (FIC) which are common diseases in old cats (2), commonly cause changes in urination and bowel movement behaviors. The kidney maintains water-electrolyte homeostasis. Even if cats with early stage of CKD are asymptomatic, they gradually show polyuria in the midterm. They might exhibit anuria or urine incontinence in the end stage. In addition, CKD causes constipation due to electrolyte imbalance, changes in hydration status, and gastrointestinal environment alterations (17). FIC (previously known as feline lower urinary tract disease) cats exhibit abnormal urination such as pollakiuria, stranguria, dysuria, hematuria, and periuria (9,11).

Unlike dogs and cats generally have urination and bowel movements in their toilets (litter box). Elimination-related clinical signs, such as polyuria, polydipsia, diarrhea, and constipation caused by various diseases alter cats' litter box usage behaviour (1,10).

Although many diseases in cats cause polyuria and constipation, cat guardians do not commonly visit hospitals because of polyuria or constipation. This implies that it is difficult for guardians to recognise the changes in elimination behavior. According to a previous study, when evaluating the frequency of cats' urination in the litter box, guardians reported a lower frequency than that determined using video recording systems. Additionally, questionnaire responses are often inaccurate observations (6). Previous studies have mainly focused on house-soiling (inappropriate elimination behavior), that is, urination or defecation outside the litter box (1,5,18). However, normal elimination behaviors in cats have rarely been assessed using an in-house objective recording machine.

The normal range (reference interval, RI) of urological biomarkers such as clinical pathology, normal urine specific gravity, and creatinine and blood urea nitrogen (BUN) levels has been established in veterinary medicine. However, the quantitative assessment of elimination behaviors such as cat urination frequency and stay duration has not been performed adequately (3,13,14). Therefore, the purpose of this study is to establish the RI of cats' litter box usage behavior by establishing a database of normal litter box usage behavior of healthy cats. The present study might help guardians and veterinarians recognize abnormal pathological elimination behavior early in the disease. This can lead to diagnosis and treatment in the early stages, and the established RIs can serve as criteria for treatment monitoring. Therefore, this study will contribute to the promotion of the health of cat.

Materials and Methods

Experimental animals

Eighty-eight indoor cats were enrolled using a cat litter box (Kangjipsa Cat Litter Box L, WALKBRAIN, Seoul, Korea) with a motion sensor (Health Monitor Pro CL1-B, Kangjipsa, WALKBRAIN, Seoul, Korea) between May 2021 and December 2022. Informed consent was obtained from the guardians. This study was approved by the Seoul National University Institutional Animal Care and Use Committee (SNU IACUC No.: SNU-210517-6-1).

Data collection of cat elimination behavior

The motion sensor (WALKBRAIN, Seoul, Korea) (Fig. 1A) for the cat identification device was used for sensing cats entering the litter box (Fig. 1B) in this study. The sensor can detect a motion within 50 cm around the device, so it is reasonable to distinguish between hanging around and using the litter box (Fig. 1B). In addition, by detecting the exit, the time of stay can be estimated. These cat behavior data were collected and seen by a guardian through the mobile phone application Kangjipsa (WALKBRAIN, Seoul, Korea) (Fig. 1C). Finally, cat elimination behavior data was transferred to a server of the company (WALKBRAIN, Seoul, Korea). The data was converted to an Excel file and used for statistical analysis. Finally, guardians can check the analyzed cat elimination behavior results using an application of mobile phones.

Case selection

There are some selection criteria for reference individual cats to establish an RI for normal elimination behavior (litter box usage behavior) of healthy cats. The exclusion criteria

Fig. 1. Motion sensor (A), litter box (B), and application (C) were used to experiment with cat elimination behavior.

were multiple cat housings, multiple litter boxes with sensors, insufficient experimental days (less than 2 weeks), and illness. The cat guardians were asked to share either the blood test results and the questionnaire about the condition of their cats (see Supplementary File 1 in supplementary material).

Except for 27 guardians who did not complete the survey,

Table 1. **Information provided by 61 participants: descriptive data about biological information of cats**

Baseline character	Number of cats (% in group)			
	Diseased group (N = 19)	Non-diseased group (N = 42)	Total (N = 61)	Reference individuals (N = 37)
Total number of cats	19 (100.0)	42 (100.0)	61 (100.0)	37 (100.0)
Age group*				
Adult	13 (68.4)	28 (66.7)	41 (67.2)	23 (62.0)
Kitten	3 (15.8)	12 (28.6)	15 (24.6)	12 (32.0)
Senior	3 (15.8)	2 (4.8)	5 (8.2)	2 (5.0)
Sex				
Male	7 (36.8)	18 (42.9)	25 (41.0)	17 (45.9)
Female (spayed)	12 (63.2)	24 (57.1)	36 (59.0)	20 (56.8)
Neutered*				
Intact	0 (0.0)	1 (2.4)	1 (1.6)	1 (2.7)
Neutered	19 (100.0)	41 (97.6)	60 (98.4)	36 (97.3)
Breed				
Abyssinian	0 (0.0)	2 (4.8)	2 (3.3)	1 (3.0)
American shorthair	1 (5.3)	0 (0.0)	1 (1.6)	2 (5.0)
Bengal	1 (5.3)	2 (4.8)	3 (4.9)	12 (32.0)
Korean shorthair	9 (47.4)	13 (31.0)	22 (36.1)	1 (3.0)
Maine coon	0 (0.0)	1 (2.4)	1 (1.6)	1 (2.0)
Munchkin	0 (0.0)	1 (2.4)	1 (1.6)	1 (3.0)
Norwegian forest	1 (5.3)	3 (7.1)	4 (6.6)	3 (8.0)
Persian	2 (10.5)	6 (14.3)	8 (13.1)	5 (14.0)
Ragdoll	0 (0.0)	2 (4.8)	2 (3.3)	2 (5.0)
Russian blue	2 (10.5)	1 (2.4)	3 (4.9)	1 (3.0)
Scottish fold	1 (5.3)	3 (7.1)	4 (6.6)	3 (8.0)
Siamese	0 (0.0)	4 (9.5)	4 (6.6)	3 (8.0)
Turkish angora	1 (5.3)	2 (4.8)	3 (4.9)	1 (3.0)
N/A	1 (5.3)	2 (4.8)	3 (4.9)	2 (5.0)
Body weight (kg)*				
2	0 (0.0)	1 (2.4)	1 (1.6)	1 (3.0)
3	0 (0.0)	4 (9.5)	4 (6.6)	4 (11.0)
4	4 (21.1)	14 (33.3)	18 (29.5)	11 (30.0)
5	5 (26.3)	17 (40.5)	22 (36.1)	16 (43.0)
6	6 (31.6)	3 (7.1)	9 (14.8)	2 (5.0)
7	4 (21.1)	2 (4.8)	6 (9.8)	2 (5.0)
8	0 (0.0)	1 (2.4)	1 (1.6)	1 (3.0)
Experimental days				
Sufficient	13 (68.4)	37 (88.1)	50 (82.0)	37 (100.0)
Insufficient	6 (31.6)	5 (11.9)	11 (18.0)	0 (0.0)
Single-cat vs. Multi-cat housing				
Single-cat	15 (78.9)	39 (92.9)	54 (88.5)	37 (100.0)
Multi-cat	4 (21.1)	3 (7.1)	7 (11.5)	0 (0.0)
Number of litter boxes with sensor				
1	18 (94.7)	42 (100.0)	60 (98.4)	37 (100.0)
2	1 (5.3)	0 (0.0)	1 (1.6)	0 (0.0)

N/A; unregistered or unknown.

*Statistically significant difference in the distribution between non-diseased and diseased cats ($p < 0.05$, chi-square or t-test statistical analysis).

61 cat guardians shared all data including cats' health status, biological information, and housing environment. Also, based on the exclusion criteria, we excluded 24 cats: 19 due to cat illnesses, and 5 due to insufficient experimental days. Finally, reference individual 37 cats were selected, and they were considered clinically healthy based on physical examination, blood analyses, urinalyses, survey radiography and abdominal ultrasonography. The cats that had been diagnosed with CKD, urinary tract disease, and/or FIC were classified into diseased cats (n = 19). It was diagnosed by identifying a cat with abnormal levels of BUN and creatinine panels. Urinary tract diseases such as urolithiasis, bacterial cystitis or FIC were diagnosed by clinical signs, radiography, ultrasonography, and urinalysis. The following data (6,555 daily data points and 1,149 weekly data points) about the elimination behavior of cats confirmed to be healthy were collected: daily total visits (times/day), daily total stay duration (s/day), weekly total visits (times/week), weekly total stay duration (s/week), and average stay duration (s/elimination).

Statistical analysis

During pre-processing, outliers in the collected data were deleted (Tukey's fence method). One-way ANOVA, two-sample t-test, and determination of RIs were conducted using MedCalc v.20.115 (MedCalc Software Ltd., Ostend, Belgium). The regression tests were performed using Microsoft Excel (Microsoft, Redmond, WA, USA). The RIs were established according to the American Society for Veterinary Clinical Pathology (ASVCP) reference interval guideline (8). In addition, the differences of elimination parameters between each subgroup (age, sex, weight, breed, and health status) were compared using one-way ANOVA or two-sample t-test. The p-values $<$ 0.05 were considered statistically significant.

Results

Sixty-one cat guardians completed the questionnaire (Supplementary File 1). For selecting reference individual cats and sample data, the cats' health status, biological information, housing environment, and possible days of experiments were recorded (Table 1). Nineteen cats (7 with FIC, 10 with renal failure, 4 with urolithiasis, 1 with acute kidney injury, and 1 with renal atrophy [four cats had two urological diseases]) were determined to be diseased and excluded. Based on the exclusion criteria, only 37 healthy cats were selected as reference individual cats (Table 1). The median age of the cats was 4 (range, 0-15) years and the median weight was 5 (2-8) kg. Collection of cat elimination behavioral data was collected from 37 reference individual cats over 20 months, accumulating a total of 6,555 daily and 1,149 weekly data points. These were utilized to establish the reference Interval (RI), after removing outliers based on predefined criteria.

Following the ASVCP reference interval guidelines, the reference interval was analyzed using the nonparametric ranked percentile method of the 2.5th and 97.5th individual percentiles and the 90% confidence interval (CI) for the upper and lower limits (of each reference interval), reflecting a sample size of more than 120 (8). The RI of daily total visits, daily total stay duration, and the average stay duration were established (1.0-7.0 times/day, 8-452 s/day, and 4.67-132.0 s/elimination) (Table 2). In terms of weekly behavior data, the RI of weekly total visits and weekly total stay duration were established (3.0-35.25 times/week, and 80.0-2249.5 s/week) (Table 2).

Based on the biological information of healthy cats, the reference individuals were classified into 3 age groups (Kitten, below 2 years old; Adult, below 7 years old; and Senior, over 7 years old) and 2 sex groups (male and female). Because of

Table 2. Reference intervals for healthy cats

Items	Sample size	Mean ± SD	Median	Range	RI (90% CI)
Daily total visits (times/day)	6,555	3.38 ± 1.45	3	1.0-7.0	1.0 (1.0-1.0) to 7.0 (7.0-7.0)
Daily total stay duration (s/day)	6,555	199.51 ± 115.51	192	2.0-522.0	8.0 (7.0-10.0) to 452 (445.0-459.0)
Average stay duration (s/elimination)	6,555	61.60 ± 33.02	59	2.0-151.0	4.67 (4.0-5.0) to 132.0 (130.0-134.5)
Weekly total visits (times/week)	1,149	19.30 ± 8.12	20	1.0-44.0	3.0 (3.0-4.0) to 35.25 (34.0-36.0)
Weekly total stay duration (s/week)	1,149	1,138.19 ± 567.36	1,147	2.0-3,112.0	80.0 (61.0-111.0) to 2,249.5 (2,164.0-2,334.0)

RI, reference interval; CI, confidence interval. Descriptive data about sample size, mean, SD, median, reference range (minimum-maximum), and reference interval (lower reference limit - upper reference limit) with 90% Cis.

the insufficient number of cats that were intact (only 1), subgrouping by neutering was excluded from the analysis. Similarly, subgrouping by breed was excluded because less than 40 cats of each breed were included. The categorized RIs were analyzed the same as previously described for healthy cats (Supplementary Table 1).

There was a significant difference in the mean elimination behavior between the age subgroups ($p < 0.001$) (Table 3). In healthy senior cats, the mean daily total visits was 4.58 ± 1.32 times/day, whereas the adult cats had 3.24 ± 1.40. Daily total stay duration (s/day) was 269.58 ± 108.83 s/day in senior cats, and 191.85 ± 113.28 in the adult cats (Table 3).

There was a significant difference in the mean elimination behavior between males and females ($p < 0.001$) (Table 4). The healthy male cats showed more frequently in daily total visits than female cats (male vs female; 3.63 ± 1.52 vs 3.15 ± 1.35 times/day). Whereas, daily total stay duration (s/day) and average stay duration (s/elimination) were longer in females (male vs female; total 191.42 ± 118.71 vs 207.27 ± 111.84 s/day; average 52.03 ± 27.49 vs 70.74 ± 35.21 s/elimination) (Table 4).

In the correlation matrix, weight was significantly correlated with stay duration (daily total stay duration and average stay duration) ($p < 0.001$) (Supplementary Table 2). Breed subgroups were not suitable for comparing reference samples because of the insufficient sample size (< 40).

Among the participants, 19 diseased cats were excluded from the reference individuals. All cats were classified as disease cats if they had a history of the disease at least once, and whether or not the disease was managed within the study period differs between each cat. To compare the characteristics of normal elimination behavior between healthy and diseased cats, a statistical analysis was conducted. After data pre-processing, 2,917 daily and 497 weekly data were selected for the analysis of final elimination behavior data of diseased cats. There was a significant difference in the mean daily total visits and stay duration, as well as in the weekly data, and the mean value of daily total visits (times/day) was 3.38 in the healthy group, and 3.77 in the diseased group (Fig. 2, Table 5).

Table 3. Comparison of mean elimination behavior between age groups

Items	Groups	N	Mean	SD	F-ratio	p-value	Scheff
Daily total visits (times/day)	Kitten (a)	518	3.76	1.56	220.002	<0.001***	b<a<c
	Adult (b)	5,556	3.24	1.40			
	Senior (c)	481	4.58	1.32			
Daily total stay duration (s/day)	Kitten (a)	518	216.61	121.51	109.952	<0.001***	b<a<c
	Adult (b)	5,556	191.85	113.28			
	Senior (c)	481	269.58	108.83			
Average stay duration (s/elimination)	Kitten (a)	518	59.19	30.19	1.932	0.145	
	Adult (b)	5,556	61.92	33.85			
	Senior (c)	481	60.46	25.29			

ANOVA was used to assess differences in the means of various parameters between the three age groups and the relation between them.
The post-analysis results are shown in the Scheff column.
N, number of data.
***Statistically significant difference in the mean between groups.

Table 4. Comparison of mean elimination behavior between sex groups

Items	Group	N	Mean	SD	t-value	p-value
Daily total visits (times/day)	Male	3,201	3.63	1.52	–13.562	<0.001***
	Female	3,354	3.15	1.35		
Daily total stay duration (s/day)	Male	3,201	191.42	118.71	5.542	<0.001***
	Female	3,354	207.27	111.84		
Average stay duration (s/elimination)	Male	3,201	52.03	27.49	24.043	<0.001***
	Female	3,354	70.74	35.21		

t-test was used to assess the difference in the means of various parameters between the two sex groups and the relation between them.
N, number of data.
***Statistically significant difference in the mean between groups.

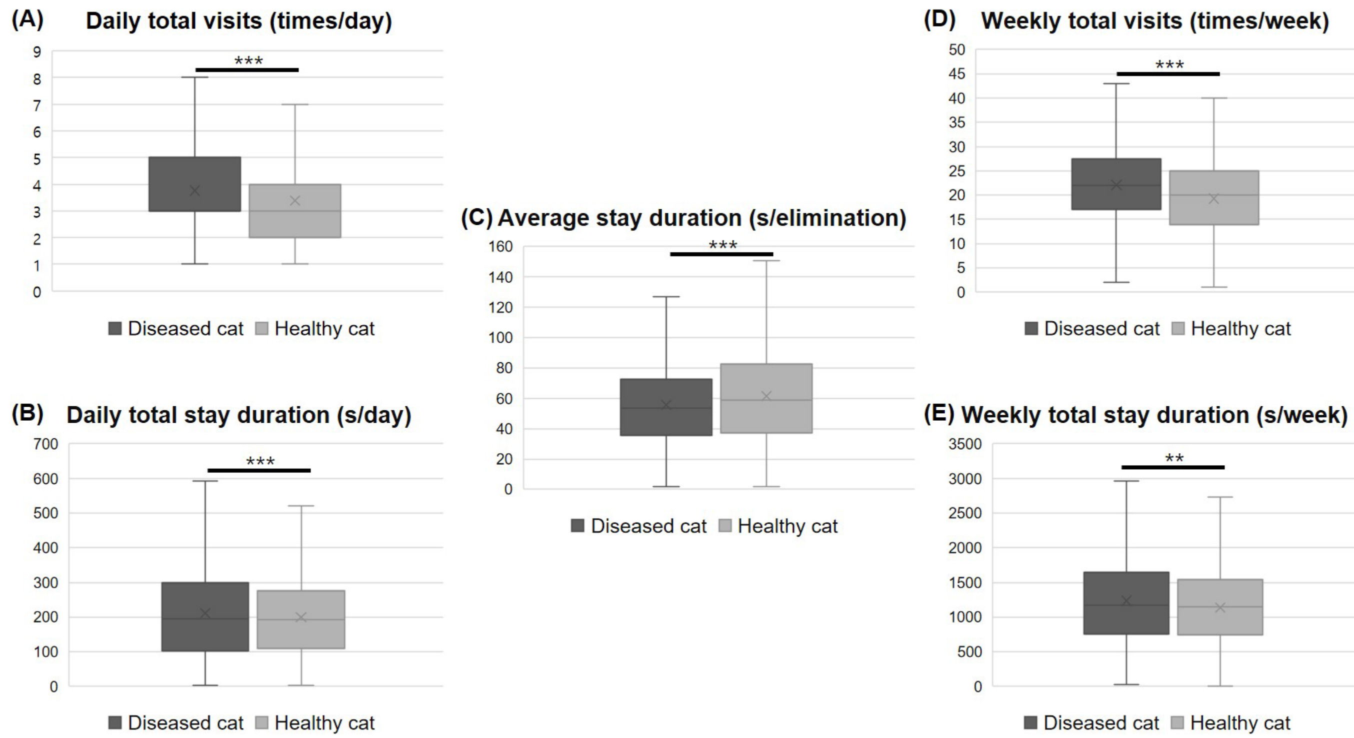

Fig. 2. Comparison of mean elimination behavior between healthy and diseased cats; daily total visits (A), daily total stay duration (B), average stay duration (C), weekly total visits (D), and weekly total stay duration (E) in healthy and diseased cats. Data are presented the statistically significant difference in mean values between the groups (**p < 0.01, ***p < 0.001).

Table 5. Comparison of mean elimination behavior between the healthy and diseased cats

Items	Group	N	Mean	SD	t-value	p-value
Daily total visits (times/day)	Healthy	6,555	3.38	1.46	10.512	<0.001***
	Diseased	2,917	3.77	1.72		
Daily total stay duration (s/day)	Healthy	6,555	199.51	115.51	3.897	0.001***
	Diseased	2,917	210.63	133.51		
Average stay duration (s/elimination)	Healthy	6,555	61.60	33.02	–9.166	<0.001***
	Diseased	2,917	55.58	27.80		
Weekly total visits (times/week)	Healthy	1,149	19.30	8.13	6.013	<0.001***
	Diseased	497	22.12	8.97		
Weekly total stay duration (s/week)	Healthy	1,149	1,138.19	567.36	2.986	0.003**
	Diseased	497	1,236.24	629.73		

Welch's t-test was used to assess difference between the means of the two groups and the relation between them (regarding the non-Gaussian distribution of data).
The table shows statistically significant difference in mean values between the groups (**p < 0.01, ***p < 0.001).

Discussion

In this study, the RIs of elimination behavior (litter box usage behavior) of cats were established. The elimination behavior was automatically determined using motion sensors and monitored in a natural in-home environment. Some previous studies had a limitation, for its controlled environment, not a natural environment (4,7).

Some previous studies reported a difference in the frequency of daily elimination behavior (urination or defecation) between healthy cats and cats with urological disease (6,12).

This study assessed the elimination behavior, both urination and defecation, through the number of box accesses. The RIs of healthy cats' litter boxes using frequency and residual time were 1.0-7.0 times/day, and 4.67-132.0 s/elimination. It can be a reference for the guardians to detect the health status of the cat only by observing the litter box access. It is not easy for typical guardians to distinguish whether a cat urinates or defecates. Using this result value, a cat showing more than 7 times a litter box entering per day can be suspected of having a disease. A higher frequency of using the litter box implies the clinical signs, either LUTS (lower urinary tract symptoms), constipation, or diarrhea, or it's a combination.

The mean value of daily total visits (3.38 ± 1.45 times/day) in this study is similar to the sum of the frequencies of urination (mean 2.43 ± 0.90 times/day, range 1-4) and defecation (mean 1.29 ± 0.56 times/day, range 0.33-3) in the other study (12).

Table 3 shows that healthy seniors and kittens visit the litter box more frequently than adults. We estimated that these differences are because of the normal aging of seniors and the immature urinary system of kittens. One previous study said that guardians observed 55.8% of elderly cats showing house-soiling behavior, because of 'normal' aging or disease (16).

Table 4 shows that the healthy male cats visited the litter box more frequently and stayed shorter for each visit. The urination frequency can be influenced by male marking behaviors. Even if neutered, male cats show an instinct for urine marking, unlike females (15).

All cats were observed from May 2021 to December 2022, but each cat was not observed at the same time point. There is a limitation that there is a difference on the day of the experiment. Depending on the observation period, factors such as seasonal effects or sensor adaptation periods may play a role, so further studies at the same observation point should be necessary.

In the current study, the mean daily total visits, daily total stay duration, weekly total visits, and weekly total stay duration of diseased cats were significantly higher than those of healthy cats (Fig. 2, Table 5). The difference in the mean value of daily total visits (healthy vs diseased; 3.38 vs 3.77 times/day) was presumed to be due to clinical signs of polyuria, pollakiuria, and diarrhea. This result is consistent with that of previous studies that diseased cats show more frequent urination (6,12). According to some previous reports, a cat with a urological disease exhibits more frequent urination than a healthy cat. One study, in which data were collected using a video recording system, showed that a diseased cat urinates 2.9 ± 0.7 times (range, 1-5 times/day) on an average (6). Another study reported that a cat with CKD urinates 3.13 ± 0.93 times (range, 1-5 times/day) on an average (12).

This study also showed the diseased cats showed a higher SD of daily total visits (healthy vs diseased; SD 1.46 vs 1.72) (Table 5). This result is analogous to that of a previous report that diseased cats show a wider range of daily urination frequency than healthy cats (6). However, a limitation of the current study is a significant difference in distribution between healthy and diseased cats. Such a disparity in distribution can affect the values of each parameter. A greater number of senior cats were included in the diseased group, and older age might have indirectly led to more frequent visits.

Each area under the receiver-operating characteristic (ROC) curve (AUC) values calculated based on the number of times the cat visited the litter box and the time it stayed were all below 0.6 and not significant. To improve these results, it will be necessary to secure multiple experimental groups, classify each disease group separately, measure drinking water and feed intake, urine and feces amounts, and process data through multiple analyses. This study was initial research results for early warning of disease through elimination behavior in cats. As a follow-up study, it is expected that a more reliable early warning system will be established if comprehensive data analysis is attempted using multiple sensors to measure body weight, water and feed intake, and urination and defecation volumes.

To our knowledge, no studies have monitored the usage of litter boxes by healthy and diseased cats in-housed environments. In this study, the use of automatic monitoring using motion sensors improved the accuracy and reliability of the results because of the absence of subjective intervention by the observer. Moreover, since monitoring was in-housed environment rather than in a controlled one, the risk of error in cat behavior variants due to stress caused by changes in the surrounding environment was less. However, this study had a limitation that the motion sensor does not distinguish between urination and defecation. The distinction between defecation (bowel movements) and urination behaviors needs to be explored in follow-up studies. Despite the limitation, this study is meaningful because we included sufficient reference individual cats, 37 healthy cats, and 6,555 daily behavior data points, and established a reliable RI of healthy cat behavior.

Conclusions

This study established RIs for the normal elimination behavior of healthy cats. Diseased cats diagnosed with urological disorders exhibited more frequent elimination and longer stay duration in the litter box than healthy cats. The study results could contribute to the detection of clinical signs in cats that manifest as abnormal litter box usage at home and help in early diagnosis and treatment.

Author Contributions

JWS drafted the initial manuscript of the research; JWS, SWH, CGC, and JSC acquired the data; JWS, SHK, MK, and JSC analysed and interpreted the data; SWH, SHK, MK, CGC, and JSC revised the article; and JSC approved the final version of the article prior to submission. All authors have read and approved the manuscript.

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Conflicts of Interest

The authors have no conflicting interests.

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