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A new technique for monitoring the detailed behaviour of terrestrial animals: A case study with the domestic cat

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Abstract

For many animal species that are difficult to access, the behaviour of free-ranging individuals cannot be assessed by direct observation. In order to remedy this, we developed a new technique using a motion detector (acceleration data-logger) for monitoring the activity and behaviour of free-ranging vertebrates and tested its efficiency on a domestic cat, *Felis catus*. A total of 3615 min of surging acceleration was measured along the longitudinal body axis of an adult male cat. The cat's behaviour was also filmed for 113 min, these video data being used to correlate the logger's signals with the cat's behaviour. Acceleration data-loggers attached on the cat's collar recorded acceleration signals which were influenced by both the gravitational acceleration resulting from the body posture and the dynamic acceleration resulting from the dynamic behaviour of the cat. By applying spectral analysis based on a fast Fourier Transform to acceleration signals, body postures and some of the dynamic behaviours of the cat such as drinking, eating, and several paces of travelling were efficiently determined. The present study shows that acceleration data-loggers represent a useful and reliable system for accurately recording the activities and detail behaviours of the terrestrial animals.

Keywords: Acceleration data-logger; Activity; Domestic cat; Motion detector; Time budget

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1. Introduction

Assessing the activity of undisturbed animals is necessary to fully understand their ecology or to provide indices of their welfare, but this is often a challenging task. While this seems especially obvious when dealing with free-ranging, highly mobile or nocturnal species, the quantitative monitoring of the behaviour of captive individuals over long periods of time can be equally problematic.

Following the advances in electronics, there have been several attempts to automatically monitor the activity of animals using data transmitters or recorders directly attached to the animals. For instance, VHF radio transmitters have allowed researchers to track free-ranging animals, providing information about their movements (White and Garrott, 1990; Samuel and Fuller, 1996; Kenward, 2001). The addition of various sensors to the transmitters meant that several physical environments and physiological parameters could be monitored simultaneously with the position of the animals (Gillingham and Bunnel, 1985; Kunkel et al., 1991; Palomares and Delibes, 1991). None the less, these telemetry systems still require a heavy commitment from the researchers that have to track the animal continuously over extended periods of time; and, therefore, it may not provide an accurate time budget of an animal's diel activities. Recently, a storage telemetry system ETHOSYS has been developed to automatically record, for instance, the diurnal rhythms of ungulates based on advanced analysis of sensor-emitted signals (Scheibe et al., 1998; Langbein et al., 1998; Berger et al., 1999). However, this system does not allow the researchers to investigate fine-scale behaviour and is still too heavy to attach to small-sized mammals ($<$15 kg, Scheibe et al., 1998).

Advances in this domain have come from the recording of data over time, which are stored in the electronic memory of the devices (a.k.a. bio-logging, Boyd et al., 2004). While primarily designed for aquatic species that are hardly accessible to direct observation, the emergence of new technologies, together with the miniaturization of electronic components, has meant that researchers could record a variety of physical and biological parameters over an increasing array of species. Facilitated by recent advances in the data-logger technology, data-loggers that record body movements through acceleration signals have been developed and deployed on a variety of animals, enabling researchers to monitor various activities (e.g. Yoda et al., 1999; Tanaka et al., 2001; Sato et al., 2003). The monitoring of the body movements and posture of an animal by a data-logger that detects the changes in static and dynamic acceleration along two axes has proved especially helpful in determining the time budget activity of free-ranging aquatic animals (Yoda et al., 1999, 2001; Kawabe et al., 2003; Ropert-Coudert et al., 2004).

In the present study, acceleration data-loggers were attached to a captive domestic cat, *Felis catus*, in order to test the potential of this device to characterize efficiently the different behaviours of a terrestrial vertebrate. We also discuss the potential of applying this method to free-ranging cats and other terrestrial mammals.

2. Method

2.1. Data collection

The study was conducted in a house, the adjacent sugar cane fields and secondary forests on Iriomote Island (24°19′N, 123°54′E), Ryukyu Archipelago, Japan, in November 2002.

An adult male domestic cat, weighing 3.2 kg was equipped with a 12-bit resolution, 16 Mbyte memory and four-channel M190-D2GT logger (15 mm in diameter, 53 mm in length, weighing 18 g (ca. 0.5% of cat mass); Little Leonardo Co. Ltd, Tokyo, Japan). The device included depth, temperature sensors, as well as two accelerometers (ADXL202E: Analog Devices, Inc.), but in the present study, we only recorded acceleration along one axis. The measurement range of accelerometers was between -29.4 and $29.4\ \mathrm{m\ s^{-2}}$ (-3 and 3G, parallel and orthogonal to the main axis of the data-logger, respectively). The logger was attached with plastic cable ties and sealing tape to a 10 g, 11 mm wide, nylon collar. The collar was fastened tightly around the cat's neck with a plastic buckle, to prevent it from turning around the neck. The logger was positioned under the cat's throat, where it recorded acceleration in the main body axis, i.e. the surging acceleration measured along the longitudinal body axis (Fig. 1). Three trials were conducted to record the surging accelerations at frequency of 16 Hz. Because the position of the collar may have varied slightly between each trial, calibrations of the acceleration signals were carried out for each trial while the logger was positioned on the collar. For each trial, acceleration was set to be $0.0\ \mathrm{m\ s^{-2}}$ on each axis when the cat was seen lying still in a horizontal position (Fig. 1B).

Following application of the equipment, the cat was released and allowed to move freely inside or outside the house. The cat was recaptured after 907, 1348, and 1360 min in each

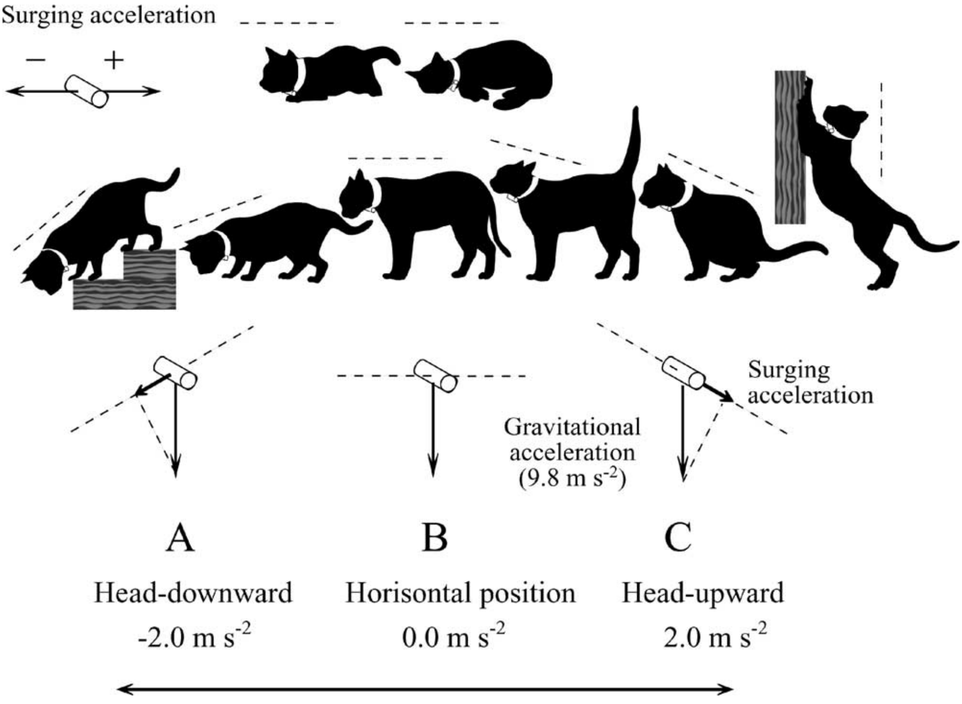


Fig. 1. Schematic diagram showing several body postures of a cat: head-downward (A), standing and lying in a horizontal position (B), and head-upwards (C). Each dashed line shows the gradient of body axis along each posture.

trial. The loggers were then retrieved; the data were downloaded into a laptop computer and analysed using IGOR Pro version 4.09 software (WaveMetrics Inc., 2000). During the experiments, the cat was directly observed as long as possible. If a behaviour of interest was observed, the cat was also filmed using a digital video camera (DCR-PC7, Sony, Japan) at 30 frames s^{-1} to relate the activities of the cat to the signals recorded by the logger.

2.2. Data analysis

2.2.1. Estimation of body posture

The acceleration sensors recorded both accelerations related to changes in the movements of the cat, i.e. dynamic accelerations, and gravitational acceleration (approx. 9.8 m s^{-2}). The periodic properties of the acceleration signals recorded during dynamic behaviours of the cat (e.g. travelling, eating, and grooming) allowed us to apply a fast Fourier Transform (FFT) in order to determine the frequency of a particular movement. The results are presented as frequency giving dominant power spectral density (PSD) calculated by the PSD macro in IGOR (Arai et al., 2000; Watanuki et al., 2003).

In addition, the amplitude of accelerations when the cat was not moving represented the component of gravitational acceleration that changes in response to the body posture (Yoda et al., 2001). Thus, we could define the following postures: (A) head bent forward, (B) standing or lying in a horizontal position, and (C) sitting up or upright on hind legs (Fig. 1). The component of the gravity of acceleration along the surging axis was given by removing the high-frequency component of the signals resulting from the dynamic behaviours of the cat using a low-pass filter of IGOR Filter Design Laboratory (IFDL) version 4.0 (WaveMetrics Inc., 2000; Tanaka et al., 2001; Watanuki et al., 2003). The low-pass filter characteristics for the cat were less than 0.1 Hz, which seems to be sufficiently low to remove frequencies of the dynamic behaviours. From the component of gravitational acceleration depending on several postures, the thresholds at which the postures of the cat would best be distinguished from each other were identified.

2.2.2. Classification of cat behaviour

To distinguish each type of the cat's behaviours, we derived five parameters from a segment of acceleration profile corresponding to each behaviour filmed by video: (i) mean, (ii) range of gravitational acceleration, i.e. average value and range (maximum–minimum values) of the component of gravitational acceleration after usage of the low-pass filter, (iii) maximum amplitude on surging accelerations, (iv) dominant power spectral density (DSD), and (v) the frequency given at the DSD (FSD) (Fig. 2). The duration of each acceleration waveform was fixed to 4 s (64-sample) or 16 s (256-sample), because an FFT can only be applied to an even number of samples (WaveMetrics Inc., 2000). In the present study, we mainly used 16 s as the duration of acceleration waveforms but for relatively short-time behaviours such as trot and gallop it was shortened to 4 s.

Using the above five parameters, we performed a stepwise canonical discriminant analysis (CDA) to classify behavioural categories of the cat from the acceleration profiles, with the variables selected based on the Wilk's *Lambda*. The purpose of using CDA in this study was to investigate the differences of acceleration data among the cat's main

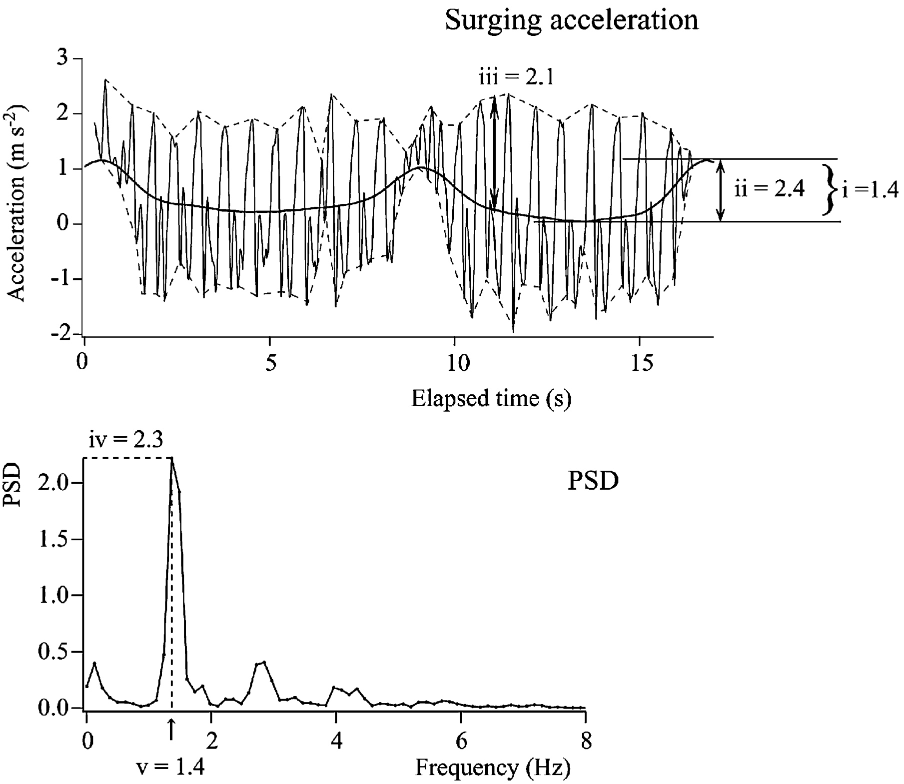


Fig. 2. Examples of variables giving in a 16 s-segment of surging acceleration profile during grooming: (i) mean posture, (ii) range of posture, (iii) maximum amplitude, derived from the waveform, (iv) dominant power spectrum (DSD) and (v) frequency giving at DSD derived from power spectral density (PSD).

behaviours and to find the variables that could be used to objectively distinguish the behaviours in acceleration data. The implementation of CDA provides some important information for classifying behaviours and identifying important variables for the classification (Huberty, 1994). The CDA was carried out using SPSS for Windows 11.5 (SPSS Inc., 2002).

3. Results

3.1. Experimental trials

A total of 3615 min of surging acceleration data was recorded on the cat. Concurrently with this, 113 min of the cat's behaviour were also filmed so that the analysis of the acceleration data was performed on these 113 min where the actual behaviour of the cat was known. During video recordings, the cat was seen lying asleep (mean duration among episodes of the behaviour: $\bar{X} \pm$ S.D., 141 ± 124 s, 33.0% of the time), grooming hairs

Table 1
Summary statistics of surging accelerations in each behaviour of a domestic cat

Behaviour type	*n*	Length of segment (s)	Mean posture ($m\ s^{-2}$)	Range of posture ($m\ s^{-2}$)	Maximum amplitude ($m\ s^{-2}$)	DSD (PSD)	FSD (Hz)
Groom by							
Licking	97	16	0.62 ± 3.67	2.47 ± 2.38	3.68 ± 1.55	1.56 ± 2.09	1.83 ± 0.77
Hind claw	7	16	−2.29 ± 4.46	4.90 ± 2.85	11.5 ± 10.0	1.54 ± 0.97	3.93 ± 1.68
Forepaw	3	16	−0.06 ± 0.24	1.55 ± 0.78	2.10 ± 0.28	0.38 ± 0.23	1.18 ± 0.28
Eat							
Cat food	19	16	−0.76 ± 0.17	0.33 ± 0.40	1.80 ± 0.63	0.08 ± 0.04	2.57 ± 0.47
Half-dried fish	14	16	−0.14 ± 0.33	0.55 ± 0.41	2.77 ± 0.94	0.09 ± 0.05	1.94 ± 0.49
Drink water	11	16	−0.43 ± 0.49	0.23 ± 0.13	0.79 ± 0.16	0.04 ± 0.04	3.31 ± 0.15
Travel							
Walk	44	4	−0.20 ± 1.97	1.83 ± 2.45	5.00 ± 3.48	0.88 ± 0.93	3.16 ± 1.27
Trot	23	4	−0.36 ± 1.02	2.33 ± 2.60	13.4 ± 4.53	16.2 ± 5.90	4.35 ± 0.70
Gallop	24	4	−0.23 ± 0.70	2.28 ± 1.44	17.2 ± 5.12	48.5 ± 30.5	3.61 ± 0.99

Mean posture, range of posture, maximum amplitude, dominant power spectrum density (DSD) and its frequency (FSD) derived from segmentised acceleration waveforms are shown.

(45.1 ± 116 s, 23.9%), eating food (104 ± 101 s, 15.3%), sitting motionless (41.4 ± 43.8 s, 14.6%), travelling, which included walking, trotting, and galloping (5.2 ± 5.6 s, 7.3%), drinking water (45.6 ± 22.6 s, 3.4%), and engaged in other miscellaneous activities (2.5%) including urinations, defecation, clawing a wooden pole, etc. An example of raw acceleration data for a complete trial is shown in Fig. 3.

3.2. Body posture in each behaviour

Based on the different acceleration values recorded on the surging axis, the following body postures could be determined by the component of gravitational acceleration: head-downward ($\leq -2.0\ m\ s^{-2}$), horizontal position ($-2.0 \ll 2.0\ m\ s^{-2}$), head-upward ($\geq 2.0\ m\ s^{-2}$; Fig. 1).

When the cat was resting (lying or sitting motionless), the acceleration profile was steady as maximum amplitude was less than $0.5\ m\ s^{-2}$. As soon as the cat moved, acceleration profiles showed a waveform whose characteristics depended on the magnitude of the activity.

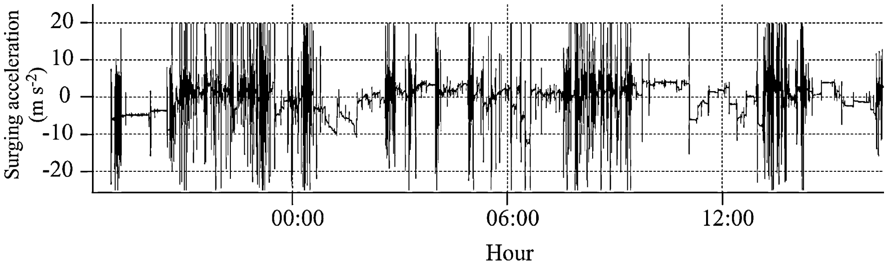


Fig. 3. An example of surging acceleration profile for a complete experimental trial.

A constant action, eating food for instance, corresponded to a cyclic and sinusoidal waveform. Eating, drinking, grooming, and travelling were determined by the posture and characteristics of the cyclic patterns in the acceleration profiles. Examples of waveforms and variables derived from the segment of acceleration profile of each behaviour are shown in Fig. 4 and Table 1, respectively. Estimation of body posture was important to identify the cat's behaviour, which was steady during some behaviours (slightly downward to horizontal position in eating, drinking, travelling) but varied when the cat was grooming (Table 1, Fig. 5).

3.3. Specific characteristics of acceleration profiles in each behaviour

3.3.1. Grooming

The cat groomed his whole body, firstly licking and scratching its neck with hind claws and washing its face with front paws, then progressing to the other parts of the body, with a corresponding change in its posture. On average, the range of the component of gravitational acceleration was 2.61 ± 2.47 m s^{-2} ($\bar{X} \pm$ S.D., $n = 107$, range 0.40–11.89 m s^{-2}). The maximum amplitudes of acceleration profiles were 4.15 ± 3.55 m s^{-2} (1.15–24.58 m s^{-2}).

The grooming pace was slow on the upper body parts, getting quicker on the lower ones, the face, and the forelegs, being maximum on the neck, with the characteristics of the cyclic patterns in the acceleration profiles varying accordingly. The frequency of acceleration spectrums during grooming ranged from 0 to 8 Hz (Fig. 4) with one to three marked peaks occurring on average at 1.95 ± 1.01 Hz ($n = 107$, 0.26–6.51 Hz) and the DSD being on average 1.53 ± 2.02 PSD (0.02–13.2 PSD).

3.3.2. Eating

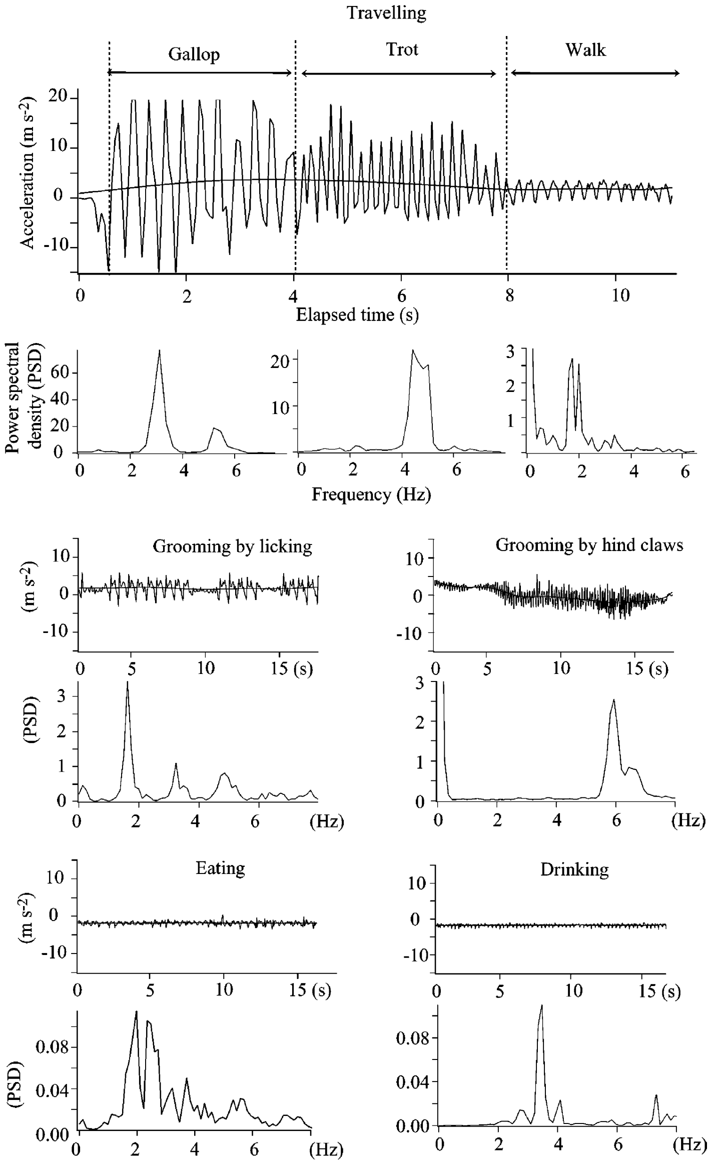
The cat eating canned wet food or large pieces of half-dried fishes adopted a horizontal steady posture, which corresponded to an average acceleration of -0.50 ± 0.40 m s^{-2} ($n = 33$, range: -0.86 to 0.39 m s^{-2}) and an average range of the component of gravitational acceleration of 0.43 ± 0.42 m s^{-2} (0.10–1.90 m s^{-2}). The maximum amplitude of acceleration profiles was on average 2.21 ± 0.91 m s^{-2} (0.87–4.90 m s^{-2}).

While eating wet canned food, the cat only moved his mouth for mastication, and thus the acceleration profiles showed a steady waveform (Fig. 4). In contrast, when eating large pieces of fish the cat needed to tear them apart using his forepaws before ingesting them, which led to an increase in the overall value of the acceleration.

While eating fish the cat masticated slowly with the mouth wide open, but when eating canned food, masticated at a higher pace but opened his mouth less. This resulted in a difference in the acceleration profiles between each type of food. Acceleration profiles of steady eating had one or two marked peaks occurring at 2.30 ± 0.58 Hz ($n = 33$, range: 1.01–3.89 Hz), with the DSD averaging 0.08 ± 0.04 PSD (0.003–0.18 PSD).

3.3.3. Drinking

When licking water in a bowl on the floor, the cat moved only its tongue, keeping a steady horizontal position. Small wiggles corresponding to each lick were visible in the acceleration profiles but their amplitudes were <1.0 m s^{-2}. Acceleration profiles during drinking showed one marked peak in frequency at 3.31 ± 0.15 Hz ($n = 11$) with remarkably low DSD: 0.04 ± 0.04 PSD.



Travelling

Grooming by licking

Grooming by hind claws

Eating

Drinking

Fig. 4. Profiles of surging acceleration and its derived posture of a cat; in traveling (slow down from galloping, trotting, to walking), grooming by licking and hind claws, eating cat food, and drinking water.

3.3.4. Traveling

Acceleration profiles during traveling were obtained for walk, trot, and gallop, as defined by the gaits (Alexander, 1982). At the slowest pace, walk is a four-beat gait in which three feet are always on the ground. The walking cat swang its fore- and hind legs on the same side more or less in phase. Walking velocity was unsteady in most cases, with the

Table 2
Data of the canonical discriminant functions (CDF) based on behavioural categories of a domestic cat

Function	1	2	3	4
Eigen values of CDF				
Eigenvalue	4.5420	0.6222	0.2278	0.0370
Percent of variance	83.7	11.5	4.2	0.7
Cumulative percent	83.7	95.1	99.3	100.0
Canonical correlation	0.9053	0.6193	0.4307	0.1888
Wilk's *Lambda*	0.0874	0.4842	0.7854	0.9643
x^2-value	565.5	168.3	56.0	8.4
d.f.	28	18	10	4
P	<0.00001	<0.00001	<0.00001	0.0773
Structure matrix of CDF				
Maximum amplitude	0.6870	0.0088	0.6567	−0.3109
DSD	0.6370	−0.6513	−0.1982	0.3615
FSD	0.3596	0.7723	−0.3046	0.4259
Range of posture	0.0456	−0.0119	0.8607	0.5069
Maximum amplitude	0.7482	0.2081	0.3923	−0.7285
DSD	0.5360	−0.6440	−0.3227	0.4845
FSD	0.4390	0.7486	−0.2659	0.4296
Range of posture	−0.2921	−0.0422	0.6941	0.8195
Group centroids				
Groom by				
Licking	−1.3251	−0.5055	0.3002	0.0238
Hind claw	1.1090	1.6669	1.3805	0.2353
Eat				
Cat food	−1.1767	0.1228	−0.7751	−0.1009
Fish	−1.2921	−0.3382	−0.4089	−0.5240
Drink water	−1.0316	0.6782	−1.1439	0.4326
Travel				
Walk	−0.3336	0.7318	−0.1215	0.0884
Trot	2.8491	1.2397	0.1875	−0.2488
Gallop	5.0715	−1.1837	−0.1964	0.0987

cat interrupting its walks to sniff around. At a faster pace, trot is a two-beat gait in which the opposite front and hind legs move forward together, covering long distances at a steady pace. At the fastest pace, gallop is a three-beat gait in which one set of legs on a diagonal move forward and land together while the other two legs advance and land separately. Galloping only occurred for short durations between trotting or walking activities. Galloping velocity was unsteady, as the cat rapidly accelerated or decelerated. An example of a series of travelling in which the speed gradually decreased from galloping, trotting, to walking, is shown in Fig. 4.

The mean of the component of gravitational acceleration during traveling corresponded to a constant surging acceleration, ca. 0 m s^{-2}. Most of the travelling corresponded to the cat adopting a horizontal posture but this changed when the cat jumped up or down, leading to an increase and a decrease, respectively, and an upwardly- or downwardly-oriented acceleration profiles, respectively.

3.4. Classification of the cat's behaviour

A CDA was carried out to distinguish the seven most frequent behaviours observed in our domestic cat: grooming by licking, grooming by hind claws, eating cat food, eating fish, drinking water, walking, trotting, and galloping (Table 2). Resting (lying or sitting motionless) and grooming by forepaw were excluded from the CDA because acceleration profiles during resting were easily distinguished from the rest as the maximum amplitudes of acceleration did not exceed 0.5 m s^{-2}; and because grooming by forepaw was extremely rare, resulting in a small sample size.

Following the CDA, independent variables, maximum amplitude, DSD, FSD, and range of the component of gravitational acceleration, were retained stepwise in this order ($\Lambda = 0.087$, $F = 28.4$, $P < 0.001$). The eigenvalue for each CDA function is an important factor indicating its power in distinguishing between different categories (Huberty, 1994). Table 2 shows that the first two functions are powerful differentiating dimensions because they account for high ratios of the total variance. The third and higher CDA functions can be ignored due to their low eigenvalues. Strong relationships between the first two CDA functions and their dependent variables also imply that the first two CDA functions can be used to distinguish different behaviours. The structure matrix shows the correlations of each variable with each discriminant function, indicating how closely a variable is related to each CDA function. The first, second, and third CDA functions were more strongly related to maximum amplitude and DSD, DSD and FSD, and the range of the component of gravitational acceleration, respectively.

Table 3 provides the CDA classification results based on the eight behavioural categories defined above. Overall, a classification accuracy of 57.3% was obtained. The classifications were archived with relatively high degree of accuracies for drinking (100%), eating fish (78.6%), trotting (78.3%), galloping (70.8%), and eating (68.4%), whereas many misclassifications occurred for grooming by licking, and by hind claw, and walking. Grooming by licking was often misclassified as eating fish, grooming by hind claws was always misclassified as grooming by licking, drinking, walking, and trotting. Finally, walking was often misclassified as eating and drinking.

4. Discussion

In the present study, we successfully monitored the detailed, fine-scale activity of a cat using acceleration data-logger. Based on the characteristics of surging acceleration profiles, we produced a model to discriminate some of the dynamic behaviours of a domestic cat using a CDA with four selected parameters. While some behaviours such as drinking, eating, trotting, and galloping were well distinguished, the acceleration profiles of some others still overlapped. This was especially the case for grooming and walking, which were often confused. In the case of free-ranging animals, the simultaneous measurement of different parameters may help improving the discrimination of the different behaviours (e.g. Yoda et al., 2001; Ropert-Coudert and Wilson, 2004). For instance, attaching an acceleration data-logger together with a VHF radio-tag or a GPS on a free-ranging animal would greatly help classifying and estimating the functions of each

Table 3
Classification results of the canonical discriminant analysis of behaviours of a domestic cat

Behaviour	Groom by		Eat		Drink	Travel			Total
	Licking	Hind claw	Cat food	Fish		Walk	Trot	Gallop	
Count									
Groom by									
Licking	49	1	0	39	4	4	0	0	97
Hind claw	1	3	0	0	1	1	1	0	7
Eat									
Cat food	0	0	13	2	4	0	0	0	19
Fish	0	0	3	11	0	0	0	0	14
Drink water	0	0	0	0	11	0	0	0	11
Travel									
Walk	3	4	6	10	5	15	1	0	44
Trot	0	2	0	0	0	2	18	1	23
Gallop	0	0	0	0	0	1	6	17	24
Percent									
Groom by									
Licking	50.5	1.0	0	40.2	4.1	4.1	0	0	100
Hind claw	14.3	42.9	0	0	14.3	14.3	14.3	0	100
Eat									
Cat food	0	0	68.4	10.5	21.1	0	0	0	100
Fish	0	0	21.4	78.6	0	0	0	0	100
Drink	0	0	0	0	100	0	0	0	100
Travel									
Walk	6.8	9.1	13.6	22.7	11.4	34.1	2.3	0	100
Trot	0	8.7	0	0	0	8.7	78.3	4.3	100
Gallop	0	0	0	0	0	4.2	25.0	70.8	100

behaviour derived from the acceleration records. Additionally, examining the succession of behaviour over time will help improve the discrimination, for instance, between grooming and walking since the former occurs during resting periods while the latter occurs during travelling periods that includes trotting and galloping, two behaviours which are accurately distinguished by our spectral analysis.

From the perspective of ethological and ecological studies of the cat family, hunting behaviours are probably most attractive since the family has evolved specialized hunting techniques (Kleiman and Eisenberg, 1973). In the present study, although we did not obtain information on hunting behaviour, we were able to reliably detect the eating behaviour of the cat, including prey handling time, with a high degree of accuracy. Detection of hunting behaviour should, none the less, be possible in the wild since cats gallop to attack a prey, following a period of seeking or ambushing (Leyhausen, 1982; Fitzgerald and Turner, 2000), activities which can be easily detected in the acceleration signals. For instance, the activity signals recorded by an accelerometer just before a eating session can reveal the hunting strategy of a cat: galloping and eating signals occurring after a long, motionless phase or after a session of walking/trotting phases will be typical of an ambushing predator or an opportunistic predator that capture prey occasionally during travelling. It may also be possible to obtain quantitative and qualitative information about the type of food ingested by the animal since, in our results, the characteristics of surging acceleration profiles were significantly different between food types. In herbivores, the use of an acceleration data-logger could prove particularly helpful in estimating the amount of grass grazed over time. However, this requires further investigations and calibrations performed on a case-by-case basis. Additionally, we were also able to determine accurately the drinking activity of our animal, a feature that has rarely been documented in wild felids (but see Sunquist and Sunquist, 2002) and other free-ranging terrestrial mammals.

Grooming, another behaviour that was detected in the acceleration profiles, is an important activity for rodents, bovids, and non human primates (Dewsbury, 1978; Wittenberger, 1981; Hart et al., 1992), as well as small felids (Eckstein and Hart, 2000a,b). Grooming in cats serves in conditioning the hair coat and removing excessive oil and ectoparasites (Eckstein and Hart, 2000a,b). Recent observations on domestic cats indicate that they spend 8 and 0.2% of their active time in self grooming by licking and by scratching with hind claws, respectively (Eckstein and Hart, 2000b), which is effective in removing fleas (Eckstein and Hart, 2000a). In spite of the potential importance of this behaviour, there is no report, to our knowledge, that quantitatively evaluated the grooming activity of free-ranging cats. Accelerometers, therefore, can bring substantial information on grooming activity of wild felids.

The present study proposes to classify behavioural pattern using spectral analysis. Further investigations should aim at producing an automatic analysis of this classification. Currently, we are investigating some algorithms for such an automatic classification of behaviour using the short-time Fourier Transform (STFT) and the continuous wavelet transform (CWT). Both algorithms have been used in signal processing analyses (e.g. Hogan and Lakey, 1995; Kıymık et al., in press). In an STFT, acceleration signals are divided into small sequential data frames and an FFT is applied to each sequence so that the output of successive STFTs can provide a time–frequency representation of the signal. The CWT can be regarded as an extension of the classic Fourier Transform, except that, instead of working on a single scale (time or frequency), it works on a multi-scale basis. This multi-scale feature of the CWT allows for the decomposition of a signal into a number of scales that depend on the duration of each behaviour. For instance, the CWT will be a more effective approach to detect brief behaviours such as jumping up and down.

Despite the obvious potential of data-loggers, difficulties are to be expected when applying this new device to free-ranging animals. For instance, attachments of external devices to animals may adversely affect their behaviours (see review in Ropert-Coudert and Wilson, 2004) and there are practical guidelines to reduce the negative impact of data-loggers on animals (e.g. Cuthill, 1991; Hawkins, 2004). In this regard, a proper design and the smallest possible size are preferable when attaching a device on an animal (White and Garrott, 1990; Samuel and Fuller, 1996; Kenward, 2001). For terrestrial mammals, devices are generally inserted in a collar weighing no more than 5% of an animal's body weight. Indeed, VHF radio-collars have been used widely for studies of free-ranging felids (Sunquist and Sunquist, 2002). In the present study, the accelerometers and the collar weighed ca. 35 g (1% of the cat's body mass) and did not seem to affect the cat behaviour, suggesting that the data-logger can be used for monitoring the behaviour of animals at least the size of a cat with a minimum impact.

In addition, individual differences in the characteristics of the acceleration profiles were not tested in the present study. However, acceleration data can be corrected depending on differences among individuals or trials. Thus, we recommend that the relationship between the animals' posture/behaviour and the acceleration signals should be calibrated on an individual basis before deploying a logger on a free-ranging animal.

Future advances in miniaturization, as well as following the proper guidelines to use bio-logging on wild animals, should help overcome most of these problems. Acceleration data-loggers appear, therefore, as a powerful tool to monitor the activity of free-ranging terrestrial mammals.

5. Conclusion

A new technique using a motion detector (acceleration data-logger) was developed to monitor activity and behaviour of free-ranging animals, and its efficiency was tested on a domestic cat. Acceleration data-loggers attached to a cat's collar recorded acceleration signals, which were influenced by both gravitational acceleration resulting from changes in the body posture and dynamic acceleration resulting from the dynamic activity of the cat. By applying spectral analysis based on a fast Fourier Transform (FFT) to acceleration signals recorded, body postures and some frequent behaviours of the cat can be efficiently distinguished. The present study shows that the acceleration data-loggers represent a useful and reliable system for accurately recording the activities and detail behaviours of terrestrial animals.

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