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The use of animal-borne cameras to video-track the behaviour of domestic cats

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ABSTRACT

Free roaming domestic animals can have a profound effect on wildlife. To better understand and mitigate any impact, it is important to understand the behaviour patterns of the domestic animals, and how other variables might influence their behaviour. Direct observation is not always feasible and bears the potential risk of observer effects. The use of animal-borne small video-cameras provides the opportunity to study behaviour from the animal's point of view. While video-tracking has been used previously to study specific aspects of the behaviour of a species, it has not been used so far to determine detailed time-budgets. The aim of this study was to provide and validate an ethogram based on cat-camera footage collected from 16 cats (*Felis catus*). The methodology was validated comparing films recorded simultaneously, from both collar-mounted video recorders and hand-held video recorders. Additionally, the inter-observer reliability of scorers was measured. Continuous and instantaneous recording regimes were compared, and behavioural accumulation curves were evaluated to provide further technique recommendations for video-tracking cats. Video-tracking allows scoring of behaviour as reliably as direct observation (linear mixed effects model: $t < 0.001$, $P = 0.99$; df = 14 in 7 cats; Cohen's $\kappa = 0.88$). Furthermore, inter-observer reliability was high (Cohen's $\kappa = 0.72$) and was not significantly different from 0.8 (one-sample *t*-test: t = 1.15. df = 5, $P = 0.30$), indicating that the method is not subject to bias in observers. Recommendations are given for the most efficient scoring protocol to reliably record feline behaviour. While the validation was concerned with cat behaviour, the approach can be easily adapted for a variety of domestic species, as well as some captive animals. Video-tracking offers a new avenue to investigate both general time-budgets and more specific behaviours such as foraging or space use from the animal's point of view and in its normal environment, without restrictions to movement. Insights gained through video-tracking will be relevant to various conservation and animal welfare issues.

1. Introduction

Domestic animals, if they roam at least to some extent freely, can have a profound effect on wildlife. For example, depending on the habitat and plant type, grazing by domestic herbivores might increase or decrease biodiversity (Hayes and Holl, 2003; Stahlheber and D'Antonio, 2013). Domestic dogs (*Canis lupus familiaris*) have been shown to negatively affect native wildlife by transmitting diseases, harassment, and killing of a wide variety of species (Young et al., 2011). Better documented, though not necessarily more severe, is the impact of predation by domestic cats (*Felis silvestris catus*, in the following simply 'cats'), in particular on island populations of birds (Medina et al., 2011)

To better understand, and potentially manage or mitigate, the influence of free-roaming domestic animals, it is important to understand their behaviour patterns, and how certain variables might influence the behaviour (Prache et al., 1998). Behaviour can sometimes be observed directly, but this can be unfeasible in many circumstances. Furthermore, behaviour can also be directly affected by the presence of human observers (Damasceno et al., 2016). Technological devices have strongly advanced our understanding of certain aspects of animal behaviour, for example ranging or habitat use behaviour by the use of VHS or GPS collars (Harris et al., 1990; Huck et al., 2008), activity patterns using accelerometers (Watanabe et al., 2005) and fixed position camera traps (Bengsen et al., 2011; Comer et al., 2018). The ranging behaviour of domestic cats has been studied to investigate differences of home-range sizes compared to wildcats (*F. s. silvestris*, Biró et al., 2004) and home-range sizes and habitat use depending on sex and season in an urban environment (Thomas et al., 2014). However,

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information on ranging behaviour gained through remote-tracking can shed light only on certain aspects of an animal's activity, and for a fuller understanding of the behaviour time budgets are needed. Cat behaviour has been studied extensively in captivity (e.g. Crowell-Davis et al., 2004; Damasceno et al., 2016; Leyhausen, 1975; Michael, 1961) and certain aspects, in particular ranging patterns, hunting behaviour, and some forms of social behaviour, also in free ranging cats (e.g. Biró et al., 2004; Fitzgerald and Turner, 2000; Macdonald et al., 2000; Natoli, 1985; Thomas et al., 2014). In fact, very extensive ethograms have been developed for cats (Stanton et al., 2015; UFAW, 1995). These studies necessarily covered only periods of times when the cats were directly visible to either human observers or fixed-position video cameras in a shelter (Damasceno et al., 2016). This essentially excludes the study of hunting behaviour of feral, stray and pet domestic cats that have the possibility to freely roam unsupervised. Yet, a more in-depth understanding of time-budgets is very important to assess the impact that the often large populations of free-ranging pet cats may have on small vertebrate populations in different areas of the world (Fitzgerald and Turner, 2000). Additionally, it may contribute to an improved understanding of general cat behaviour, for which research is lacking (Bradshaw, 2018). Lack of knowledge contributes to a substantial proportion of abandonments as well as returns to animal shelters (Casey et al., 2009), increasing the number of feral cats, which likely have a higher impact on wildlife than pet cats.

Relatively recently, researchers have begun to use small video cameras that can be worn on a collar around the neck of cats (in the following 'catcams'). This video-tracking has been used to either determine predation rates (Loyd et al., 2013b) or to evaluate certain aspects of cat behaviour deemed "risky", such as the crossing of roads (Loyd et al., 2013a). To date there is no published study that used the cat's-point-of-view footage to determine time budgets in a way that is comparable to direct observations. The aim of this study was therefore to adapt and validate an existing standardized ethogram of felids (Stanton et al., 2015) for the use on footage gained from cat cameras. A secondary aim was to provide advice on feasible and representative recording rules (*sensu* Martin and Bateson, 2007) to analyse catcam footage. Validating this approach for one species should open avenues to modify it for the use with suitable other animals.

2. Methods

To validate the use of catcams for behavioural data recording, two different approaches were used. For the actual validation, cats wearing catcams were simultaneously filmed using a camera. Secondly, inter-observer reliability (IOR) was calculated. To aid future studies, instantaneous recording was compared to continuous recording of the same film. Additionally, for the cat with the largest number of sessions accumulation curves were calculated to determine the minimum required sample sizes to obtain reliable estimates of behavioural time budgets.

2.1. Study subjects and device

Data were collected on 16 cats (Table 1). Data collection spanned the time between 14th June 2015 and 31st March 2019, but observation times varied widely between cats (Table 1). All but three cats were not personally known to the first author, and none was known to the second author. At irregular intervals, each cat was fitted with a cat-camera (Eyenimal cat videocam, in the following 'catcam'; Fig. 1). The devices weighed 32 g, which was less than 1% of the body mass of all of the cats. During periods of low light, the camera operates with infrared LEDs. When the camera is switched on, a blue light shines. To minimise possible influences on other animals, this light was covered with blu tack™ (a chewing gum like reusable adhesive), or adhesive tape, which, however, did not completely prevent the blue light from shining through behind the LED bulbs. These cameras also record sounds, enabling researchers to record cat vocalisations.

Table 1
Study animals participating in the video-catcam validation (V), comparison of continuous vs. instantaneous recording (R), and inter-observer reliability (IOR). A total of 7625 min (over 127 h) of footage was observed.

Cat	Sex, age (y)	Total observation time (min)	Number of sessions	Analyses
Alfie	M, 10	23	1	V
Esme	F, 9	387	3	R, IOR
Ivan	M, 4	433	4	R, IOR
Jet	M, 6	346	4	R, IOR
Kenny	M, unk.	21	1	V, IOR
Leyhausen	M, 1	10	1	V
Loki	F, 1	191	3	R, IOR
Mouse	F, unk	99	1	R, IOR
Nala	F, 5	88	1	V, R
Pauline	F, 14	45	2	V, R
Psycho	F, unk	94	1	R, IOR
Pushkin	M, 12	16	1	V
Rocky	M, 6	1529	17	R
Sooty	M, 8	171	2	R
Treacle	F, 2-4	4107	64	V, R, IOR
VanDerPuss	M, unk	65	1	R, IOR

Fig. 1. Cat 'Treacle' wearing a cat-camera.

2.2. Ethical note

For the use of radio-tracking devices it is often recommended that the total package should not weigh more than 5% of the animal’s body mass (NSW Department of Primary Industries and Animal Research Review Panel, n.d.). The catcam, including collar, weighed less than 1%

of all the cats' body masses. After few seconds or minutes of signs of irritation, the cats directly observed by the author showed no obvious discomfort wearing the collar with the camera (see videos of cat who wore cat camera for the first time, available at: https://www.researchgate.net/project/Use-of-cat-cameras-to-analyse-time-budgets). The owners of other cats participating in this study confirmed this impression. Some other owners, however, reported that their cats would show strong signs of distress, and these cats were removed from the study. Approximately 5 out of 21 cats, i.e. ca. 24% of cats did show distress signs; however, numbers were not recorded systematically. The cameras were attached to reflective collars with safety-buckle that would snap open if the cats were entangled, or on collars that the cats wore regularly outside this study. The investigation was approved by the College Research Ethics Committee for the College of Life and Natural Sciences of the University of Derby. Throughout the investigation, the guidelines for the treatment of animals in behavioural research and teaching and in applied animal behaviour research were adhered to (ASAB, 2014; Sherwin et al., 2003).

2.3. Data collection

Catcams were set to record films continuously, i.e. recording was not interrupted when the cat was stationary, which is an option with this camera. Individual films lasted up to 30 min, and up to five films (i.e. a total of 2.5 h) were recorded continuously, which is the limit due to storage and battery capacity of the device. Films that were more than two hours apart were considered separate sessions, and only sessions lasting at least 8 min were used (median duration of sessions: 77.4 min, mean: 71.0 min, only 14 videos (12%) lasted less than 20 min). A minimum of 8 min was chosen since this allowed to get at least 50 instantaneous recordings if using a 10 s interval (see below). In total, 107 film-sessions with 127.1 h of catcam footage were analysed.

2.4. Ethogram

Previously published ethograms for felids (Stanton et al., 2015; UFAW, 1995) were used to ascertain behaviours that might be identifiable from catcam footage. In ‘normal’ ethograms behaviours are defined by what a human can observe an animal doing. In contrast, when using a catcam the behaviour needs to be defined by what can be seen in the video ('footage') recorded from the animal's point of view, without seeing the animal itself. An indication of the behaviour performed might be obtained by the perspective of the footage, e.g. whether the footage is close or further away from the ground, or whether a particular part of the visible structures might be seen more from the left or from the right. For example, when an animal is lying down, this changes perspective vertically, while head movements might change the perspective horizontally. In contrast, walking changes the location, not just the perspective (see demonstration videos A1-A6, available at: https://www.researchgate.net/project/Use-of-cat-cameras-to-analyse-time-budgets).

For the analyses performed here, 21 behaviours were distinguished, some of which encompassed several more specific behaviours (Table 2): sleeping, lying, resting, walking, running (which includes trotting), jumping, pouncing, locomotion other than those previously mentioned, clawing, digging, exploring, pawing & manipulating object, hunting, eating, drinking, self-grooming, affiliative behaviour, agonistic behaviour, neutral social behaviour, vocalising, and other behaviours. Several other behaviours listed in the standardized felid ethogram (Stanton et al., 2015) were *a priori* excluded for this study, because they are unlikely to be reliably detectable from catcam footage (Supporting Material Table S1).

2.5. Data recording

Behaviour was scored using the Behavioral Observation Research Interactive Software vs. 4.1.4 (BORIS, Friard and Gamba, 2016). Behaviour was recorded instantaneously at 10 s intervals, and for some analyses continuously. The frequencies of rare behaviours (i.e. behaviours that were not observed in the majority of sessions) of short-duration were recorded continuously (all occurrence recording). Short events (e.g. jumping and vocalisation) were considered to last 0.5 s when calculating durations of each event for comparisons between continuous and instantaneous recording. BORIS calculated the total duration and total frequency of each behaviour per session. For continuous recording of durations, all behaviours were treated as mutually exclusive states, except carrying. From the original 10 s instantaneous recordings, the frequencies of behaviours were also recalculated assuming that data were recorded every 20 s, 30 s, or 60 s instead of every 10 s.

2.6. Validation of catcam ethogram

To validate whether it was possible to identify various behaviours reliably based on catcam footage, seven cats were filmed using a Canon G10 camera or smartphones ('video') whilst wearing the catcams (Table 1). These videos (and parallel catcam footage) covered a total of 238.1 min (mean per cat: 34.0 min, median per cat: 21 min), always during daytime.

Based on instantaneous data recording at 10 s intervals on both the videos and the catcam footage, it was determined whether the assigned behaviour based on the catcam agreed with the behaviour identified on the video, using a linear mixed model with GLS extension. The percentage of the behaviour was the dependent variable, and type of recording (video or catcam) and behaviour the independent fixed factors. Cat identity, with recording type nested within cat identity, was taken as random factor, with different variance structures for each cat. This and all other analyses were performed using R vs. 3.2.2 (R Core Team, 2015), using package nlme (Pinheiro et al., 2015). Additionally, concordances were calculated for each individual cat, by dividing the number of agreements by the total number of instantaneous records, as well as Cohen's κ (Cohen, 1960). Following classifications by Landis and Koch (1977), κ-values of 0.61 – 0.80 were considered "substantial" and values above 0.81 as "almost perfect".

2.7. Inter-observer reliability (IOR)

Two methods were used to quantify IOR. In a pilot study, an unexperienced person, a high school pupil aged 15, with no prior experience in recording of animal behaviour, was given a document with instructions (Electronic Supplement A1), and three training videos that covered all behaviours recorded (apart from hunting, which had not been observed at that time). After completion of these training videos, some further explanations were given. The pupil was then given 12 videos (total video time: 14h29 min) from a total of nine cats for scoring.

Main IOR analyses were carried out between the two authors on a total of six cats. The second author received feedback after each of the three training videos, and the final sampling protocol and final ethogram was slightly adjusted based on the joint experience. The concordances, as well as Cohen's κ between the pupil's or second author's and the first author's scoring at the exact timings were calculated for each video in the same way as described above for the validation. The Cohen's κ values were tested in a one-sample *t*-test against the value of 0.8 (considered to indicate very good agreement; Landis and Koch, 1977). Because exact matches cannot always be expected, due to split-second decisions when the behaviour changed exactly at the recording time, we also calculated whether estimated overall percentages of each behaviour differed between the observers, using paired Wilcoxon signed rank test (because samples were not normally distributed but showed homogeneity of variance; Bartlett-test: $K^2 = 0.009$, df = 1, P = 0.92), with observer as independent variable.

Table 2
Ethogram of domestic cat behaviour that can be identified through cat camera video footage. Original definitions of the behaviour ('Title') are taken from Stanton et al. (2015). Behaviours in bold are modified to combine several categories from previous ethograms. The last but one column indicates whether the behaviour has been observed (O) and validated (V) in this study, and the last column refers to videos portraying the behaviour, available at https://www.researchgate.net/project/Use-of-cat-cameras-to-analyse-time-budgets. Some further behaviours that might be distinguishable but were not observed in the available footage are defined in the supplementary Table S2.

Behaviour ('Title')	Corresponding title in UFAW (1995)	Definition from Stanton et al. (2015)	Definition for catcam footage & notes	Obs./val.	Video
Approach	Approach	Cat moves towards (modifier) while looking at it.	Due to the limited perspective, using this for other than approaches to other animals (in particular cats and humans) will be difficult. For approaches to animals: the (modifier) is visible and comes more and more into focus.	O	A3
Avoid	Avoid interaction	Cat moves, or changes direction while moving, in order to keep away from (modifier).	Needs to be determined circumstantially: After a period of →STARING, cat changes direction. The gait may be peculiarly slow, indicated by very slow but uneven movements. Will be difficult to ascertain in some circumstances due to the perspective (narrow angle of the camera's vision).	O	A3
Body shake	NA	Cat rotates its abdomen from side to side.	Footage shakes, oscillating back and forth and "shaking" noises can be heard.	O	A2
Carry	NA/Retrieve kitten/Bring food	Cat picks (modifier) up off the ground and moves it to another location.	(Modifier) can be seen (in parts) hanging in front of camera. This might depend on size of (modifier). Just previously, the footage indicates that the cat had been moving towards the (modifier).	O	A4
Charge	NA	Cat rushes towards (modifier)	(Modifier) gets rapidly in closer view (indicated by shakiness of footage), but not necessarily up to body contact (compare →ATTACK and →CHASE)	O	A3
Clawing	Object scratch	Cat drags front claws along an object or surface, likely leaving visual marks behind.	Extended forelegs visible and alternate movement by both front legs can be seen. Scratching noises might be heard.	**V**	A5
Climb	Climb	Cat ascends or descend an object or structure	The object or structure is very close to the camera and a vertical movement along this object can be seen.	O	A5
Dig	(Object cover)	Cat breaks up or moves substrate around with its paws.	Digging can be inferred from a combination of occasional visibility of paws, sounds indicating digging, and a footage that is shaky but does not change location.	O	A5
Displace	(avoid interaction/retreat)	Cat provokes an avoidance behaviour from another cat.	Footage initially shows other cat and then shows that this cat changes direction or retreats. Might be difficult to ascertain in some circumstances.	O	A3
Drink	Drink	Cat ingests water (or other liquids) by lapping up with the tongue.	Footage might show the close-up of drinking source or the ground or the chin of the cat. Lapping sounds can be clearly heard.	O	A5
Eat	Feed	Cat ingests food (or other edible substances) by means of chewing with the teeth and swallowing.	Footage might show the close-up of the food source or the ground or also commonly the chin of the cat. Feeding sounds can be heard	**V**	A5, A4
Explore (incl. Investigate & Sniff)	Explore	Explore: Cat moves around attentively while sniffing the ground or object. Investigate: Cat shows attention toward a specific stimulus by sniffing or pawing at it. Sniff: Cat smells (modifier) by inhaling air through the nose.	Very close-up of object or substrate (modifier could be used) with a very slowly changing perspective and also commonly the chin can be seen. Cannot be distinguished from →SNIFF or →INVESTIGATE, so these are included here.	**V**	**A1, A4**
Flee	Flee	Cat runs away from (modifier)	Can only be determined circumstantial: (Modifier) has been in view before this behaviour starts and this is then followed by →RUNNING.	O	A3
Follow	Follow	One cat travels closely behind (modifier)	(Modifier) stays in view but change of perspective indicates movement. Only following by the focal cat can be detected, since footage cannot show what is behind the focal cat.	O	A3
Forage	Forage	Cat searches for food or other edible substances.	Can be similar to EXLORE in that the footage is very close up, but in such cases much faster changes, more blurred. Noises like scratching or snuffling might be heard. Footage may for example show short quick pounces and use of paws in undergrowth.	O	A4
Groom	Groom self (excluding scratching)	Cat cleans itself by licking, scratching, biting or chewing the fur on its body. May also include the licking of a front paw and wiping it over one's head.	Close up of focal cat's fur or chin, with fairly rhythmical movements visible, consistent with the licking movement, or the repeated passing of a front paw in front of the camera. Licking noises might be audible. This includes anogenital grooming, which cannot be distinguished from other forms of grooming using video footage.	**V**	A2
Hunt	(Forage)	Cat actively pursues live prey. Includes movements such as crouching, stalking, or any other species-specific behaviours.	Circumstantial evidence may be needed. Can be similar to FORAGE, but prey is at least intermittently visible, e.g. movement following previously caught prey. Movements are quicker than in STALKING.	O	A4, A6

(*continued on next page*)

Table 2 (*continued*)

Behaviour ('Title')	Corresponding title in UFAW (1995)	Definition from Stanton et al. (2015)	Definition for catcam footage & notes	Obs./val.	Video
Jumping	NA	Cat leaps from one point to another, either vertically or horizontally.	The footage changes rapidly and might be blurred, and afterwards the perspective is either from a conceivably higher or lower angle than previously. Since a horizontal jump cannot be distinguished from a short bout of running or a pounce, this definition includes only vertical jumps.	**V**	**A1**
Lying	Lie (various positions distinguished)	Cat's body is on the ground in a horizontal position, including on its side, back, belly, or curled in a circular formation.	The perspective indicates closeness to the ground/substrate. In slight contrast to the original definition, this only includes alert lying. While the footage cannot prove that eyes are open, the frequent slight changes of perspective indicate head movements. Very tilted angle might indicate that cat is lying on its side or back.	**V**	**A1**
Manipulate object		Cat uses any part of body to touch, hold, move, or pick up, an object.	(Modifier) occasionally in view, as well as possibly paws. Often very close-up footage. More movement (and noise) than with →EXPLORE. If prey (incl. arthropods) in view, use FORAGE.	**V**	A5
Other	NA	Any behaviour that does not fit into one of the descriptions provided.		O	
Paw	Paw	Cat pats (modifier) with its forepaw(s). Claws are usually retracted.	Front paw(s) are visible, resting briefly or for a longer period of time on (modifier). It is unlikely that it can be seen whether claws are retracted or extended. Movements slower than for cuffs (Supp. Table S2) and not in an agonistic context.	**V**	A4
Pounce	Pounce	Cat leaps onto (modifier)	Sudden horizontal, but very shaky change of footage, including a movement away from the ground followed by getting closer to the ground again. (modifier) might have been seen before or after or during pounce. The pounce typically ends at the location where the (modifier) was prior to the pounce. Front paws might be briefly visible.	O	A4
Rear	Object rear / Rear at cat	Cat stands up on its hind legs with forelegs toward or against (modifier).	Initial vertical change of perspective for a prolonged (at least some seconds) period of time, i.e. then little change of perspective, close-up of (modifier)	O	A5
RESTING ALERT	(Passive explore / Sitting / Standing)	Sitting: Cat is in an upright position, with the hind legs flexed and resting on the ground, while front legs are extended and straight. Standing: Cat is in an upright position and immobile, with all four paws on the ground and legs extended, supporting the body.	The perspective of the footage suggests that cat is not lying low. Since it is difficult to distinguish between SITTING and STANDING just based on the perspective, these original behaviours are combined into this new behaviour. Video footage does not show change of location, but slight changes in perspective may indicate head movements. Crouching (all paws flat on the ground but with a raised chest) is included here. This is the most ambiguous aspect of Resting, since it can be confused with - > Lying.	**V**	**A1**
Roll	Roll	While lying on the ground, cat rotates body from one side to another. During the roll, the back is rubbed against ground, the belly is exposed and all paws are in the air. Cat may continue rolling repeatedly from side to side.	Change of perspective whereby footage might include the sky/ceiling. Paws might come into view for brief moments.	**V**	A5
(Fast) Running	Trotting / Run	Trot: Forward locomotion at a swift gait performed with alternating steps. Movement is faster than walking but slower than running Run: Forward locomotion in a rapid gait, which is faster than walking or trotting.	The footage changes rapidly (indicating change of location) and is shaky to very shaky (because the camera swings with the body movements of the cat). With trotting, the movement of the footage is mainly sidewise, while for running it is rather following a galloping/cantering movement, i.e. both up and down and sidewise.	**V**	**A1**
Scratching	Groom self	Cat scratches its body using the claws of its hind feet.	While the scratching itself is unlikely to be seen directly, the rapid shaking of the footage and scratching sounds allow identifying the behaviour.	**V**	A2
Sleeping	Sleep (& Rest)	Cat is lying on the ground with its head down and eyes closed, performing minimal head or leg movement, and is not easily disturbed.	Video footage is very still and close to the ground/surface, or might only show fur of cat for an extended period of time. 'Extended' is here defined as 'at least 90 seconds', i.e. if the "Lying alert" does not change perspective of footage for 90 s the recording is switched to Sleeping. Once a sleeping bout has been identified, there might be brief changes in the position of the body when the cat briefly wakes up to find a different posture. Sleeping will then again be recorded if the new posture has not changed for 40 s. **Note:** It should be noted that "sleeping" implies a certain state of consciousness. Our definition of "sleeping" should probably more cautiously be called "inactive for prolonged periods of time", because without seeing the eyes of the cat and breathing patterns, real sleep should not be assumed.	**V**	**A5**

(*continued on next page*)

Table 2 (*continued*)

Behaviour ('Title')	Corresponding title in UFAW (1995)	Definition from Stanton et al. (2015)	Definition for catcam footage & notes	Obs./val.	Video
Stalk	Stalk	Slow, forward locomotion in a crouched position directed toward (modifier), with head kept low and eyes focused on (modifier).	Video footage shows at least intermittently the (modifier). Footage shows at slow changes of location, generally towards the (modifier). The perspective indicates that the head of the cat is close to the ground (i.e. close-up of ground surface/vegetation).	O	A4
Stare-hunting		Cat gazes fixedly at (modifier) and is not easily distracted. In the case of social stare, gaze may be directed at another cat's eyes.	Potential prey is visible and footage is centred clearly on this animal.	O	A4
Stare-social		Cat gazes fixedly at other cat and is not easily distracted. In the case of social stare, gaze may be directed at another cat's eyes.	Other cat is visible and footage is centred clearly on this cat.	O	A3
Stretching		Cat extends its forelegs while curving its back inwards.	Perspective indicates a change from a slightly higher position of the head to one close to the ground, with front paws both visible.	O	A5
Touch noses (incl. Sniff cat)	Touch noses & Sniff cat	Touch noses: Two cats sniff at and touch each other with their noses. Sniff cat: Two cats smell the nasal regions of each other.	Increasingly closer view of face or chest of other cat until only fur can be seen. (Includes SNIFF NOSE)	O	A3
Vocalize	**Sounds**	Cat produces sounds or calls, originating from the throat and mouth.	If cat camera has a microphone included, vocalizations can be clearly heard. It might be difficult to distinguish who made the sounds if another cat is at close distance.	**V**	**A4, A5**
Walking	**Walk**	Forward locomotion at a slow gait.	The footage changes perceptibly in one direction with very little swinging (shakiness) of the footage, but some up and down movements.	**V**	**A1**
Watch		Cat observes a specific stimulus (or modifier).	Might be difficult to distinguish from →STARE, so here is made a context specific difference: WATCH is only used for non-prey, non-cat (modifiers), e.g. insects or dogs. The footage is similar to →RESTING, →LYING ALERT or →EXPLORE, but a (modifier) is visible.	O	A4

2.8. Determination of Best recording regime

In order to determine for which cat behaviours instantaneous recording (with intervals of 10, 20, 30 or 60 s) offers a reliable alternative to continuous recording, the total durations of behaviours recorded continuously, and the frequencies recorded instantaneously were converted into proportions for each session. This was done for the nine most common state-like behaviours as well as for two very common event-type behaviours, i.e. vocalising and jumping. *A priori* power analyses indicated that in order to detect a medium effect size (i.e. a Cohen's d of 0.5, with a power of 0.8, and an alpha level of 0.05) a sample size of at least 33 was needed. A total of 95 sessions were used, covering 112.9 h (Table 1), but not all sessions were used for all behaviours, and continuous recording for state behaviours was done for no more than 57 sessions to reduce the time necessary to watch the videos.

The behaviours hunting, pouncing, social interaction (combining affiliative, agonistic and neutral behaviours) and others (which included drinking) were observed in between 18 and 24 sessions. The effect of sampling rule (continuous vs. instantaneous recording) on the percentage time performing a particular behaviour was evaluated in linear mixed models with video session nested in sampling rule nested in individual cats, who were considered random factors. For most tests, an increase of variance with increasing fitted values was modelled.

2.9. Behaviour accumulation curves

Finally, we determined the minimum number of sessions necessary to get accurate representation of various (common and rare) domestic cat behaviours for the cat with most observations. For this, we created accumulation curves of the number of sessions against the cumulative mean of each continuously recorded behaviour for the eleven most common behaviours. These behaviours included resting, walking, exploring, lying, sleeping, hunting (incl. foraging, hunting, and staring at prey), running, grooming (incl. scratching, body shake and licking), social (all neutral, socio-positive and agonistic behaviours combined), investigating (pawing and manipulate object), and eating, as well as jumping and vocalising. These latter two behaviours occurred in most sessions, albeit at low frequencies per session and had very short total durations.

3. Results

3.1. Validation of ethogram

Thirty-six behaviours were observed during the 127.1 h of recorded behaviour, 15 of which were also simultaneously filmed for direct validation (Table 2). Catcam footage allowed reliably identifying many behaviours commonly shown by cats (linear mixed effects model: $t < 0.001$, $P = 0.99$; df = 14 in 7 cats). Concordances (range: 0.82 – 0.95, mean = 0.89, median = 0.91) and Cohen's κ (range: 0.62 – 0.94, mean = 0.83, median = 0.90; overall κ = 0.88) indicated excellent agreement between video and catcam scorings.

Additionally, the comparisons of continuous and 10 s instantaneous recording (see next section) can be viewed as further evidence of the feasibility to distinguish behaviours. The instantaneous recording was conducted independently from the continuous recording, so that, if behaviours were too difficult to distinguish, less concordance would be expected. In fact, preliminary analyses had led to some adaptations of the original ethogram (Stanton et al., 2015), leading to categories that were easier to distinguish (Table 2). Short, annotated videos (both from video and from cat-camera footage) of the observed behaviours and three longer videos (ca. 30 min each), compiled in a way to include all observed behaviours that would allow to establish inter-observer reliability, can be accessed at https://www.researchgate.net/project/Use-of-cat-cameras-to-analyse-time-budgets.

3.2. Inter-observer reliability (IOR)

Inter-observer reliability was good even between an experienced scorer (MH) and an unexperienced observer with minimal training, with mean concordance values of 0.68 (median: 0.73; range: 0.47 – 0.93, N = 12 sessions on 9 cats, with a total of 5159 events) for the common behaviours and mean concordance of 0.89 (median: 0.94, range: 0.62–1.0, N = 12 sessions on 9 cats, with a total of 200 events) for rare, event-type behaviours. Between two experienced scorers (the two authors), mean concordance values were 0.77 (N = 6, range: 0.66 – 0.87). Even more importantly, Cohen's kappa indicated substantial to excellent agreement with an overall value of 0.72 (range = 0.41 – 0.81, N = 6 cats, 2525 events). The lowest value stems from a session that was scored first after the training videos, after a break of more than 6 months. These values did not differ significantly from a threshold value of 0.8 (one-sample *t*-test: t = 1.15, df = 5, p = 0.30). Estimated proportions of behaviours for each cat did not differ between observers (paired Wilcoxon test: W = 4751, N(pairs) = 97, *P* = 0.90).

3.3. Determination of best recording regime

According to the classification by the package 'effsize' in R (Torchiano, 2017), effect sizes for state-like behaviours with respect to the difference between estimated proportions of behaviours recorded either continuously or instantaneously at 10 s intervals were usually negligible (smaller than 0.2) or small (smaller than 0.5; Table 3; see Fig. 2 for examples). Despite the very similar means for continuous and instantaneous recordings of grooming, and rather small effectsize (Cohen's d = 0.22, Table 3), the linear mixed model with increasing variance structure indicated a significant difference between the recording methods, while other tests (mixed models without adjusting the variance, paired Wilcoxon signed rank test, paired *t*-test) and boxplots (Fig. 2b) did not suggest a systematic difference. Similarly ambivalent were the results for other types of locomotion (i.e. apart from walking and running) and clawing. The common event type behaviours jumping and vocalisation could not be reliably represented using instantaneous recording (Table 3). Several of the most common behaviours could even be reliably estimated at 60 s intervals, but some behaviours (eating, lying, running) were only reliably recorded with up to 20 or 30 s intervals. While the calculated Cohen's d for the event-type behaviours vocalization and jumping were considered negligible or small, variances for instantaneously recorded behaviour was much higher than when recorded continuously. This meant that in many sessions no vocalisations or jumping were recorded with instantaneous sampling, but in the cases it was recorded, the calculated proportional time spent on these behaviours was often overestimated.

3.4. Behaviour accumulation curves

Accumulation curves indicated that for the four most common behaviours (resting, walking, exploring, lying) a stable mean percentage was reached after about 15–20 sessions (Fig. 3a). Hunting, running, and combined social behaviours reached a stable point after 35 sessions, while sleeping (recorded only during 15 sessions, 9 of these in the last nine sessions) and grooming, after having also reached an apparent plateau at this point, started to increase again after session 47 (Fig. 3b). Frequent event-type behaviours such as jumping and vocalising reached a fairly stable mean percentage also at about 40 sessions (Fig. 3c). Eating (recorded in 23 of the sessions) and investigating (mainly: opening the cat flap, recorded in 27 of the sessions) also reached a fairly stable mean after 40 sessions.

Table 3
Test statistics for linear mixed effects models comparing proportions of behaviours recorded continuously or with instantaneous recording every 10 s, 30 s, or 60 s. For each behaviour only the values for the highest recording interval that was non-significant are shown (or the result of a 10 s sampling interval if that is already significant). A full table can be seen in the Supplementary Table S3. Cat identity was modelled as a random factor, with video number nested within recording type (continuous or instantaneous) nested within cat, which makes this equivalent to a paired test.

Behaviour (*N* of cats/videos)	Recording method	Mean (of means per cat)	Cohen's *d*	*t* value	*P*
Walking	continuous	11.1			
(12/57)	Inst 60 s	9.9	0.17	0.98	0.35
Fast running	continuous	0.91			
(11/57)	Inst 30 s	1.14	0.15	1.3	0.19
Exploring	continuous	7.0			
(12/57)	Inst 60 s	9.0	0.23	0.58	0.58
Resting	continuous	44.1			
(12/57)	Inst 60 s	43.3	0.0009	0.002	0.99
Lying	continuous	19.5			
(12/53)	Inst 30 s	19.3	0.28	1.9	0.065
Sleeping	continuous	20.3			
(7/37)	Inst 60 s	20.5	0.02	0.61	0.55
Grooming	continuous	6.9			
(12/63)	Inst 10 s	6.8	0.23	0.28	0.78
Jumping	continuous	0.07			
12/89	Inst 10 s	0.22	0.20	3.9	**< 0.001**
Eating	continuous	2.5			
7/44	Inst 20 s	2.6	0.11	1.6	0.11
Vocalization	continuous	0.15			
10/71	Inst 10 s	0.30	0.27	2.2	**0.033**
Social	continuous	1.39			
9/24	Inst 60 s	1.58	0.16	1.8	0.086
Investigate	continuous	0.40			
5/55	Inst 30 s	0.53	0.15	1.49	0.14
Hunt	continuous	4.4			
3/23	Inst 60 s	1.9	0.17	1.24	0.23
Clawing	continuous	0.16			
7/24	Inst 10 s	0.19	0.25	2.2	**0.043**
Digging	continuous	0.31			
6/22	Inst 10 s	0.41	0.27	0.89	0.39
Locomotion (other types)	continuous	0.49			
8/30	Inst 10 s	0.47	0.33	3.3	**0.003**

4. Discussion

4.1. Validation of approach

Small cameras borne directly by study animals offer a reliable alternative to direct observation, allowing the collection of behavioural data on domestic, and possibly other amenable species. In the current case of domestic cats, with 36 observed behaviours it was possible to distinguish a much larger number of behaviours than originally anticipated. An additional 19 behaviours from Stanton et al. (2015) were not present in this study, but are likely to be detectable (Supplementary Table S2). For example, neither sexual nor infant care behaviour were observed, since all participating cats had been neutered. Both the actual validation, comparing catcam footage with videos of the cat, and the good agreement between observers indicate that scoring behavioural time-budgets based on catcam footage is feasible and reliable. Furthermore, video-tracking could minimise observer effects.

The potential problem of observer effect when investigating the cat behaviour has been demonstrated in a study showing increased feeding behaviour in shelter cats when a familiar human is present, compared to times without (Damasceno et al., 2016). It is further supported by anecdotal observations during this study. While sample size of video-

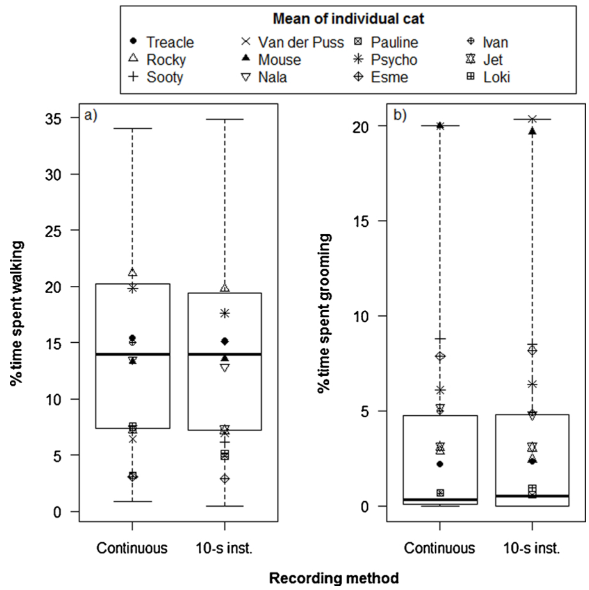

Fig. 2. Comparison of continuous and 10 s- instantaneous recording for two representative behaviours: walking and grooming. Boxes represent the upper and lower quartiles, whiskers show the range. The thick line represents the median. Symbols indicate the means for individual cats.

filmed behaviour was not large enough to allow a rigorous analysis, qualitative comparisons strongly suggested that at least the best studied cat in the sample was less active outdoors when her human was present than when she was on her own. Likewise, on one occasion, during an interaction with a neighbouring cat that had lasted several minutes, including an affiliative nose-to-nose contact, the neighbouring cat suddenly ran away on the human's approach. This indicates that social interactions between cats are also likely to be influenced by the presence or absence of humans.

4.2. Recommendations for the collection of cat behavioural data

While the comparison between filmed behaviour and behaviour recorded from catcam footage, as well as the high inter-observer-reliability, clearly showed that many behaviours can be distinguished, it should still be noted that behaviours recorded from catcam footage are more likely to be misidentified, in particular if a very detailed ethogram as that of Stanton et al. (2015) is used. In an agile species like the cat, some behaviours like resting, crouching and lying, or stalking, walking, trotting and running are on a fluid scale, and difficult to exactly distinguish based just on catcam footage. This can be partly circumvented by combining similar categories if the distinction is of no particular interest to the study, or by using the context of previous and following behaviours. With video footage it is easy to go back and forward in time, and programmes such as BORIS (Friard and Gamba, 2016) allow easy editing of records.

If catcams are used to study cat behaviour it is recommended to use a mixture of continuous and instantaneous recording. As this analysis demonstrates, common states such as lying, resting, exploring, or walking can be represented accurately using instantaneous recording with 1 min intervals. Rare states, however, are more reliably recorded using shorter intervals (e.g. eating, grooming). If they are of special interest (e.g. social behaviour, hunting), they will be better represented using continuous recording of durations. Some behaviours, while of a measurable duration, still have an event type character, where the duration has little meaning in itself (e.g. approach, avoid, clawing). Such behaviours, and also true event-type behaviours (e.g. jumping, vocalization) should be recorded continuously as frequencies (all-occurrence). For a suggested protocol see Supplement B. Unless only very rough time-budgets are intended, a minimum of 40 sessions per individual are recommended, given that the majority of behaviours reached a stable cumulative mean by this time, although for the most common states as few as 15 might be sufficient.

4.3. Potential applications for cat studies

An improved understanding of time-budgets and behaviour in general of domestic cats would be important in various areas. Video-tracking has been used to determine predation rates (Loyd et al., 2013b), but to date it has not been used to investigate how hunting behaviour is affected by the habitat type. For this, general behavioural profiles or time-budgets could be combined with information on both habitat types and predation rates. This could allow development of predictive profiles that could help identify high-risk cats. Previous studies have shown that there are large inter-individual differences in predation rates and prey preferences (Moseby et al., 2015). A better understanding of factors increasing predation risks would therefore make attempts to reduce predation on wildlife more efficient. Before

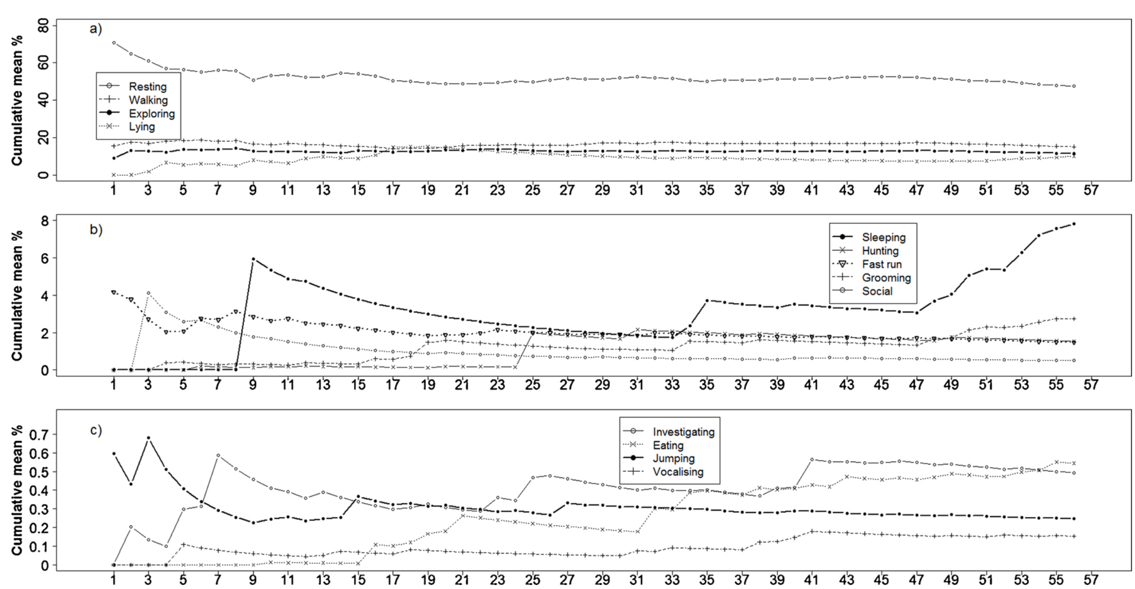

Fig. 3. Cumulative mean percentage of behaviours over successive sessions.

the impact of cats on wildlife is studied using video-tracking, however, it needs to be tested whether the device is likely to affect predation rates or success rates (see section 4.5 Caveats).

Predation pressure by cats is very likely higher from individual feral cats than individual pet cats, even if these do hunt to some degree. Reducing the number of cats that are abandoned is therefore important both from an animal welfare perspective and a wildlife conservation perspective. Misinterpreting cat behaviour is a common reason for relinquishing cats or returning them to shelters (Bradshaw, 2018; Casey et al., 2009). Understanding the behavioural repertoire of cats, both indoors and outdoors, with and without humans or conspecifics present, will provide greater insight to cat welfare needs.

As a final example how video-tracking could increase understanding of the species, catcam footage contained a variety vocalisations. Even vocalisations as ubiquitous as the purr remain poorly understood (Brown and Bradshaw, 2014), which in turn, can lead to human misinterpretation of the message contained therein. Studying vocal behaviour, with or without the presence of humans and conspecifics, will shed further light on the evolution of the communication in cats, as well as elucidating the context in which different types of vocalisations are made (Bradshaw et al., 2012, Chapter 9).

4.4. Applications for other species

These recommendations and potential applications are obviously very specific to the behaviour of domestic cats. However, the approach can be applied widely. A number of studies using small animal-borne cameras have been conducted, for example, with New Caledonian crows, *Corvus moneduloides* (Rutz et al., 2007). While the short battery life and limited storage capacity of animal-borne video cameras makes the approach currently unfeasible for most wild species, many animals that can be easily handled on a daily basis could be fitted with such animal cameras. For example, zoo professionals are often interested in the behaviour of animals outside visitor times in order to better assess behavioural problems and other welfare issues (Hosey, 2000). In some cases, fixed cameras can be used (e.g. Hogan et al., 2009), but depending on the number of cameras installed and if animals are allowed a more varied environment, this might not be suitable, and animals may be often out of view of the cameras (Carlstead, 1991). For species that are tolerant of frequent human handling, e.g. some ungulates or smaller primates of at least 640 g body mass (so that the weight of the cameras is less than 5% of the body mass), animal-borne cameras might be a feasible way to study some aspects of social interactions and space use, comparing times when humans are or are not present.

Furthermore, in a quite different context, habitat conservation managers frequently use cattle, sheep, or horses for low-intensity grazing regimes to preserve certain habitat types such as semi-natural mesic (Pykälä, 2003) or mesotrophic grasslands (Stewart and Pullin, 2008). This can lead to conflict of interest if it is not well established whether particular rare plant species or sensitive areas are preferred by the animals, since herbivores might exhibit partial food preferences that can also shift depending on the plant diversity (Wang et al., 2011). A camera might allow to determine not only which sections within a protected area are particularly frequently visited, but also which plant species are encountered or eaten. Grazing behaviour has already been studied in sheep using such devices (*Ovis aries*; Terra-Braga et al., 2018).

More generally, the footage viewed for this study already allowed to distinguish some rough habitat types (garden, shrub, backyards, in-house) and so studies linking behavioural profiles to different habitat types are possible. Such studies have been conducted previously using direct observation or radio-tracking of animals, for instance, finding that urban badgers (*Meles meles*) preferentially use gardens for foraging, while scrubland and allotments were used for travelling (Davison et al., 2009).

4.5. Caveats

Despite the potentially broad applicability, a few points should be kept in mind. For mini-cameras such as the ones used in this study, battery life is obviously limited, so that in the best case, recording sessions lasted for 2.5 h. However, if researchers wish to study comparatively rare behaviour like predation by cats (Loyd et al., 2013b), a large number of films have to be recorded. We did not find at the time commercially available, suitable light-weight cameras with longer battery life, but this might change in the future. Furthermore, the blue light emitted might actually affect other wildlife, such as potential prey, and either attract them to the light, making them more susceptible to predation, or make them aware of the approaching cat and thus leading to underestimates of predation rates. Many rodents and shrews have S-cones that have their highest sensitivity in the blue to ultra-violet range and thus can see blue light to some extent, although in more nocturnal species like house mice, *Mus musculus*, this tends to be shifted more towards ultra-violet (Jacobs, 2009; Peichl, 2005). Additionally, the cameras, even if small and lightweight, might still hinder the animal in at least some of its movements. If these cameras are to be used in the context of predation this requires further evaluation to see whether it affects predation success. Preliminary evaluations seem promising, though, as two cats (Treacle and Rocky) were recorded depredating (a woodmouse, *Apodemus sylvaticus*, and a bank vole, M*yodes glareolus*, respectively). Based on preliminary calculations (not shown), this number of successful hunts recorded with catcams for these two cats is in line with expected predation based on prey diaries. Obviously, this needs to be tested on more cats and more video footage time, also taking into account season and time of day, as these strongly influence predation patterns (Blancher, 2013).

While direct qualitative observation of the cats used in this study did not suggest that they felt uncomfortable or changed their behaviour, trials on some other cats showed that some cats are not tolerant of wearing collars, and possibly even less so with a device attached. This may potentially lead to bias, whereby data are collected only by "compliant" individuals, which may show differences in other aspects of their behaviour. However, in our experience, about three-quarters of cats accepted the collar, so the possible bias is unlikely to substantially shift results.

4.6. Conclusions

Animal-borne cameras allow to investigate the behaviour of both domestic and non-domesticated animals. Video-tracking will allow the construction of an animal's general time-budget, or the investigation of more specific aspects of its behaviour, from the animal's point of view, in its normal environment, whilst also avoiding observer effects. Insights gained through this method might also be relevant to various conservation and animal welfare issues, such as feeding habits of cattle and predation effects of domestic cats.

Authors' contributions

MH and SW conceived the approach independently. MH (or rather the cats) collected the data. SW scored some and MH all of the videos. MH led the writing of the manuscript with contributions of SW. Both authors gave final approval for the publication.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.applanim.2019.04.016.

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