Understanding the Interaction Between Animals and Wearables: The Wearer Experience of Cats

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ABSTRACT

Animals can be negatively affected by wearable tracking devices, even those marketed as 'animal friendly' and increasingly used with companion animals, such as cats. To understand the wearer experience of cats fitted with popular GPS trackers, we measured the behavior of 13 feline participants while they were wearing the devices during a field study. The aim of our behavioral analysis was twofold: investigating potential signs of discomfort generated by the devices to evaluate the impact that such interventions have on cat wearers; identifying wearability flaws that might account for the observed impact and wearability requirements to improve the design of the devices. Based on our findings, we propose a set of requirements that should inform the design of trackers to afford better wearability and thus provide better wearer experience for cat wearers.

Author Keywords

Animal-Computer Interaction; animal wearables; animal biotelemetry; wearability; wearer-experience.

CCS Concepts

• Human-centered computing~Interaction Design ~Empirical studies in interaction design

INTRODUCTION

Animal biotelemetry, such as electronic trackers, activity monitors, or vital parameter sensors, are used in a range of activities from pet caring to wildlife research. For example, cat guardians might use GPS receivers to track their pets when these roam outdoors [37], and biologists might use them to monitor wide-ranging and migratory species [39]. While people are the *users* of such devices, interested in gathering biological data, animals are the *wearers,* bearing these tags on their bodies. While human users actively interact with the interface of such systems, animal wearers have a passive interaction with the tag they carry, which involves their sensory and physical apparatuses. Such

interaction has been described as adverse by various animal biologists and welfare scientists, due to behavioral and physical impacts that impinge on the animal's life and welfare, and which ultimately defeat the purpose of using the technology [3][38]. Indeed, if the technology alters the health, behavior and life patterns of tagged animals, the data recorded by those who study them may be biased and, ironically, the caring intentions of animal guardians may result in a lower quality of life for their animals. Thus, for animal welfare and scientific reasons, it is important that potential impacts produced by the wearer's physical interaction with the worn device are minimized through *wearer-centered* design.

With the migration of computing capabilities from desktops to wearables, the human body has become the new place from which to operate and interact with technology; and designers have increasingly endeavored to ensure that devices afford good wearability for wearers in order to provide good wearer as well as user experience. Gemperle *et al.* [7] defined wearability as the sensory and corporal interaction between the body and the wearable device. The authors argued that "*a product that is wearable should have wearability*" and that designing for wearability means to shape the wearable in accordance with the body form. Arguably, a similar perspective is relevant when designing wearables for animals and, by default, wearability should be accounted for throughout the design process, as it is for human wearables [14]. This perspective is grounded in the stance taken within the discipline of Animal-Computer Interaction (ACI), which draws from interaction design principles to inform the development of animal-centered interactive technologies [17], including wearables [23].

Arguably, to afford good wearability, the design of animal wearables should primarily reflect the animal wearer's needs, as determined by their characteristics, activities and living environments. However, this does not appear to be systematically the case, even for devices that are marketed as animal-friendly and whose function is to help human guardians caring for the welfare of their animals. To explore this issue, we conducted an observational study to investigate the wearability of two popular off-the-shelf pet trackers and the wearer experience of cats, based on both qualitative and quantitative measures of feline behavior [22]. We were particularly interested in identifying signs of discomfort [40] and tag features that might account for the negative interference. We identified both wearability problems and

unmet wearability requirements pointing at the inadequacy of these wearables to accord with the animal form.

BACKGROUND

A Rising Trend

With more than 70 thousand pets gone missing in the UK alone between 2003 and 2014 [29], pet owners have become a target group for the wearables industry, which offers animal-attached biotelemetry tags for pet carers who wish to monitor activities and locations of their cats and dogs [2][26]. These include both devices originally designed for humans but promoted as also suitable for pets, such as Trackimo [31], and tags designed for specific animal species, such as PawTrax [24]. Typically, product reviews [26] report that important features to be considered when purchasing these products are tracking range, accuracy, adds-on sensors, waterproofing, durability, in-build or existing collar attachment, size, and weight. These considerations primarily reflect the need of users to obtain reliable and useful data from hard-wearing devices that are suitable for the outdoor life of animals, while also reassuring owners that the tags are not too heavy to be worn. However, devices' size and weight are only two of the characteristics that could affect wearers and therefore their consideration is insufficient to determine the wearer-friendliness and comfortability of biotelemetry tags.

Biotelemetry and its Impacts

Beyond the pet market, biotelemetry is used to monitor activities, behaviors and physiological status of a variety of animals [25]. Its use has yielded important benefits for the protection of endangered species [4] and the refinement of laboratory procedures [10]. It has also increased the practice of leaving farm and companion animals to roam free outside shelters and homes [27][37]. However, there is evidence that carrying body-attached devices can have negative impacts on physiological functions, survival probabilities, sociality, and psychological wellbeing of individual carriers [36][38][40]. These tags can obtrude animals' movements, causing physical and behavioral interferences [36]. For example, device components and attachments may snag in vegetation [3]; add drag in water [40]; meddling with postures (e.g. resting) [9]; rub and abrade skin, feathers or fur [3]; increase the visibility of wearers, exposing them to predators or prey [9]; disrupt individual or social behavior [13].

Researchers have proposed guidelines to improve biotelemetry applications with laboratory [10][20] and wild animals [3][9][40]. In particular, Morton et al. [20], Hawkins [9], and Casper [3] highlighted the importance, on both welfare and scientific grounds, of considering the needs of individual animals in more detail. The authors argue that developers and researchers should carefully consider the shape, material, color, location, and method of attachment of devices in relation to the animal's biological and behavioral characteristics. They also provide directions for applying their guidelines based on the biological and behavioral requirements of animals involved in biotelemetry studies.

For example, they recommend the streamlining of the tag shape following the aero- and hydrodynamics of the animal's body, and advocate the use of biocompatible, non-buoyant, and dissolvable or time-releasable materials.

These instructions implicitly relate to the concept of wearer experience, determined by any impacts affecting the animals, but are mainly derived from occurrences of impacts found during field studies that used biotelemetry. They are not explicitly informed by the notion of wearability as a design goal and by the kind of detailed requirements analysis that designers systematically conduct in order to achieve good wearability. In contrast, our study investigated the impacts generated by two devices in order to evaluate aspects of their design and establishing specific wearability requirements from the animals involved.

Animal Wearability in Design-Related Disciplines

ACI researchers have addressed animal wearability as a design goal and pioneered requirements analyses in this respect. In particular, Valentin et al. [34] highlighted safety, space, comfort, and weight as important aspects of wearability for electronically enhanced collars and harnesses used on working dogs. Based on their design experience with dogs [12][35], the authors proposed recommendations, which include: keeping the projection of the device to a minimum to avoid the risk of the wearer being caught or bumping on surfaces, using break-away mechanisms that release the collar if caught, arranging wearable components so the animal can comfortably lie, opting for tag's weight of less than 2% of the animals' body weight, ensuring that hair does not get caught in components and attachments (e.g. buckles or electronic modules), and that the inner side of the wearable is soft and seamless.

This work provides an important starting point for understanding the issues involved in designing for animal wearability. However, the authors' wearability guidelines derive from their extensive knowledge and handling experience of the dogs they trained and worked with, rather than from a systematic interpretation of the dogs' responses to the devices, which would derive specific requirements from specific behaviors. Their approach makes it possible to identify design aspects with familiar individuals and, more generally, collaborative (e.g. trained) animal species such as dogs, who share millennia of coevolution with humans [15]. However, when designers are unfamiliar with the individual animals involved, or a species is not used to human handling, or the impact is not obvious, developing appropriate design guidelines is more challenging. Unlike Valentin et al. [34], our study aimed to establish animal-informed requirements through systematic observations of the participants' behavioral responses to the devices they were wearing. We adapted and applied a well-established method in Ethology and Animal Behavior science to investigate the reactions of domestic cats to two popular off-the-shelf devices, in order to identify specific design limitations and establish specific wearability requirements through behavioral analysis.

THE STUDY

Methodology

The study aimed to understand the cats' wearer experience with common animal tags. This is particularly challenging due to physical, sensory and cognitive interspecies differences between human investigator and animal wearer, resulting in perceptual discrepancies and communication barriers that limit the investigator's ability to interpret the animal's needs. Since the 1930s [30], ethologists have addressed this issue by conducting non-manipulative experiments in natural and non-controlled settings (i.e. in the field), in which pre-selected behaviors are measured and unexpected behaviors are annotated, to achieve as objective as possible an interpretation of animals' behavior [6]. In *ethological observation*, the observer plans their observations by choosing the units (i.e. individual animals, groups or body part), the sampling and recording technique, and preselecting behaviors of interest. Such behaviors are then quantified, while exceptional behaviors are qualitatively annotated as they occur and may form the basis for new experiments or provide additional information [6]. We applied the same method but manipulated the experimental conditions by fitting cat participants with tracking devices, to study their response to the foreign presence. While the cats were wearing the devices, we recorded and measured a set of pre-defined behaviors known to indicate discomfort in cats [1]; we also recorded other emerging reactions explicitly directed at the devices, which were qualitatively analyzed. Combining quantitative and qualitative measures mitigated the observer's subjective interpretation of the cats' reactions.

Participants

Domestic cats (*Felis catus*) are largely available and relatively easy to involve in novel experimental research; they are familiar with humans' presence and handling, which reduces the influence that an observer may have on their behavior; this has been extensively studied and ethograms (i.e. lists of behaviors exhibited by a species [19], p.41) are available from which we selected behaviors to measure the animals' reactions.

We worked with 13 neutered indoor cats - eight males and five females - whose average age was 7.1 years (s.d. = 2.36) and average weight was 6.0 kg (s.d. = 1.21). 7 of them were Maine coons (medium-long hair), 6 were house cats (5 shorthairs, 1 medium hair). Minimum weight for being recruited was 4.5 Kg as per device sellers' recommendation. None of the participants were used to wearing collars. We checked the cats' health with their carers, who declared that their feline companions were healthy and had no known skin or other ailments. These cats were potential wearers of tracking technology, as their keepers were interested in knowing their reactions to such devices before purchasing any for their pets. Observing indoor individuals enabled the observer to keep the cats in view constantly and record their behaviors throughout the observation period while in their habitual environment. We rewarded the cats offering a £20 pet retailer voucher to their guardians to buy treats and toys.

Monitoring Devices

We tested two commercial GPS tags: PawTrax® Halo [24] and Tractive® [32]. We chose two substantially different models to investigate distinct aspects of physical design, such as various sizes, weights, materials, colors, textures, and shapes. PawTrax® Halo (Fig.1) featured two curved black boxes hinged along their shorter side. This allowed the casing to be flexible at its center and bend around the cat's neck to accommodate different sizes. The case was 21mm wide and 8.3mm thick, weighing 21.7g. It had two distal and two central specular eyelets through which slid a rubbery and elasticated 13.5mm-wide collar (5g). The collar's edges were fastened with Velcro®. Tractive® (Fig.2) featured a white case sizing 51x41x15mm and weighing 41.2g. The case was attached to a 9.4mm-wide black leather collar (8g) with a snap-fit clip. The collar fastened with a buckle. At the time of writing, the PawTrax still has the same external design; the Tractive's case has been slightly elongated and its weight reduced to 30g, with the possibility of an integrated collar.

Figure 1. PawTrax. Left: two-part case. Center: collar and case (with 23mm diameter coin). Right: device on cat.

Figure 2. Tractive. Left: case. Center, collar and case (with 23mm diameter coin); Right: device on cat.

Procedure

The three behaviors of interest for our study were grooming (i.e. cats groom themselves by licking, scratching, biting, or chewing their fur; and licking a front paw to wipe it over their head), scratching (i.e. cats scratch their bodies using their hind feet's claws), and head or body shaking (i.e. cats rotate their head or body from side to side) [28]. These behaviors are often performed in response to external stimuli (e.g. skin irritation, dirt on the fur) including stressful ones [1].

Prior to the study, the cats became acquainted with the observer. The collars were fastened following the manufacturer's guidelines. As we were interested in studying wearability aspects of the devices, rather than in locating the animals, the trackers were not activated. Each cat was observed for three different non-consecutive days, each day under a different experimental condition: 1) wearing nothing (*C*), 2) wearing PawTrax (*P*), 3) wearing Tractive (*T*). Option 1 was our control condition. We excluded a control condition that involved wearing a plain collar because attachments are integral part of wearables and the tags that we evaluated had collar attachments; hence, our testing conditions were whole devices or nothing. Conditions were assigned randomly to

avoid order effects. The cats wore the devices for 6 continuous hours each day, after which the tag was removed. Following a standard technique in ethology used to record a range of daily activities (e.g. resting, eating, walking) without overloading the observer [6], cats were observed for 20 minutes every hour. Although cats are usually more active at night, for sampling consistency, all observations occurred during the same time of day across cats, compatibly with the keepers' availability. At the start of each observation period, to minimize any interference, the observer discreetly followed the cats to video record their activities or to position a camera and quietly watch from a distance, if the cat was stationary (e.g. sleeping). When the cats were hiding (e.g. under a bed), the camera was suitably positioned so that monitoring could continue. In environments where cats have various spots suitable for hiding, as in human houses, such flexible use of a video aid allowed the observer to continuously record the cats' activities for the whole sampling session, preventing sampling inconsistencies that would have occurred if a cat had left the field of vision of stationary cameras.

Ethical Considerations
The experimental design was approved by the Animal Welfare Ethical Review Body of The Open University and conformed with existing ethics protocols for Animal-Computer Interaction research [18]. We obtained *mediated consent* from the cats' carers and sought *contingent consent* from cats by fitting them with the devices only if they allowed it ([18], sec.10, principle 2, part 1 and 2). Throughout the study, we monitored them for signs of distress, discussing any concerns with the carers. During the fitting process, none of the cats showed signs of fear, pain, or distress. Once instrumented, any cats who showed fearful or tense behavior were immediately withdrawn. The choice of indoor cats protected the participants from safety hazards, such as getting stuck in vegetation. Observing the cats in their habitual environment minimized the study's impact.

Data Analysis
Videos were analyzed to describe any reactions to the device and measure the three pre-selected behaviors.

Measurement of Behaviors
We counted frequency (number of occurrences) for each of three pre-selected behaviors (grooming, scratching, and head/body shaking), and duration (for grooming and scratching). For head shaking, incomplete rotations (only to one side) were counted as half occurrences. Scratching was counted only when directed at the collar region. Device and control conditions were compared to identify differences in the occurrence and duration of the pre-selected behaviors that might have indicated a negative impact of the devices. We conducted a statistical analysis to see whether any increase in the cats' reactions across conditions (C, P, T) was significant. Nonparametric Friedman's two-way ANOVA for repeated measures ([16], p.434) was used to test differences within frequencies and durations in grooming, scratching, and head/body shaking. Where a statistical

significance was found, a Wilcoxon signed-ranks test ([16], p.423) was used to identify where the differences were.

Frequency data are counts of behavioral events. Due to their non-numerical nature, they follow a Poisson distribution rather than a normal distribution ([8], p.258), so we used nonparametric tests instead of parametric tests ([8], p.136). Conversely, durations are counts of actual numbers (e.g. seconds or minutes) which could follow a normal distribution with a large enough sample size (more than 30 measurements [33]). Since our sample size was smaller (N = 13), nonparametric statistics were used for durations too. The *p-value* was selected as p < 0.05, as conventional in ethological studies ([16], p.325). We hypothesized that grooming, scratching and head/body shaking would increase with the presence of both devices. As the Tractive was bulkier than the PawTrax, we hypothesized that the former would impinge more than the latter, consistent with previous studies [5]. Therefore, the alternative hypothesis was directional (implying the use of one-tailed statistical tests), with H_1: Control (C) < PawTrax (P) < Tractive (T). The software IBM SPSS Statistics Version 21.0 was used for the analysis [11].

Qualitative Description of Behaviors
During the two device conditions, reactions seemingly directed at the device (different from the three pre-selected behaviors) were annotated. These included the cats biting or licking or trying to bite the device, rolling their heads to investigate what was on their neck, cuffing the tag with their forepaws, and striking a forepaw towards the collar. These were interpreted as reactions to overstimulation from the device and were grouped into the category of behaviors *active interaction*. These behaviors occurred in aggregated patterns (e.g. a cat shaking the head twice, then licking the case of the tag, and scratching immediately after) and were systematically described, using the cat ethogram [28]. Environmental, contextual, and species or breed-specific factors were also noted, including species/breed-specific behavioral and morphological characteristics (e.g. sniffing or rubbing behavior, fur length), interactions with other household animals (e.g. other cats) or ambient features (e.g. walking surfaces, outdoor enclosures). These behaviors and factors were only qualitatively analyzed, since even a single occurrence was meaningful.

Video sequences of behavioral aggregated patterns were transcribed into text, breaking down the composite reactions into discrete behavioral components and assigning qualifiers to them. For example, a sequence might show a cat who scratched his neck, shook his body, walked a few steps, stopped and licked the collar region, and then scratched his body again. The vocabulary used for species-specific descriptions complied with the ethogram's terminology, but when qualifiers were used to describe the quality of reactions, they were in accordance with the observer's frame of reference. Such an observer's subjectivity (*Observer Effect* [16], p.211) was systematized by defining each

qualifier and using it according to its definition. For example, '*the cat shook his body twice consecutively*' described the cat's base behavior of rotating the abdomen from side to side as per the ethogram [28], with the addition of the qualifier '*consecutively*', defined as multiple shaking events in continuous repetition.

Using this technique, transcribed reactions were sorted into '*topic nodes*' using the NVivo qualitative data analysis software [21]. The coding of nodes (descriptive containers gathering converging material) is a dynamic process during which the meaning and structure of the nodes may be modified, with nodes being generated, merged, aggregated, separated, or sub-grouped. In our analysis, coding was done both by placing each transcribed reaction into previously created nodes and by creating new nodes as appropriate. While initial nodes corresponded to the three behaviors of interest, progressively they were modified and hierarchically organized as pertinent behavior qualities were found. For example, head/body shaking occurrences were placed into the node accordingly named '*shaking*'; when the 'consecutive' qualifier was found in the transcription, a child node, called '*shaking consecutively*' was created. In this way, all relevant reactions, and related ambient features, individual habits, and morphological characteristics were described. This served to identify device features that might provoke a reaction and cause wearability flaws.

FINDINGS

Quantitative and statistical results are reported first, and then salient video sequences of aggregated behavior patterns are described. Table 1 and Table 2 summarize the descriptive statistics for frequencies and mean duration for grooming, scratching, and head/body shaking under different experimental conditions.

	Mean	Median	Std. dev.
Control groom frequency	4.15	4.00	2.85
PawTrax groom frequency	3.62	2.00	4.73
Tractive groom frequency	4.69	3.00	4.67
Control scratch frequency	.54	1.00	.51
PawTrax scratch frequency	4.92	1.00	6.44
Tractive scratch frequency	4.00	2.00	5.91
Control shaking frequency	3.53	3.50	2.61
PawTrax shaking frequency	9.88	11.00	7.37
Tractive shaking frequency	8.50	8.00	6.60

Table 1. Descriptive statistics (mean, median, standard deviation) for frequency.

	Mean	Median	Std. dev.
Control groom mean duration	43.33	20.72	41.41
PawTrax groom mean duration	30.05	17.52	32.35
Tractive groom mean duration	38.50	12.27	62.30
Control scratch mean duration	2.82	3.61	3.05
PawTrax scratch mean duration	2.62	2.80	2.81
Tractive scratch mean duration	3.99	4.25	3.42

Table 2. Descriptive statistics (mean, median, standard deviation) for mean duration in seconds.

Grooming

Grooming frequency was *equal* (i.e. difference is 0) or *similar* (i.e. difference is between 1 and 3) across the three conditions for 3 cats (C2, C5, C9). 5 cats (C1, C8, C11, C12, C13) had higher frequencies (more than 3) during *C* than *P* and *T*. 2 cats (C3, C4) groomed *more frequently* (i.e. > 3) with *P* but equally or similarly with *C* and *T*. On the contrary, 3 cats (C6, C7, C10) groomed more frequently with *T* but similarly with *P* and *C*. These results do not show the trend hypothesized, according to which 'during-control' grooming would be less frequent than 'during-device' grooming. Statistical analysis showed that there was no statistically significant difference in grooming frequencies across the 3 conditions, with Friedman's test result $X^2(2) = 3.061$, p = 0.216 (p > 0.05). Duration did not show any trend and did not show a statistically significant difference across conditions either, with $X^2(2) = 1.440$, p = 0.487 (p > 0.05). Thus, grooming was discarded as an indicator of discomfort.

Consistent with statistical findings, the analysis of prolonged grooming shows that this behavior was performed in a relatively similar way across the 3 conditions. However, events of single or repetitive lickings exclusively directed at the collar region (neck and throat) were detected. These were uncharacteristic reactions (e.g. tongue strokes on the collar or case; deep neck bends; tongue protrusion to reach the device, even if contact with the case or collar was not made). Selected video sequences of aggregated patterns showed that some cats physically licked the Tractive case. As a consequence, the regular tongue movements of the grooming action were disrupted by the obstructing device (i.e. C1, C6). For example, after his tongue made contact with the case, C1 stopped licking and immediately pulled his head back, retracting and protruding his tongue, and contracting his neck muscles. Then, he tried to lick his throat but did not succeed because the hard case was in the way, preventing the neck from bending forward. This was evident from the double nodding movement of the head immediately followed by an insistent scratching of the throat that lasted around 7 seconds. In other cats, the tongue's contact with the case triggered more conspicuous reactions. For example, while licking his throat, C7 touched the case with his tongue, at which point he suddenly rolled the head as if looking at the foreign body felt by the tongue and grasped the case with both forepaws while opening and shutting his mouth, attempting to bite the case. The same happened with C10, who, after licking the collar, pulled his head backward and then bent his neck forward. Impeded by the case, he rolled the head and stroked the case with the tongue; then he contracted his body, repeatedly licking the neck on either side of the case, suggesting a reaction against the device. In contrast, the PawTrax case was never licked directly, consistent with the fact that PawTrax is slimmer than its counterpart, visually and spatially less conspicuous, and harder to target. However, C7 repeatedly turned his head licking the collar area on either side, making the same head turns, tosses, and shakes as if reacting to a stimulus.

Two licking patterns were deemed relevant for evaluating the devices' wearability (Table 3).

Licking pattern	PawTrax	Tractive
• licking collar area with single strokes	C7	C4, C6, C7, C10, C11
• licking the case	-	C1, C6, C7, C10

Table 3. List of licking qualities performed by the cats.

Scratching

Scratching frequencies during C were very low for all 13 cats (never scratched or once). 6 cats scratched more frequently (> 3) with either one or both devices: C3 increased scratching with P; C6 with T; C4, C7, C9, and C10 with both devices. The other 7 cats did not show a difference greater than 3 occurrences across conditions. Although 4 cats showed a noticeable increment in scratching with both devices, Friedman's test showed that there was no statistically significant difference in frequency across the 3 conditions, with $X^2(2) = 2.837$, p = 0.242 (p > 0.05), neither in mean duration, with $X^2(2) = 0.311$, p = 0.856 (p > 0.05).

From these results, scratching duration was discarded as an indicator of discomfort. However, scratching frequency was further analyzed since most of the cats exhibited scratching patterns suggesting discomfort caused by device features, as reported in Table 4.

Scratching pattern	PawTrax	Tractive
• repeated scratching on same spot of neck	C3, C4, C7, C9, C10	C4, C9, C10
• insistent scratching (> 6 sec.)	C3, C4, C7, C8, C9, C10, C12	C1, C4, C6, C10, C12
• alternated scratches on neck's sides	C4, C7, C8, C9, C10	-
• scratching the case or collar	C3, C4, C9, C10	C1, C4, C6, C10, C11
• scratch the buckle	-	C4, C6, C9

Table 4. List of scratching qualities performed by the cats.

With PawTrax, the most salient incidences occurred for C4, C7, C9, and C10. C4 scratched the case insistently (9 sec.), shook his body, and then resumed scratching the case (8 sec.), as evidenced by the sound of the claws against it. C7 repeatedly scratched the same spot of the neck within just over a minute, hitting the collar instead of the skin underneath, as evidenced by the sound of the claws against it. Similarly, C9 repeatedly scratched the same spot on the neck within 30 seconds. Both C9 and C7 scratched either side of the neck in rapid succession, as did C4 and C10. In particular, C10 was crouching when he suddenly sat to scratch his throat with his right foot; then he licked the foot and resumed scratching the same spot next to the case; he again licked his foot and shook his head; then he shook his body, sniffed around for a few seconds and scratched again the same spot twice; he stopped, groomed for a few seconds, and scratched insistently (11 sec.) his throat on the left side, next to the case. Despite the force exerted by the leg, the case did not slide around the neck, remaining firmly in place.

When he stopped scratching, C10 licked the scratching foot and shook his head. He then resumed scratching the same left spot next to the case (14 sec.), which remained firmly in place, before going back to scratching the right side.

With Tractive, a noteworthy scratching behavior of C4, C6, and C9 regarded the nape of the neck, where the collar's buckle was. C4 repeatedly scratched his nape while wearing the Tractive. On one occasion, he started scratching the right side of his neck, moving on to the nape; then, he stiffly tilted the head back while stretching the neck upwards and froze for an instant; he then released the position, slightly rolling the head and licking the left side of his neck; then he scratched again the nape with his left foot. For comparison, while wearing PawTrax - which has no buckle - he only scratched his nape twice for a few seconds. In contrast, C6 and C9 never scratched their nape with PawTrax but did so insistently with Tractive.

Head/Body Shaking

6 cats had a >3 occurrences increment in head/body shaking with both devices, compared to Control (C4, C6, C7, C9, C10, C11). For C3 and C13 there was a >3 increment with P but not with T, while for C12 there was an >3 increment with T but not with P. 3 cats (C1, C5, C8) exhibited similar frequencies of shaking under all three conditions. C2 shook his head/body more frequently during C.

The statistical analysis with Friedman's test showed a significant difference in head/body shaking frequency across the three conditions, with $X^2(2) = 6.533$, p = 0.038 (p < 0.05). Further post-hoc analysis with Wilcoxon signed-ranks test was performed to see where the significant differences were, to do which we used the Bonferroni adjustment to the p-value [8]. Comparisons were $C*P$, $C*T$, and $P*T$. Bonferroni was calculated taking the level of significance used in the previous Friedman's test (i.e. p = 0.05) and dividing it by 3 (i.e. n. of conditions in the experimental design): Bonferroni adjustment = 0.05/3 = 0.0166. This means that outputs from Wilcoxon must be compared with the Bonferroni adjustment. Significance outputs bigger than the Bonferroni adjustment (p > 0.0166) mean that there is no significant difference between coupled conditions. Wilcoxon (one-tailed) showed statistical significance between P and C, with Z = -2.244, p = 0.0125 (p < 0.0166), and T and C, with Z = -2.15, p = 0.0155 (p < 0.0166). There was no significant difference between P and T, with Z = -0.445, p = 0.328 (p > 0.0166).

Head/body shaking was often performed in aggregated patterns, as detailed in Table 5.

Shaking pattern	PawTrax	Tractive
• consecutively	C3, C7, C11, C13	C9, C11, C12
• forcefully	C3, C10, C11, C13	C10, C11, C12, C13
• repeatedly	C4, C7, C9, C10, C13	C7, C9, C10, C12
• while walking	C7, C9, C11, C13	C7

Table 5. List of shaking patterns performed by the cats.

Active Interaction

Seven behaviors were identified as active interactions (Table 6). Although described as distinct, these behaviors were grouped in the same category since, in our opinion, their manifestation indicated a reaction undoubtedly caused by the device. At times, such active interactions co-occurred with licking, scratching, and shaking behaviors; at times, they were triggered by environmental factors or species-specific behaviors (e.g. rubbing the neck - and thus the device - on objects or the floor).

Cat	Active Interaction behaviors per cat
C1	Tractive: actual licking of the case
C4	Tractive: attempting to bite the case, head rolling, licking the collar area
C6	Tractive: attempting to bite the case, actual biting of the case, head rolling, cuffing the case with forepaws while standing on hind legs, actual licking of the case, licking the collar area
C7	PawTrax: licking the collar area Tractive: actual licking of the case, actual biting of the case, head rolling, cuffing the case with forepaws while standing on hind legs, licking the collar area
C10	Tractive: attempting to bite the case, actual biting of the case, head rolling, actual licking of the case, licking the collar area
C11	Tractive: licking the collar area
C13	Tractive: attempting to strike the collar region with a forepaw

Table 6. Kind of active interaction performed by 7 cats.

Table 6 shows which interactive behaviors were performed by each cat and with which device. 7 cats (C1, C4, C6, C7, C10, C11, C13) had an active interaction with at least one of the devices. C13 interacted with PawTrax (but not Tractive) by attempting to strike the device with her paws several times. C7 reacted to both devices by repeatedly licking the collar when wearing both PawTrax and Tractive, and by biting and cuffing the case of Tractive, rearing on his hind limbs while cuffing the device with his forepaws. He also rolled his head on various occasions while wearing Tractive. The other 5 cats interacted with Tractive only: C4, C6, and C10 bit or attempted to bite the case and rolled their heads; C6 also reared on hind legs and cuffed the case with his forepaws. In addition, C1, C6, and C10 licked the case, while C4, C6, C7, C10, and C11 licked the collar.

Behavioral sequences of clear hostility against Tractive were observed in C6, C7, and C10. For example, as during scratching the case slid to one side of his neck, C6 stiffened and pulled back his body, rolled his head and started snap-biting at the case, before raising his forepaws in rapid succession, rearing on his hind legs and trying to cuff the case, as he kept trying to bite the case. 8 biting sequences and 3 cuffing strings were recorded for C6, who also showed

consecutive rolling of the head on various occasions as if trying to see what was attached to his neck.

C7 and C10 had similar interactions with Tractive. On one occasion, C7 licked his neck and throat, then lay down rubbing his neck against the tiled floor for few seconds, before shaking his head and suddenly stiffly tilting his head toward the case, freezing for an instant; he then made a jerking movement, tilting his head to bite and fight against the case. After licking his paw, he suddenly rolled his head, pulled the neck backward and, as he licked his throat, his tongue touched the case, at which point he started cuffing and biting the case, rearing and standing upright with his forepaws clutched onto the case. The sequence continued with a series of interactions, alternating sudden contortions to licking, clutching and biting of the case.

PawTrax did not generate such conspicuous reactions. For example, its case was never cuffed or licked directly. However, C7 showed repetitive single-stroke alternated licking of each side of his neck, pointing to a collar-induced stimulus; while C13 raised a paw and simultaneously twitched her neck repeatedly while walking.

Environmental and Species-Specific Factors

Environmental and species-specific behaviors seemed important to appraise potential wearability flaws. These regarded the cats' physical and social domestic environment, in conjunction with wearing a device, and included sniffing objects, rolling on the floor, rubbing head and body against objects, the floor, or other individuals (Table 7). Although these are typical cat behaviors, they were noted given their potential implications for design. For example, C6 repeatedly sniffed the air and the floor during the whole observational period (control included). This highlighted the importance that scent and ambient odors have in a cat's life and stresses the need to carefully consider the use of materials, particularly if they produce strong odors.

Environmental and sp-specific factors	PawTrax	Tractive
• sniffing objects	C6, C10	C6, C10
• rolling body on floor	C7	C6, C7, C10
• rubbing against objects, floor, others	-	C4, C6, C7, C10, C11, C13

Table 7. List of other behaviors performed by the cats.

Noteworthy episodes involved C7 and C10, who rolled their body and rubbed their necks on tiled and wooden floors respectively while wearing Tractive. The impact of the case on the hard floors produced a noise, immediately followed by active interaction behaviors. C7 rigidly tilted his head toward his throat freezing for an instant; jerking and agitated movements followed that culminated with the cat rearing on his hind limbs, clutching the case and biting it. A similar reaction was exhibited by C10, who responded to the loud noise by jerking his head, rolling repeatedly and increasingly twisting and turning his neck and shoulders, protruding his tongue and repeatedly trying to bite the case. Towards the

end of the sequence, at short intervals, he rolled his body again a few times causing the case to produce the same noise, before finally standing up and shaking his body.

DISCUSSION

The above findings show that both tracking devices elicited a range of reactions. The discussion below focuses on 1) behaviors that might indicate wearability flaws in the device, and 2) wearability aspects that might suggest implications for design and help establish requirements.

Understand Biotelemetry Impacts on Cats

Grooming is a composite behavior that includes licking, scratching, biting or chewing the body's fur [28]. Its duration may vary (e.g. from the time of a tongue stroke to various minutes of constant licking), and it may be interrupted and resumed various seconds after suspension. It is a complex behavior performed by cats for reasons that range from cleaning purposes to stress release [1]. These aspects raised three issues when measuring grooming. Firstly, scratching is both a sub-behavior of grooming and a base behavior in the cat ethogram [28]. Since scratching was counted as an independent category of behavior, grooming duration had to be calculated net from the scratching time, which complicated the recording of this behavior. Secondly, although we defined what constituted a grooming episode (including start and endpoints, and duration of any pauses) to enable their precise measurement, the observer had to make various arbitrary choices based on experience (e.g. deciding how many seconds define a pause before a grooming event should be classified as two separate episodes). This added a degree of subjectivity to the quantification. Thirdly, the variability of grooming in terms of duration, composition (how many strokes, how many pauses) and purpose (cleaning, stress release) makes difficult to recognize a particular stimulus (e.g. presence of the device) as the trigger of the behavior. All these aspects make grooming difficult to measure reliably. Indeed, the statistical analysis of grooming supports its elimination as a possible indicator of discomfort in evaluative studies of cat-centered wearables, as its frequency and duration did not significantly vary across conditions. However, single strokes of licking the neck and throat emerged as signs of active interaction with the device and, especially in C1, C6, C7, and C10, they were performed in a way that implies directionality towards the devices. C7 was a typical example, whose various tongue strokes alternating between the sides of his neck were deemed part of an active interaction with the wearables. Thus, *licking*, defined as tongue strokes directed at the device, may be used for measuring the wearer's experience.

For scratching, the statistical analysis also did not support its use as an indicator. However, the analysis of aggregated patterns strongly suggests a device-induced effect in those cats that increased scratching while wearing the devices. Indeed, on various occasions cats scratched the site of the device attachment insistently or repeatedly, suggesting that the reaction was due to the presence of the wearable. The device might generate a stimulus that needs to be relieved, as suggested by repeated scratching on both sides of the neck while wearing PawTrax, whose mirroring collar eyelets bulged inwardly (Fig. 1), touching or itching the wearer's skin, thus provoking the scratching on both sides of the neck. But even if the urge to scratch were not caused by the device, the uniformly elongated shape of PawTrax, along with its wide collar, might prevent the wearer's claws from reaching the skin under its surface to relieve an itch, thus provoking repeated albeit ineffective attempts. In brief, the insistent scratching observed might signal either a continuous stimulus generated by the device or the impossibility to relieve an otherwise generated stimulus. This suggests that scratching might be an indicator of discomfort, even though the statistical analysis did not give significant results.

For head and body shaking, the results of the statistical analysis suggest that the increment counted during the device conditions is *probably* not due to chance, but may depend on the presence of a device, thus indicating a device-induced effect. Although shaking is a relatively short event, repeated or consecutive occurrences, along with forceful shaking able to unbalance the cat's posture or movement, were noted as particularly relevant patterns. While they did not provide insights into which particular device features might have provoked the behavior, they strengthen the hypothesis that shaking could indicate general impact and discomfort. Hence, shaking seems to be an important indicator that could be used to assess a general stimulation (probably to the head) when evaluating wearable designs.

Active interaction turned out to be especially valuable regardless of the frequency observed in each cat. The fact that cats physically interacted with the device (with forepaws, tongue, or teeth) provides a strong indication that the device had an influence on their behavior. However, not all the cats had an active interaction with the tags and, for those who had, the intensity of the interaction varied. This means that active interaction cannot be the only way to assess the impact on the wearer, since some individuals may react less overtly (i.e. with an increase of head shaking rather than cuffing or biting a case). Hence, while an active interaction alone might indicate an impact and show what device feature may generate it, other indicators might be needed for participants who show less overt reactions.

Wearability Flaws and Wearability Requirements

The findings that show active interaction episodes point to position and protrusion of the case as two design weaknesses in Tractive. The bulky Tractive case obstructed and even impeded smooth movements of the neck when cats licked their throat. At times, this led to conspicuous reactions against Tractive, such as rearing on hind legs and cuffing or biting the case. Such occurrences seem related to the significant protrusion of the case and to the fact that it was easily sliding under the chin. On the other hand, cuffing and biting were not observed with PawTrax, which had a slimmer case. Head rolling seems linked to the possibility that the

bulkier Tractive case might have been visible. Cats might see the case attached to their throats, direct their glance and focus their attention on it, then follow the case, which would move with the rotation of their heads. When analyzing case cuffing or biting and head rolling, two important requirements were established: protrusion should be kept at a minimum (e.g. by distributing electronics and battery components); the case should be positioned in an area of the neck not reachable by the cat's tongue (e.g. the nape).

Insistent scratching suggests design limitations in PawTrax. If the elongated case shape and the collar width prevent the wearer's claws from reaching the skin, the area occupied by the device's components should be carefully considered. The Tractive *collar* is substantially narrower (9.4mm) than the PawTrax' (13.5mm) and indeed multi-scratching occurred less frequently with Tractive than with PawTrax, suggesting that the narrower collar allowed the claws to reach the irritated spot. Furthermore, the bulkier but more compact Tractive case could slide around the wearers' neck, thus exposing different areas of the skin and allowing cats to relieve themselves, while the more uniform PawTrax case did not slide around the wearers' neck, thus preventing cats from reaching the skin underneath. This suggests that the area (extension) of both collar and case should be kept at a minimum in a trade-off with the protrusion. It also suggests that the case should not cover the whole perimeter of the collar and that the collar should be able to easily slide around the neck to free sections of it, allowing any part of the neck to be scratched. However, this feature would require careful consideration: a movable case might be a safety hazard if associated with a loose collar, which could get more easily caught; while observations of licking behavior suggest that the best position for the case would be on the nape, this could not be maintained if the case were to freely slide around the neck. A solution to these issues might be a mechanism that allows the case to slightly slide on the collar in a restricted area of the nape, but that never allows the case to slide down the front or sides of the neck.

Another flaw related to scratching is that any inner protrusion might generate a stimulus or exert pressure that might be difficult to alleviate. The clip that attaches the Tractive case to the collar has a smooth surface and, indeed, the cats did not scratch the neck in an alternate fashion, as they did with PawTrax, which has inner eyelets. This suggests that such eyelets might be involved in the scratching impulse. Thus, discontinuities in the tags' inner side in contact with the skin should be avoided (e.g. eyelets, stitching).

A further design flaw appears to exist where parts of a device catch the wearer's hair, as with the buckle of the Tractive collar. Cats with medium-long hair prone to scratch the site of the buckle, suggesting that long fur gets trapped into the buckle mechanism, pricking the hair follicles. This suggests that collar fastening methods that catch fur (e.g. buckles, Velcro) should be avoided. Moreover, although the collars

were fastened according to manufacturer guidelines, medium-long hair cats were more difficult to fit. When fitting it, the collar was positioned over the coat; as the wearer moved, their hair slipped out and over the collar thus loosening the collar. This indicates that the fur length plays a role in the sliding as well as the fastening of the tag and suggests that any fastening method should have the ability to adapt to the varying measurements of the wearer in order to maintain a constant hold. For cats with medium or long hair, body size did not to mitigate the discomfort of wearing a device. Medium-long fur C6 and C7, and medium fur C10 were large cats (5.5, 7.0, and 5.5 kg respectively) yet they were among the most reactive participants. This provides evidence that the equation 'large animal's size equals less susceptibility to bulkier devices' is too coarse a rule and needs further testing. Statistical studies with larger samples are needed to investigate demographic-dependent discomfort (i.e. potential correlations with age, gender, weight, etc.) and acquire a more precise measure of wearability.

Finally, unambiguous reactions against Tractive resulted from the physical interaction between the wearer and their environment. When C10 and C7 rolled their bodies on hard surfaces, their reaction was likely triggered by the noise from the impact of the plastic case. This suggests that the material used for encasing the electronics should be carefully considered to avoid it interfering with habitual behaviors, such as rubbing against objects, surfaces, and other individuals. Routine rubbing to leave one's odor on surfaces or another cat is key in marking territory and maintaining bonds within social groups, which hard materials could disrupt by producing an irritating auditory stimulus or by pressing on the body when rubbed (preventing cat's neck glands from depositing their scent). On the other hand, softer materials, such as rubber, could emanate odors that interfere with cats' highly sensitive olfaction. Thus, flexible and odorless materials should be preferred.

Table 8 summarizes design features relevant to the cats' reactions and related requirements.

Feature	Cat's reaction	Requirements
Exterior protrusion	direct contact between tongue and case; grasping and biting case; device hitting the floor.	Protrusion should be kept at a minimum (e.g. distributing electronics along available perimeter and over available surface).
Case position	licking and scratching.	Case should be positioned on an area not reachable by tongue (e.g. the nape).
Area covered by collar and case	scratching.	Area should be kept at a minimum, in trade-off between covered area and protrusion.
Device's inner protrusion in contact with skin	licking and scratching.	Eyelets, seams and similar inner protrusions should be avoided.

Collar fastening method	scratching.	Fastening methods that may catch fur should be avoided.
Movement of collar around neck	scratching.	Fastening mechanisms should allow case to slide within a restricted range of nape.
Case material	rubbing and body-rolling.	Hard materials that disrupt rubbing should be avoided; materials should be odorless.
Collar material	difficulty of fitting collars on cats due to hair length.	Low-tension elasticated and frictionless material that prevents collar from getting loose should be preferred.

Table 8. Design features and relative requirements.

Changing What 'Pet-friendly' Means

The aim of this study was to investigate cats' experience when wearing off-the-shelf tags marketed for them, to identify indicators of discomfort and wearability flaws from which to establish design requirements useful to improve cat devices' wearability. Our findings show that cats might experience various degrees of irritation and discomfort while wearing trackers, even those products that are designed to be worn by them. This highlights the importance of committing to wearability as a design goal to be systematically pursued in animal biotelemetry design practice. In this regard, a key question is to what extent the attributes 'comfortable for pets', 'ergonomically designed' [24], and more generally 'pet-friendly' are based on the actual wearer experience of cats and other target species. Pet tracker companies seem to address the demand of paying customers by providing products that appeal to their aesthetic sense and satisfy the functional need to 'keep an eye' on their pets and enjoy the 'peace of mind' that comes with the reassurance that they will be able to retrieve their animals should they get lost [24]. This translates into a design that is together reliable, sturdy, usable, and pleasant in humans' perception, and supposedly comfortable for animal wearers. However, how animal comfortability is addressed is still up to what we, as humans, imagine might be comfortable for an animal. In most cases, this means focusing on weight and size, and on some ergonomic aspects such as physical adaptability (e.g. through adjustable parts). These are still relatively rudimentary parameters that do not account for the range and complexity of animal wearers' experience and its physiological, psychological and social dimensions. Nor do they attempt to modulate such an experience capitalizing on the many design dimensions that might qualify a physical artefact (e.g. materials, shapes, colors, texture, sound). This speaks volumes about the imbalance currently existing between user and wearer requirements, when the wearers are nonhuman animals. To help redress this imbalance and design wearables that are truly animal-friendly, a systematic, data-driven approach is needed to eliciting animal-centered requirements that accord with the animal form (as happens for human wearables), together with a conscious effort to give animals proper consideration as primary stakeholders of the devices they wear in order to properly balance the needs of users and wearers. The present study provides a data-driven example of how systematic evaluations of animals' experiences with wearables can be undertaken to identify animal-centered requirements useful to improve the 'animal-friendliness' of tags. Another form of systematic account of animals as primary stakeholders is the implementation of requirement analysis through the use of design frameworks. For example, in a parallel study [23], we built a cat-centered prototype following the wearability requirements established by designers through the application of a wearer-centered framework during dedicated design workshops. When we evaluated the prototype with cat wearers, we found that cats responded well to the resulting wearer-centered device. We hope that this work will encourage researchers and producers of wearable technologies for animals to take systematic approaches to wearable design and evaluation from an animal wearer's perspective.

CONCLUSIONS

Monitoring pets through electronic wearables is an increasing trend. While humans are users, animals are wearers directly affected by carrying tags on their bodies, thus primary stakeholders. Improper fitting and physical design inconsistent with the wearers' characteristics interfere with the sensory and physical experience of animals, with adverse consequences for their welfare and unreliable results for human consumers. Designing for animal wearability is central for improving the quality of both wearers' and users' experience. Thus, it is essential to understand how animals experience the wearables they are fitted with. To this end, this paper presents an observational study with 13 cats, during which their behavioral responses while wearing devices were recorded under three experimental conditions, including wearing one or the other of two off-the-shelf tags, or wearing nothing. The aim was to investigate the experience of cats, to find any flaws in the wearables' design that could serve to systematically establish species-specific requirements for wearability. Committing to wearability as a design goal promises to improve animal biotelemetry design and practice.

REFERENCES

[1] Ruud van den Bos. 1998. Post-conflict stress-response in confined group-living cats (Felis silvestris catus). *Applied Animal Behaviour Science* 59, 4, 323–330. https://doi.org/10.1016/S0168-1591(98)00147-6

[2] Buskerscat.com. 2020. The 9 best cat trackers of 2020. Retrieved January 29, 2020 from https://www.buskerscat.com/best-cat-tracker-uk

[3] Ruth M. Casper. 2009. Guidelines for the instrumentation of wild birds and mammals. *Animal Behaviour* 78: 1477–1483.

[4] Sj Cooke. 2008. Biotelemetry and biologging in endangered species research and animal conservation: relevance to regional, national, and IUCN Red List threat assessments. *Endangered Species Research* 4: 165–185. https://doi.org/10.3354/esr00063

[5] Cayley E. Coughlin and Yolanda van Heezik. 2015. Weighed down by science: do collar-mounted devices affect domestic cat behaviour and movement? *Wildlife Research* 41, 7: 606–614.

[6] Marian Stamp Dawkins. 2007. *Observing animal behaviour: design and analysis of quantitative data.* Oxford University Press, Oxford.

[7] Francine Gemperle, Chris Kasabach, John Stivoric, Malcolm Bauer, and Richard Martin. 1998. Design for wearability. In *Wearable Computers, 1998. Digest of Papers. Second International Symposium on*, 116–122. Retrieved November 3, 2015 from http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=729537

[8] Alan Grafen, Rosemary Hails, and Rosie Hails. 2002. *Modern statistics for the life sciences.* Oxford University Press, Oxford.

[9] Penny Hawkins. 2004. Bio-logging and animal welfare: practical refinements. *Memoirs of National Institute of Polar Research. Special issue* 58: 58–68.

[10] Penny Hawkins. 2014. Refining housing, husbandry and care for animals used in studies involving biotelemetry. *Animals* 4: 361.

[11] IBM Corp. Released 2012. *IBM SPSS Statistics for Windows, Version 21.0.* Armonk, NY: IBM Corp.

[12] Melody M. Jackson, Giancarlo Valentin, Larry Freil, Lily Burkeen, Clint Zeagler, Scott Gilliland, Barbara Currier, and Thad Starner. 2015. FIDO—Facilitating interactions for dogs with occupations: wearable communication interfaces for working dogs. *Personal and Ubiquitous Computing* 19, 1: 155–173. https://doi.org/10.1007/s00779-014-0817-9

[13] Robert E. Kenward. 2000. *A Manual for Wildlife Radio Tagging.* Academic Press.

[14] J.F. Knight, D. Deen-Williams, T.N. Arvanitis, C. Baber, S. Sotiriou, S. Anastopoulou, and M. Gargalakos. 2006. Assessing the wearability of wearable computers. In *2006 10th IEEE International Symposium on Wearable Computers*, 75–82. http://doi.ieeecomputersociety.org/10.1109/ISWC.2006.286347

[15] Greger Larson and Daniel G. Bradley. 2014. How much is that in dog years? The advent of canine population genomics. *PLoS genetics* 10: e1004093.

[16] Philip N. Lehner. 1998. *Handbook of ethological methods.* Cambridge University Press.

[17] Clara Mancini. 2013. Animal-computer interaction (ACI): changing perspective on HCI, participation and sustainability. In *Extended Abstract on CHI'13*, 2227–2236. https://doi.org/10.1145/2468356.2468744

[18] Clara Mancini. 2017. Towards an animal-centred ethics for Animal–Computer Interaction. *International Journal of Human-Computer Studies* 98: 221–233. https://doi.org/10.1016/j.ijhcs.2016.04.008

[19] Paul Martin and Patrick Bateson. 1993. *Measuring behaviour: an introductory guide.* Cambridge University Press.

[20] David B. Morton, Penny Hawkins, Richard Bevan, K. Heath, James Kirkwood, Peter Pearce, L. Scott, Greg Whelan, and A. Webb. 2003. Refinements in telemetry procedures. *Seventh report of the BVAAWF/FRAME/RSPCA/UFAW Joint working group on refinement, part A. Lab Anim* 37, 4: 261–299.

[21] 2016 NVivo qualitative data analysis Software; QSR International Pty Ltd. Version 11. 2016.

[22] Patrizia Paci, Clara Mancini, and Blaine A. Price. 2017. The role of ethological observation for measuring animal reactions to biotelemetry devices. In *Proceedings of the Fourth International Conference on Animal-Computer Interaction* (ACI2017), 5:1–5:12. https://doi.org/10.1145/3152130.3152144

[23] Patrizia Paci, Clara Mancini, and Blaine A. Price. 2019. Wearer-Centered Design for Animal Biotelemetry: Implementation and Wearability Test of a Prototype. In *Proceedings of the 2019 International Symposium on Wearable Computers*, 177–185. https://doi.org/10.1145/3341163.3347750

[24] Pawtrax. co.uk. PawTrax GPS Cat&Dog Trackers. Retrieved May 4, 2018 from https://www.pawtrax.co.uk

[25] N. L. Payne, M. D. Taylor, Y. Y. Watanabe, and J. M. Semmens. 2014. From physiology to physics: are we recognizing the flexibility of biologging tools? *Journal of Experimental Biology* 217, 3: 317–322. https://doi.org/10.1242/jeb.093922

[26] Rebecca Desfosse. 2020. The best GPS dog trackers & collars (2020 reviews). *Puplife Today*. Retrieved January 29, 2020 from https://puplifetoday.com/best-gps-dog-trackers/

[27] Pavan Sikka, Peter Corke, Philip Valencia, Christopher Crossman, Dave Swain, and Greg Bishop-Hurley. 2006. Wireless adhoc sensor and actuator networks on the farm. In *Proceedings of the 5th international conference on Information processing in sensor*

networks, 492–499. Retrieved April 28, 2016 from http://dl.acm.org/citation.cfm?id=1127852

[28] Lauren Ashley Stanton, Matthew Stephen Sullivan, and Jilian Marie Fazio. 2015. A standardized ethogram for the felidae: A tool for behavioral researchers. *Applied Animal Behaviour Science* 173: 3–16. https://doi.org/10.1016/j.applanim.2015.04.001

[29] Thekennelclub.org.uk. 2014. More Than 70,000 Pets Missing In The UK - The Equivalent Of Ten Times The Population Of The City Of London. Retrieved January 29, 2020 from https://www.thekennelclub.org.uk/press-releases/2014/june/more-than-70-000-pets-missing-in-the-uk-the-equivalent-of-ten-times-the-population-of-the-city-of-london/

[30] Niko Tinbergen. 1963. On aims and methods of ethology. *Ethology* 20: 410–433.

[31] Trackimo.com. Trackimo 3G Guardian GPS tracker. *Trackimo always there*. Retrieved January 29, 2020 from https://store.trackimo.com/products/3g-trackimo-guardian

[32] Tractive. com. Tractive GPS Tracker for Dogs and Cats. Retrieved May 4, 2018 from https://tractive.com/uk_en

[33] Graham Upton and Ian Cook. 2008. Central Limit Theorem. *A Dictionary of Statistics*.

[34] Giancarlo Valentin, Joelle Alcaidinho, and Melody Moore Jackson. 2015. The challenges of wearable computing for working dogs. 1279–1284. https://doi.org/10.1145/2800835.2807925

[35] Giancarlo Valentin, Larry Freil, Joelle Alcaidinho, Jay Zuerndorfer, Celeste Mason, and Melody M Jackson. 2015. Wearable alert system for mobility-assistance service dogs. 184–203.

[36] Kristen A Walker, Andrew W Trites, Martin Haulena, and Daniel M Weary. 2012. A review of the effects of different marking and tagging techniques on marine mammals. *Wildlife Research* 39: 15–30. https://doi.org/10.1071/WR10177

[37] Stephan von Watzdorf and Florian Michahelles. 2010. Improving the Design of Track and Trace Products: Evidence from a Field Study on Pet Tracking Devices. 177–180. https://doi.org/10.1109/SUTC.2010.69

[38] Gary C. White and Robert A. Garrott. 1990. *Analysis of Wildlife Radio-Tracking Data*. Elsevier.

[39] Christopher C. Wilmers, Barry Nickel, Caleb M. Bryce, Justine A. Smith, Rachel E. Wheat, and Veronica Yovovich. 2015. The golden age of bio-logging: how animal-borne sensors are advancing the frontiers of ecology. *Ecology* 96, 7: 1741–1753. http://dx.doi.org/10.1890/14-1401.1

[40] Rory P. Wilson and Clive R. McMahon. 2006. Measuring devices on wild animals: what constitutes acceptable practice? *Front Ecol Environ* 4, 3: 147–154. https://doi.org/10.1890/1540-9295(2006)004[0147:MDOWAW]2.0.CO;2