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Wearer-Centered Design for Animal Biotelemetry: Implementation and Wearability Test of a Prototype

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ABSTRACT

In this paper we present an approach to designing wearer-centered biotelemetry for non-human (and human) animal wearers. Drawing from fundamental values and principles of user-centered design, we describe a wearer-centered framework to heuristically establish design requirements, which was used during a series of workshops to perform a requirements analysis for a cat-tracking device. The resulting requirements informed a feline-centered prototype whose wearability was evaluated with cat wearers. Compared to the wearability of previously tested off-the-shelf devices, our findings show an improvement and suggest that our framework-based approach can help design teams with a range of skills to systematically design for wearability.

CCS CONCEPTS

• Interaction Design process and methods • Ubiquitous and mobile computing design and evaluation methods

KEYWORDS

Animal-Computer Interaction; animal biotelemetry; wearability; wearer-centered design

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1 Introduction

Telecommunication and satellite technologies are increasingly being exploited for the monitoring of pets. A variety of wearables are being sold on the market to satisfy the need of

pet carers who are interested in quantifying and managing their pets' activity [11]. Indeed, phenomena like lifelogging and quantification have become a new trend among pet carers worried about the safety and health of their animal companions [1]. However, there is evidence that wearing tracking devices may impact animals physically and behaviorally; for example, electronic tags mounted on collars or harnesses may snag in vegetation, abrade the skin or fur, and increase the intensity of behaviors such as overgrooming [2]. These issues raise welfare concerns about the appropriateness of using wearables with animals.

In a recent study, Paci et al. [7] used specific behavioral indicators to evaluate the response of domestic cats to two off-the-shelf collared devices marketed as cat-friendly. The authors found increments of head shaking and scratching (regarded as indicators of discomfort) in the area of attachment, and peculiar responses (such as cuffing and biting) directed at the device. They also found that these responses were attributable to design features of the tags' components, highlighting a need for ergonomic improvement (for example, a bulky case protruding under the chin prompted some of the cat participants to cuff and bite the device seemingly in an attempt to remove it). Building on these findings and on the extensive literature on the impacts of animal biotelemetry [2, 12], our research addresses wearability-related problems in animal wearables. In this paper, we report on the evaluation of a wearer-centered framework (the WCF) that interprets and adapts fundamental values and principles of user-centered design to inform the design of animal biotelemetry by systematically guiding designers through a requirements analysis that sees animal wearers as the primary stakeholders. We present the first application of the WCF in a series of workshops during which different design teams, with varying backgrounds and expertise, applied the framework to establish design requirements for a cat-tracking prototype. Our findings suggest that our framework-based approach can help design teams with a range of skills to systematically design for wearability.

The assumption behind this work is that designing for *good wearability* leads to a reduction of the effects of tagging, thus improving the bodily experience that wearers have when

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wearing a tag and, consequently, their welfare. At the same time, reducing the effects of tagging reduces device-induced interference on the wearer's behavior and physiology, thus enabling monitoring technology to collect more reliable data, consistent with the caring purposes of human users. From a philosophical perspective, this work is fundamentally informed by, and consistent with, the disciplinary values of *Animal-Computer Interaction (ACI)*, an emerging field whose mission is to advance research and practices related to the design of technologies for animals, recognizing them as the central stakeholders [6].

2 A Wearer-Centered Framework

Although animals do not *use* the monitoring devices they wear (e.g. by intentionally activating them), they have a bodily interaction with them, which can generate impacts and result in a negative *wearer experience*. In order to develop devices that are useful for human carers (who choose to use them to obtain information from their pets) and that, at the same time, do not impinge on their pets (who do not choose to wear them), it is essential that designers understand the *wearer experience* as far as possible.

The WCF, which we introduced elsewhere [8], aims to foster designers' understanding of the wearer experience as they establish requirements for animal wearables. We have developed the original framework further; and the version summarized here consists of seven interconnected components which designers can consider and work through. These are described below:

1. **Values and principles for wearability.** *Usability* and *experience* are key concepts in user-centered design and depend on a product's ability to provide a positive sensory, cognitive and physical interaction [9]. However, when interactors are not also users and do not cognitively engage with a product, the extent to which a product affords good wearability and wearer experience depends on the extent to which the physical and sensory interaction with it disappears in the background of the wearer's daily experience. Thus, the key value and main conceptual trigger to designing for good wearability and wearer experience is *annulment of effect* (i.e. achieving the ideal condition of producing no impact or, when this is not possible, endeavoring to minimize any effect). This can be achieved by observing three fundamental principles: *sensory imperceptibility* (i.e. a device should not be at all perceived), *physical unobtrusiveness* (a device should not impede limb movements or access to locations) and *cognitive acceptability* (the presence of a device should be acceptable to the wearer).
2. **Species knowledge.** In order to comply with the above principles, it is essential that designers understand the species they design for, appropriately referring to experts, species-specific literature and ethograms (i.e. description

of the behavioral repertoire of a species) to acquire relevant biological information.

3. **Animal variables.** It is also essential that designers focus their thinking on the characteristics of the interactors, their activities and environments, consistent with their biology and lifestyle.
4. **Interactor ecology.** Designers need to consider not only the individual wearers, but also other individuals related to and significantly interacting with them (e.g. prey, predators, offspring) who may be affected by the technology.
5. **Device design.** Further, designers need to consider the physical and functional aspects of the tag they are designing.
6. **Requirements and capabilities.** Working through steps 1-5 above, designers can identify a series of *wearability requirements* (accounting for the need of animal wearers), *usability requirements* (accounting for the needs of human users) and *system capabilities* (accounting for any technological constraints).
7. **Trade-offs.** Considering the needs of the different stakeholders (animal wearers and human users) as well as technological capabilities and constraints allows designers to identify conflicting requirements and possible trade-offs, necessary to achieve practical solutions that are both appropriately wearable and functional.

In brief, given the availability of resources (e.g. animal experts, ethograms, etc.) that allow designers to understand the species of interest (*species knowledge*), the *values and principles for wearability* would help the designer to identify the set of *animal variables* that inform the wearer needs that are also relevant for the *interactors*. Principles and values would also help designers to individuate *device features, components and attachments* that need to be designed to achieve wearability in relation to the set of variables identified. From the combination of wearer needs and device design *wearability requirements* are derived. Wearability and *usability requirements*, along with *system capabilities*, need to be *traded-off* in order to identify possible designs that provide optimal wearability and functionality. The WCF focuses on what is ideal for the wearer; user requirements and system capabilities are analyzed only to identify suitable trade-offs.

For example, consider a project that makes use of trackers to monitor stray cats. Biotelemetrists aim at using devices that do not affect the individuals being monitored. Wearer-centered designers are involved in the design of the tags. As they use the WCF as a guiding tool, they recognize cat wearers as the key interactors, applying the principles one at a time. They firstly focus on the principle of sensory imperceptibility for the sense of hearing and aim at designing an aurally imperceptible tag. They consult an animal expert to acquire the relevant information regarding the wearer and the wearer's significant others. The WCF helps them consider who the prey and predators of cats are, which hearing capabilities all possess (e.g. which frequencies are audible by the species of interest),

which critical and delicate activities the tag might influence (e.g. by interfering with mating calls, alerting and dispersing prey, disrupting ambushes), and which environments have to be considered (e.g. type of habitat that propagates sound). This process enables designers to determine and focus on the interactors' needs. Next, electronic components of the device that may be responsible for frequency emission are individuated. Wearability requirements for the tag are thus established in relation to the components that need to be designed and in relation to the sensory characteristics of cats and of their significant others, excluding components that contravene aural perceptibility as far as possible.

3 Collaborative Requirements Workshops

To validate the usefulness of the WCF as a design tool, we conducted three separate one-day workshops during which three teams of designers respectively were asked to use the WCF to establish design requirements for a collared tracking device for domestic cats. Cats were chosen as a model species due to their ubiquity and tractability but also relative independence, and for consistency with the study conducted by Paci et al. [7]. The *collaborative requirements workshops* [3] were organized following a template derived from the +ACUMEN-IDEO.org course for roughly prototyping a physical artefact [4]. The aim of the workshops was to facilitate a collaborative design process, allowing participants to perform a 'quick and dirty' requirements analysis and prototyping activity in a relatively short time. We identified three categories of stakeholders with which to test the WCF. They were computer scientists (team 1), biologists (team 2), and cat carers (team 3). Differentiating the composition across teams served to explore whether the background of participants would influence the application of the WCF.

The workshops consisted of four parts: 1) an introduction phase, whose aim was to expose the problem of impacts on animal wearers and explain the WCF role in the design process; 2) an instruction phase, in which the WCF components were illustrated and their use explained; 3) an exploration phase, in which designers were asked to apply the WCF to a case study for which they needed to establish wearability requirements (designing a tracking device for cats); 4) a crafting phase, in which the team was asked to build a low-fidelity mock-up based on the requirements discussed during the exploration phase and whose purpose was just to help designers refine the requirements they had previously identified. During the workshops, designers were invited to confer with each other and share their thoughts, ideas, and design propositions. They were also asked to describe the low-tech mock-ups crafted during the crafting activity and to discuss their design details. The designers' conversations and activities were video-recorded to facilitate post-study data processing, which consisted of transcribing the participants' dialogues and linking their words to the actions they performed during the

crafting activity. From the transcripts, statements were collected to gather the wearability requirements identified by each designer team, resulting in three sets of requirements.

3.1 Workshop Requirements

Each team identified a set of requirements, from which we derived a sub-set of 22 requirements, 13 of which were in common across all of them, 3 of which were in common across two teams and 6 were identified by a single team (see Table 1). The sub-set was derived by applying the following criteria:

- a) All the requirements that were in common across the three teams were selected.
- b) Where they differed, the requirements were chosen from one or another set, depending on the extent to which data from the respective designer team showed evidence that the designers considered wearability implications and expressed aspects accounted for by the framework. For example, team 1 specified that the device should be a single piece of elasticated material in order to avoid buckles or Velcro that could scratch or chaff the cats' skin, while team 2 opted for standard collars to be easily fastened through closing mechanisms. In choosing which solution could achieve better wearability, we selected the avoidance of fastening mechanisms since the proposing team was concerned about the discomfort that any fastening method could cumulatively produce on the wearers over time, while the other group was more worried about the momentary difficulty of fastening the collar. In other words, the perspective of the former was more wearer-centered than the latter's.
- c) If a requirement was identified by only one team, it was selected.

The derived requirements are reported here in reference to specific device features (in *italics*) as follow:

Exterior protrusion: 1) components should be narrow, thin, and distributed along the collar to avoid protrusion; 2) case should protrude minimally outward the edges of the collar;

Position of the case: 3) the case should be positioned on the least intrusive and least reachable place on the cat's body (i.e. near the shoulder blades/base of neck);

Area covered by collar and case: 4) components should be distributed along the collar to avoid protrusion; 5) collar should be narrow to minimize the body's area covered but not threadlike;

Protrusion of the device inner surface in contact with the cat's skin: 6) components should not bulge inward against the neck of the animal (at least);

Collar fastening method: 7) buckles or Velcro strips should be avoided because they could scratch/chafing the skin or pull the hair; 8) collar should be easy to attach;

Case material: 9) it must have a protecting thin coating in turn wrapped by soft and flexible material; 10) materials that have odors should be avoided to not irritate cats' smell sensitivity;

Collar material: 11) collar should be made of soft and flexible material to not irritate cats' skin and adapt to the neck form;
Device weight: 12) the device should be as light as possible to avoid extra burden;
Device color: 13) the device should be blended with the animal's fur color to avoid disrupting camouflage;
Components connection: 14) components should be wired together and not communicate wirelessly to avoid unwanted background noise;
Light spectra / (ultra)sound frequencies: 15) emissions perceivable by the wearer should be avoided to not irritate cats' sensory perception;
Batteries characteristics: 16) chargeable wireless stations should be preferred to minimize the weight of batteries;
Aerial's characteristics: 17) the aerial should be diffuse all around the collar to allow a reliable signal (not dependent on the electronics' position);
Safety: 18) the device should be easily released if wearers get entangled;
Device retrievability: 19) the device should be somehow retrievable if lost;
Collar adjustability: 20) collar should be adjustable to the neck size;
Device visibility: 21) the device should be inconspicuous for other animals (e.g. avoiding reflective material);
Personalization: 22) modular adds-on may render the device user personalized and more sellable.

N of teams supporting the requirements	Requirement n.	Tot
3 teams	1, 2, 3, 4, 5, 6, 9, 11, 12, 14, 14, 18, 19.	13
2 teams	15, 16, 21	3
1 team	7, 8, 10, 17, 20, 22	6

Table 1: Requirements supported by 3 teams, 2 teams, and 1 team

A few (i.e. 5 out of 22) requirements identified during the workshops appear to be more functional and user-centered than wearer-centered (i.e. having a device easy to attach; covering the components with a protecting layer; having a reliable signal; making the device easily retrievable; and personalizing the device with adds-on). However, the design features that these requirements implied would in fact lead to improvements benefitting wearability (a device that was easy to attach would likely reduce the cats' stress induced by attaching procedures; a thin case would minimize protrusion and the need of a hard encase; a threadlike antenna would help reducing the bulkiness of the device; using a GPS signal to retrieve lost devices would not add extra components).

4 Prototyping Stage

In order to test the extent to which the application of the WCF could be operationalized, we used the sub-set of wearability requirements heuristically established by the designers during the workshops to design a prototype tracking device for cats (Figure 1).

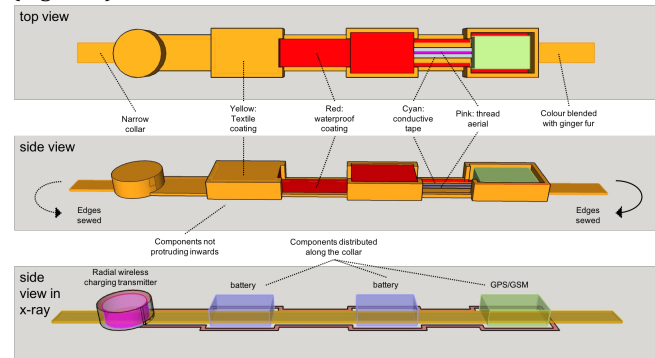


Figure 1: The sketched prototype derived by the workshop requirements

4.1 Sketched Prototype

As established by all three teams, in order to maximize wearability, the device had to be a narrow built-in collar; not protruding inwardly and minimally protruding outwardly; weighing less or no more than the lightest device on the market; color blended with individuals' fur; easy to take off; retrievable; soft textured; wrapped in a thin waterproof coat; featuring thin and narrow components distributed along the collar and aligned end-to-end, connected to each other through some conductive material.

During sketching, to implement the requirement that the tag should be as light as possible, the number and sizes of the electronic components were assumed as in the PawTrax® Halo tracker tested in Paci et al. [7], which, at the time of this research, was the lightest GPS available on the market (weighing 21.7 grams), including two batteries, an integrated GPS/GSM unit, an antenna, and a charging element.

As proposed by team 1, we opted for a unique piece of elasticated collar that can be pulled on and off the cat's head without needing to fasten and unfasten the collar extremities. This solution was chosen to avoid fastening mechanisms that might irritate the cat's skin. This feature also affords safety since a low-tension elastic textile pulls easily off the neck if stretched, as hypothesized by the team.

Although the need to use soft and flexible material was established by all three teams, there was no agreement on a specific material. Following the concern from team 2 that devices should be odorless, the use of silicone or rubbery material was dismissed, since these might emit strong odors. Instead, fabric was chosen as proposed by both team 1 and 2.

There was no agreement across teams about how to recharge the batteries, with team 2 proposing that these should

be detached when out of power and the other two teams (2 and 3) positing that the batteries should be charged wirelessly. Since both battery detachability (to avoid potential battery overheating) and wireless recharging (to minimize intrusiveness) were suggested based on wearer-centered considerations, the sketched device was designed to have a radial wireless charger as established by two of the teams.

We ensured that any actuation sound was avoided consistent with the requirement that acoustic signals should be avoided, established by teams 1 and 2.

Also, team 2 established that visual (e.g. LED) and osmic elements should be avoided on the grounds that they increase the likelihood that the device is detected by other individuals; and team 3 proposed that, in order to reduce the bulkiness of the tag, the antenna should be a threadlike aerial along the collar.

When it came to implementing the prototype, some of the features were partly modified based on the available resources and the feasibility of what the workshop designers had proposed. This resulted in an actual prototype that partially differed from the one sketched in Figure 1.

4.2 Actual Prototype

The actual cat-centered prototype is illustrated in Figure 2. Its technological components are those of a disassembled PawTrax® Halo device (these were chosen to keep the collar as light as possible). Components included two lithium batteries (3.7 v, 160 mAh), a micro USB port, a switch, a customized GPS/GSM unit and an antenna (from left to right in Figure 2a). In the original product, the components were wired together and kept side by side inside two rigid boxes. For the prototype, the electronics were disconnected and re-wired together to evenly distribute them and thus allow flexibility. Then, they were wrapped inside a thin waterproof coat (Figure 2.b). Furtherly, the wrap was placed on a 9mm-width elasticated band, which was covered with a textile (Figure 2.c). In this way, the elastic band was inserted into the fabric wrap which could slide along it. Finally, the two elastic band's edges were sewn together to make a collar (Figure 2.d) and the seam was slid under the textile cover in order to hide any discontinuity of the band's inner line that might prickle the skin. Figure 2.e shows the prototype attached to a life-size stuffed cat toy.

When designing the actual prototype, we tried to follow the sketch in Figure 1 as much as possible. The concept of a built-in collar made of a soft and stretchy textile was implemented; the solution of an unclasped collar in the shape of a hoop was adopted; the overall device was kept as narrow as possible by choosing a narrow elasticated band; the electronics were coated with a thin protecting film; the components were distributed along the band as much as possible to minimize their inner and outer protrusion.

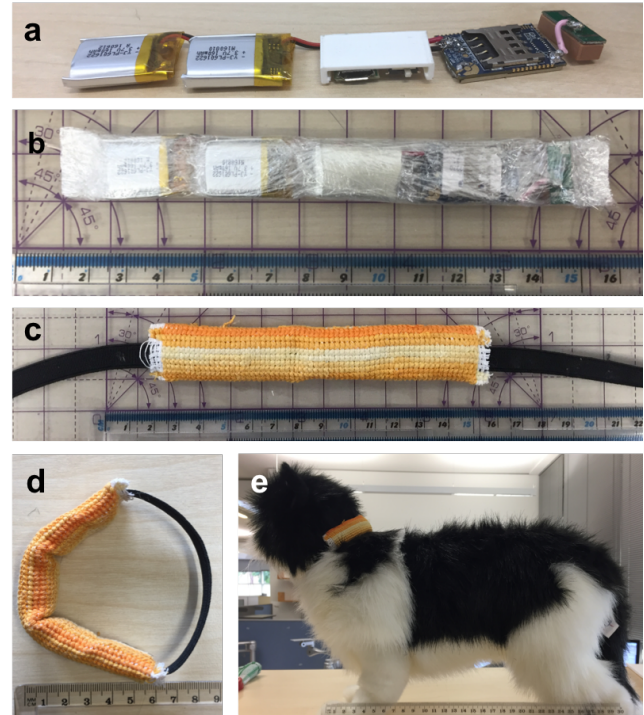


Figure 2: The actual prototype - a) the components wired together to allow flexibility, b) the components wrapped inside a thin protecting layer, c) the wrap is covered with textile, d) the completed prototype, e) the prototype worn by a stuffed cat

As mentioned above, due to feasibility issues that emerged while making the collar, some features had to be traded-off. Firstly, the idea of having the component spread at equal intervals all around the collar had to be modified due to the difficulty of crafting a complex stretchy design. For example, we could not find stretchy but resistant conductive material to connect the electronics such as coiled or elasticated wires, or elasticated conductive tape, or conductive ink resistant to pulling stress. Hence, normal wires were used to connect all the parts together, resulting in a narrower distribution of the components contained in a flexible but non-stretching section, connected to a 'naked' elastic band that provided the stretchy function. Secondly, we did not have the availability of a threadlike aerial. Thus, we used the rectangular one obtained by disassembling the PawTrax device. Thirdly, the wireless charging transmitters available were too big and heavy to accord with the requirements of keeping weight and size of the device to a minimum. Thus, we opted for a standard mini-USB charging port. In spite of these trade-offs, from a wearability perspective, the prototype featured important differences from the devices previously tested by Paci et al. [7], as discussed later.

To see whether the prototype afforded improved wearability, we evaluated it with cats. In particular, we contacted the same cat carers who had participated in [7]'s

study so that we could conduct the evaluation with the same cats.

5 Wearability Test of the Prototype

In Paci et al.’s study [7], thirteen cats were observed while wearing two off-the-shelf devices (a PawTrax® and a Tractive®). Their behaviors were recorded and analyzed to detect and measure behavioral indicators of discomfort. Scratching, shaking, and episodes of direct interactions (e.g. licking the case or cuffing it with forepaws) were identified as behaviors that evidence device-induced discomfort, while species- or breed-specific behaviors (e.g. how cats rub on surfaces to deposit their scent, signal their presence and mark territory) and contextual features (e.g. the type of surfaces on which cats rubbed their bodies) were accounted for as providing design-related information.

These same behaviors were measured, and the same context accounted for again when we evaluated the wearability of our prototype. Two of the thirteen cats from Paci et al. [7]’s study who had shown significant reactions to the commercial devices took part to our evaluation, which also took place in the same environment (i.e. the cats’ home). To comply with ACI ethics standards [6], the selection of participants was determined by a compromise between the need to acquire feedback directly from the animals in a way that was sufficiently informative and the need to minimize any disruption or risk of stress for the cats.

5.1 Observational Protocol

The two participants were fitted with the prototype for 6 continuous hours over a period of one day and they were observed for 20 minutes of every hour for each of the 6 hours. Occurrences of licking strokes at the collar region, scratching, and head/body shaking were counted, employing an all-occurrences sampling technique. This consists of counting each episode of pre-selected behaviors during a determined period of time [5]. We also recorded whether any direct interaction that the two cats had performed during Paci et al. [7]’s study occurred while the participants were wearing our prototype. For example, if in Paci et al. [7]’s study a cat had cuffed the device, we noted whether the same cat performed the same behavior during the evaluation of our prototype. Then we compared the occurrences of the recorded behaviors with those recorded for the same cats by Paci et al. [7] to assess whether the cats experienced less, more or equal discomfort. Furtherly, we annotated any information deemed important for assessing the wearability of our prototype. The complete set of Paci et al. [7]’s findings used to compare our prototype with the PawTrax and Tractive devices was made available in [13].

5.2 Findings

Two types of outcome are reported in this section: measures of the behaviors (corresponding to those performed by the same

cats in Paci et al. [7]’s study and fully reported in [13]), and further observations regarding the design of the prototype.

5.2.1 Measures of behaviors. Tables 2 and 3 show the number of occurrences for licking, scratching and head/body shaking we recorded for cat 1 and cat 2 respectively while they were wearing the prototype, against the same behaviors reported in [13] while the same cats were wearing the PawTrax, and Tractive devices.

Device	N. of occurrences cat 1		
	Licking	Scratching	Shaking
Prototype	0	5	11
PawTrax	0	9	20
Tractive	1	21	12

Table 2: Occurrences of licking the collar area, scratching and head/body shaking in cat 1 while wearing the prototype, the PawTrax, and Tractive devices

Device	N. of occurrences cat 2		
	Licking	Scratching	Shaking
Prototype	1	11	14
PawTrax	0	18	18
Tractive	4	5	18

Table 3: Occurrences of licking the collar area, scratching and head/body shaking in cat 2 while wearing the prototype, the PawTrax, and Tractive devices

During our evaluation, cat 1 never licked the collar area while wearing the prototype. This finding was similar to those reported with PawTrax and Tractive. Cat 1’s scratching behavior occurred less while wearing our prototype (5 times) compared to the findings reported with PawTrax (9 times) and Tractive (21 times). The cat’s head/body shaking was also less frequent (11 times) compared to the findings previously reported with PawTrax (20 times) although the behavior’s occurrence was similar compared to findings reported with Tractive (12 times).

For cat 1, there are eight peculiar responses reported [13] directed at the PawTrax and Tractive devices: scratching repeatedly the same spot on the collar, scratching the area around the collar insistently, scratching alternatively on both sides of the neck, scratching the case, scratching the nape where the buckle/Velcro of the Tractive/PawTrax was, attempting to bite the case, licking the collar area, and rolling the head trying to catch the case. However, while cat 1 was

wearing our prototype we observed only two of those behaviors: scratching the case and scratching the nape.

While wearing our prototype, cat 2 licked the collar area once, fewer occurrences compared to those reported with Tractive (4 times), although the behavior's occurrence was similar to that previously reported with PawTrax. For this cat, occurrences of scratching behavior were also fewer with respect to those previously recorded with PawTrax (11 versus 18), although there were more occurrences compared to those previously recorded with Tractive (11 versus 5). While cat 2 was wearing our prototype, the frequency of head/body shaking was slightly lower with respect to those previously recorded for both PawTrax and Tractive (14 versus 18).

As reported in [13], cat 2 performed ten peculiar responses directed at the PawTrax and Tractive devices: scratching repeatedly the same spot on the collar, scratching the area around the collar insistently, scratching alternatively on both sides of the neck, scratching the case, licking the case, attempting to bite the case, licking the collar area, actually biting the case, rolling the head, and rolling the body on the floor. However, while cat 2 was wearing our prototype, we observed only four of those behaviors: scratching repeatedly the same spot on the collar, scratching the area around the collar insistently, scratching the case, and licking the collar area.

5.2.2 Further observations. An important observation regarded the ease and speed with which we could fit the stretchy collared prototype on the two cat participants. Pulling the elasticated hoop and sliding it over the head was a two-movement operation, quick to perform. Cats did not need to be held and remained in their resting position during the fitting process. In practice, they were either sitting or lying on their bellies, and did not move while the experimenter was fitting the prototype collar. In contrast, fitting the PawTrax and Tractive required placing the collar around the neck and then attaching its two extremities. In [13] it is reported that when fitting the commercial devices' collars, the thirteen participants of Paci et al. [7] reacted with individual responses such as sneaking, crouching, retracting their head or rolling it to look at what was happening, or hitting the approaching human hands with a paw. These behaviors could have been triggered by the way in which the experimenter approached, or by the extra time needed to close the devices' buckle or Velcro strips at the right collar's length, operations rendered more difficult by the hair tufts that could get caught in the fastening mechanism.

On the other hand, putting on our prototype was easier than taking it off. When we put it on, the cats' ears naturally retracted, favoring the required sliding movement; but when we pulled it off, the ears obstructed the sliding movement, so that the elasticated collar had to be stretched further. Nevertheless, the cats allowed us to take off the collar without any particular reaction, which suggested that they were not particularly affected.

5.3 Discussion of the Wearability Test

The aim of this evaluation was to investigate whether our prototype afforded better wearability in relation to the commercial devices previously tested by Paci et al. [7]. The investigation was conducted by measuring, under the same contextual conditions, how two of the cats involved in both studies responded to our prototype and whether their response differed from how they responded to the off-the-shelf devices in tests by Paci et al. [7], whose completed findings are available at [13].

Less intense direct interactions and lower scores of licking, scratching, and head/body shaking with our prototype suggest that our tag affected the wearers less. Our prototype evaluation shows lower occurrences of behavioral indicators of discomfort, including the absence of many of the reactions that the same cats had directed toward the devices [13]. In particular, with the exception of the scratching frequency for cat 2, with our prototype both cats showed fewer behaviors selected as indicators of discomfort and only few of the various peculiar responses directed at the device.

These findings suggest that our prototype provides a better wearer experience for the cats in relation to either the Tractive or PawTrax. Since the wearability features of our prototype were designed by applying the WCF, these preliminary empirical findings seem to suggest that the framework is a useful tool to inform wearability.

However, although these findings suggest that our prototype is less disruptive and thus affords better wearability compared to the previously tested commercial counterparts, some remaining wearability flaws will need to be addressed in future iterations. In particular, in most of the scratching bouts we observed, both cat 1 and cat 2 hit the fabric case with their claws. Although this did not trigger more intense responses (e.g. head rolling or case biting as it happened with the off-the-shelf devices [13]), it is apparent that the device prevents the cat from reaching the skin underneath the collar to relieve the itch it may be causing. This is probably the reason why cat 2 performed repeated double-scratchings on the same spot of the neck, some of which lasted several seconds. Indeed, the prototype's external encasement has a similar length and width to that of the PawTrax, with which the same cat had a similar behavior [13]. As mentioned above when we described the limitations of implementing the sketched prototype, we were unable to evaluate the solution we had designed. However, the fact that the same issue was reported with the PawTrax further highlights a need for collared devices to feature the slimmest case possible and evenly distributed components (Figure 1), enabling the wearer to easily scratch all around their neck when needed, as envisaged by the workshop designers who used the WCF.

Another important observation is that, unlike the findings with the PawTrax reported in [13], in our prototype evaluation neither cats scratched both sides of their neck in alternation. This behavior (reported in [13]) might have been due to the

fact that the PawTrax's collar features two distal inner eyelets, which might have exerted pressure or cause an itch on the sides of the cats' neck. In contrast, our prototype was seamless and had not inner protrusions and the fact that we did not record the behavior suggests that the design requirement according to which the surface in contact with the animal's skin should be kept as smooth as possible is a valid one.

Regarding the attachment method, the cats' apparent lack of reaction when we passed our stretchy prototype over their heads is noteworthy. The ease with which we could fit our stretchy collar might be attributed to three factors influencing the cats' behavior: 1) the position of the person fitting the collar relative to the cat, 2) the movement of the person's hands when inserting the collar, and 3) the speed of the operation. When passing the stretchy hoop over the cats' head our experimenter was facing the cats and their hands remained visible to the cats, allowing them to see movements, predict intentions, and exert some control over the situation. Likely the whole operation resembled a head stroke, something which domestic cats are used to and usually associate with a pleasant experience. Additionally, the stretchy collar was very quick to fit. In contrast, to buckle-up the off-the-shelf collars the experimenter approached the cat from behind or sideways and their hands operated outside the visual field of the cat, preventing them from predicting or controlling what was happening to them and possibly making them feel ambushed [10]. This might explain why, in [13], reactions such as fleeing, or retracting or tilting the head are reported, all behaviors that likely complicated the operation, requiring the experimenter to hold the cat or abort the fitting and restart later (with the cat likely expecting the same unpleasant experience); not to mention that buckling-up a collar takes some time and is complicated by the presence of hair. Overall, it is likely that our prototype's method of attachment and related fitting procedure influenced our experimenter's behavior, which in turn influenced the cats' behavior.

6 Discussion

Physical aspects of a tracking device can significantly impact on the animals who carry the tags on their bodies and defy the very purpose of monitoring, if the wearer's welfare is impoverished. This work was motivated by a need to reduce device-induced negative effects on wearers and, at the same time, by a lack of systematic approaches to designing for good wearability. We hypothesized that designing for good wearability would improve the bodily interaction that animal wearers have with tracking devices, thus reducing the impacts of tagging on animal wearers and improving human users' satisfaction with tracking devices. To achieve a wearer-centered design we proposed a Wearer-Centered Framework (WCF) as a tool that designers could use to conduct a systematic requirement analysis from a wearer's perspective and thus achieve optimal wearability in their design. In this

regard, we validated the usefulness of the WCF by conducting a series of workshops during which the WCF was applied by teams of designers to conduct a requirements analysis for a cat-centered tracking device; and we used the requirements identified during the workshops to design a prototype whose wearability was evaluated with cats against previously tested commercial products. As preliminary outcomes, we found indication that, with our prototype, the behaviors selected as indicators of possible discomfort either did not occur or occurred with less frequency and intensity in relation to findings previously reported for the same cats. This suggests that our prototype, whose design was informed by the WCF, provided a better wearer experience for cats than the off-the-shelf counterparts. In turn, this arguably suggest that the WCF could be a useful and valuable tool for designing wearable devices that afford good wearability.

The findings from our wearability test of the prototype are preliminary. Further experimental investigation with a larger number of cat participants and a firmer 'baseline' condition against which to compare the prototype would have provided a more robust validation of the WCF. However, the prototype that we tested (Figure 2) was a traded-off version and not the implementation of the exact requirements established during the workshop exercise. Conducting an experimental evaluation of such a prototype against the two-off-the-shelf devices and a control condition with a large number of cats would not have been appropriate at this stage of the design. Nevertheless, we wanted to evaluate the prototype that we had managed to realize against the ethological parameters that were used during the previous study with the off-the-shelf devices [7], in order to gather preliminary data to begin to validate the usefulness of the framework when establishing wearability requirements. Indeed, such an evaluation yielded interesting findings. For example, during the workshops it was established that soft materials such as fabric must be used to cover the electronics or that the collar should be an elasticated loop. The behavioral analysis of the data collected during the wearability test indicates that scratching a soft material did not produce the disruptive effect that was observed when the cats' claws hit the hard plastic of the off-the-shelf device, and that fitting an elasticated band on the cats' neck was better tolerated than fitting a collar with a fastening mechanism. Thus, although our wearability test does not provide overarching conclusions and does not quantify how much better the prototype design is compared to the off-the-shelf devices, it nevertheless provides evidence that better wearability was achieved for some features. The next iteration in this research will involve developing a prototype that implements the exact requirements identified during the workshops and conducting an experiment that compares the prototype against the off-the-shelf devices and a control condition.

When it comes to wearables, designing for usability and user experience is not sufficient to deliver a good product and it is critical to design for wearability, particularly where

wearers are not also users. The WCF extends the fundamental tenets of User-Centered Design to account for wearer experience. By providing essential values, principles, and goals of wearer-centered design, the WCF can help designers to systematically focus on animal wearer stakeholders, thus facilitating wearer-centred design and reducing wearable-induced impacts from wearables. From our workshops, we obtained evidence that the WCF enabled designers to elicit a wide range of wearability requirements, and findings from our wearability test seem to suggest that the prototype produced through the use of the WCF was better tolerated than the off-the-shelf devices. Further studies of the application of the WCF during specific design exercises are envisaged to validate the usefulness of the framework as a design tool. For example, we expect to conduct comparative analyses of requirements identified by groups of designers who have used the framework, on the one hand, and requirements identified by designers who have not used the framework, on the other hand. Similarly, we expect to compare the effects of prototypes resulting from the different sets of requirements. Through future studies of this kind, we hope to pinpoint more precisely how the WCF is used by designers, what its strength and limitation are as a roadmap tool and how it can be improved to best support the design process.

While our findings suggest that our application of the WCF could inform wearability in animal biotelemetry to the benefit of both animal wearers and human users, we propose that the WCF could similarly be applied to the design of a wide range of wearables for humans. Indeed, tools such as the WCF could facilitate wearer-centered design for many different categories of human interactors. In particular, non-voluntary human biotelemetry wearers, such as hospital patients, parolees, car drivers, and those whose job requires some degree of monitoring, may have no choice but to wear monitoring technology that is used by others, such as medical staff, judicial officers or insurance employees. This has ethical implications that a wearer-centered design approach can help address. Additionally, where wearers who are not also users do have a choice, poor wearability may result in non-compliance. For example, as with most biotelemetry equipment for animals, medical equipment in human hospitals and for ambulatory patients may be designed for the convenience of those who pay for it and want to use the data but not necessarily for the patient's convenience. In these situations, the technology may not adequately meet the wearer's requirements, which may result in patients not fully complying with medical monitoring. A design approach that systematically takes the wearer's perspective into account and helps designers identify the best possible trade-offs is likely to deliver better wearer experience, higher compliance, and a more ethical use of monitoring technology.

7 Conclusion

Using the wearability requirements established by workshop designers, we built a prototype and evaluated it with cat wearers. The aim was evaluating whether a Wearer-Centered Framework (WCF) had helped the workshop participants to design for cat wearability. Overall, the WCF enabled designers to establish requirements heuristically that were validated through the design and wearability test of the prototype. The evidence from the evaluation supports the thesis that wearability in animal tracking systems can be systematically designed by means of the WCF that was developed and that adopting wearability as a design goal has the potential of reducing negative effects of a wearer experience. Ultimately, the WCF could be employed as an instrument to inform design practice when the aim is placing (animal) wearers at the center of the design process.

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