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Designing for wearability: an animal-centred framework

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ABSTRACT

This paper presents a Wearer-Centered Framework (WCF) developed to support designing for good wearability in animal biotelemetry. Firstly, we describe the framework and the systematic process followed to develop it. Then, we report on how the WCF was evaluated with three teams of designers, who used it collaboratively to design a cat-centered tracking collar during dedicated workshops. We discuss our analysis of the designers' dialogues, whose aim was to understand the extent to which the framework informed the designers' thinking. Our findings indicate that the WCF was a useful tool to support the systematic elicitation of wearability requirements. They also suggest that designers could be provided with additional tools to support the WCF's application more effectively.

Author Keywords

Animal-Computer Interactions; animal biotelemetry; wearability; wearer-centered design; design framework.

ACM Classification Keywords

Interaction design theory, concepts and paradigms; Ubiquitous and mobile computing design and evaluation methods

INTRODUCTION

In our technological era, monitoring animals for scientific, husbandry, or caring purposes is often done by using electronic tracking systems attached to the animals' body [31]. Biotelemetry, the remote acquisition of data from animals, has enhanced knowledge about animals' biology and ecology. However, there is evidence that carrying biotelemetry tags can have negative impacts on individual animal wearers [29]. For example, external tags may snag in dense vegetation [6], add drag in water [32], rub and abrade the skin, feathers or fur [6], or increase the visibility of wearers with consequent greater exposure to predators or prey [11]. These impacts raise doubts about the validity of acquired experimental data ([24], pp. 15-16) as well as animal welfare concerns [11].

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There is consensus that biotelemetry wearables should acquire data without interfering with the wearer's behaviors and activities, ideally producing no impacts, while yielding accurate and reliable data. To achieve this, various welfarists and bioteletrists [6][11][12][19][23][29][34] have advocated a more careful approach to the design of physical and functional aspects of tags, and proposed guidelines aimed at minimizing device-induced impacts. For example, Casper [6] recommends that a tag's shape should accord with the hydro- or aerodynamic shape of the wearer's body.

However, guidelines and recommendations in literature are spread across different domains and are therefore difficult to apply systematically. Improvements of biotelemetry wearables for animals have so far been mainly focused on the reduction of devices' size and weight [17], according to the rule that the mass of tags should not exceed the 2-5% of the animal's bodyweight [2][15][28]. This has proven insufficient to account for the factors that affect wearability [15]. Instead, an approach is needed that can enable designers to systematically account for all relevant factors and achieve optimal wearability. In this regard, methodological research in computing shows that, compared to guidelines, frameworks are more effective in helping developers design complex technological systems for human interaction [3]. Thus, we developed a *wearer-centered design framework (WCF)*, an instrument to help designers to systematically conceive of, and develop, wearer-centered devices more effectively.

Here, we present the literature that has informed the development of our framework; we describe the WCF and how it was developed; and we report on an evaluation of the framework with different teams of designers assessing its usefulness to systematically design for good wearability.

RELATED WORKS

Guideline-based approaches

Biotelemetry studies and welfare reviews on impacts show evidence of tag-related detriment on animals' daily life (e.g. [33]) and recommend designing devices that are more consistent with the animals' characteristics, in order to reduce the effects of tagging (e.g. [6]). To this end, animal welfarists and bioteletrists have proposed design standards related to the wearing of biotelemetry tags, to the physical design of attachment and hardware components, and to the choice of the location of attachment. The most commonly reported and debated design guideline is the so called '5% (or 2% or 3%) rule', according to which the weight of the tag should not exceed a certain percentage (2%

or 3% or 5%) of the wearer's body weight. Such standards encourage the use of lighter tags in order to reduce the impact associated with too heavy a load. However, beyond the fact that there is not even agreement on an optimal percentage, various authors have criticized the rule. For example, Jepsen *et al.* [15] noted that a 'credible' tag-body/mass-ratios recommendation must consider other aspects, such as the tag attachment method in relation to the wearer's life stage, size, species, sex and habitat. Despite proposals to discard the rule, this is still followed and considered standard practice by many. In a study conducted by Smircich *et al.* [28] on the safety of the 2% rule in brook trout, the authors even suggest that the percentage can be safely increased to 7%.

In contrast to the simplistic 5% (or 2% or 3%) rule, several animal welfare researchers [6][11][23][34] highlighted the importance, on both welfare and scientific grounds, of considering the needs of individual animals in more detail. With respect to equipment, welfarists have offered a more inclusive set of recommendations, arguing that, in addition to mass (which must be kept to a minimum), designers and researchers should carefully consider the physical aspects of shape, material, color, location and method of attachment in relation to the biological and behavioral characteristics of the animal. Some of their considerations include:

- the shape and orientation of the device should be such that drag and abrasion on the animal's body are minimized, and that movement and performance of vital functions are not impaired [6][23][34]
- the materials used for the implementation and attachment of the devices should be wherever possible dissolvable so that the device does not have to remain attached to the animal longer than necessary [6][23]
- the color of the external components including harnesses, cases and markers should ensure that the appearance of the device does not affect the animal's social status or attract the attention of predators or prey [6][23]
- the length and size of the device should be considered in relation to the animal's sleeping habits, to avoid pressure on the bladder, liver or diaphragm whilst in the sleeping position [11][23]
- the device should be positioned in relation to the animal's barycentre in order not to compromise their posture and equilibrium [6][23]
- the attachment should be tailored to the species such that it causes the least discomfort or distress possible [23] and it should minimise the risk of trapping wearers [6].

The above design recommendations help designers consider wearer-related aspects other than just size and weight, and develop devices that have at least some wearer-centered properties. However, they present a number of limitations. Firstly, in our search we found these recommendations to be scattered across different sources from different domains (e.g. ecology, animal welfare). So it is clear that designers seeking to follow best practice have to search far and wide. This is time-consuming and there is a risk that relevant

design recommendations may be missed. Moreover, on some of these recommendations, there is no agreement within the biotelemetry community (the 5% rule being an example). It follows that the application of such guidelines is limited and inconsistent, in other words, unsystematic.

Secondly, while these guidelines advocate consistency with the wearers' physical and lifestyle characteristics to account for the wearers' needs (e.g. [6][34]), their proponents do not offer general directions as to how designers could systematically identify and account for these needs within a principled design approach.

Thirdly, it could be argued that some of these guidelines lack the animal perspective they aim to support. For example, Hawkins [11] discourages the use of the red hue in device components, suggesting that this particular color can be interpreted as blood by predators or conspecifics. Indeed, this may be the case, if said predators or conspecifics are able to see colors as humans do and, more importantly, if they use sight as the guiding sense towards prey and color as the characterizing feature of blood. However, many mammal species have di-chromatic vision [13] and are attracted towards prey by scent rather than sight. For example, wolves have a highly sophisticated olfactory system, which they use to track prey [7], but a scarce ability to detect red objects, perceiving them in shades of grey instead. Although a red harness or tag encase might generate an impact (e.g. by disrupting the camouflage of a wearer, or being seen by creatures that discern a wider gamut of colors, such as birds), generally speaking design recommendations should be informed by criteria that systematically extend beyond the human perspective (which, for example, associates the color red with blood and color as a salient marker of blood).

These limitations highlight the need to improve on the current guideline-based approach, to address the problem of access, enhance systematicity and account for the animals' perspective when identifying wearability requirements.

Framework-based approach

The choice of developing a conceptual framework to achieve systematicity in animal wearability is based on Blackwell and Green's approach to User-Centered Design (UCD) [3]. In UCD, the emphasis is on the users and a designer is required to interpret and apply their perspective throughout the design process. According to Blackwell and Green, in order to do so, designers need to be in the position to carry out the design activities (e.g. establishing requirements) in a creative but focused way, consistent with the design goals they are required to meet (e.g. usability and user experience goals). The authors note how, in some areas, such as software development, designers are commonly guided by existing protocols, guidelines, and standards. Where available, these are usually expressed in the form of checklists reminding designers to comply. This is a highly structured approach developed to ensure that designers do not forget dimensions that are already known to be important. However, as Blackwell and Green state, it has limitations. Firstly, a design

concept might not yet be defined or refined enough to be formulated as a list of instructions and related checklists, which makes this technique not applicable. In cases where some form of guidance has already been formulated, this might be scattered and/or not comprehensive, which makes guidelines and protocols inconvenient to retrieve and/or insufficient to support the designer's task. Where formulation is immature, and direction is scanty, checklists tend to be too rigid tools to stimulate a productive discussion about novel elements of a design. They also tend to be too simplistic tools for complex designs that need to satisfy many and diverse requirements ([3], p. 104).

In response to the limitations of checklists, Blackwell and Green propose design frameworks as conceptual and descriptive tools able to both inspire and scope particular aspects of a design, rather than ask designers to merely apply a set of rules or guidelines that may hold creativity back and overlook important but yet uncovered aspects of a design problem ([3], pp. 104, 106). For the authors, a framework is "*a set of discussion tools for use by designers and people evaluating designs*" ([3], p. 106). If the aim is to enable a discussion, frameworks can provide core concepts, questions, principles and terms that allow designers to think about and discuss a design problem ([3], p. 107). Critically, frameworks allow designers to both systematize a design and encourage innovative thinking.

From an animal-centred perspective, a framework-based approach is not only a desirable and more efficient way of designing for animal wearability, it is also necessary. In ACI, which commonly follows a UCD approach, animals' participation in the design process is considered essential to understand their perspective and experience [21]. However, in the case of animal biotelemetry, wearers' involvement would mostly mean fitting animals with devices in order to understand their experience with it. Since, for animals, testing such devices is a potential source of stress, optimising their direct involvement during the design process is fundamental. At the same time, consistent with a UCD philosophy, it is paramount that the design focus is kept on *interactors* [25], so that they are adequately represented as the main stakeholders. Thus, taking a heuristic approach informed by a design framework that accounts for as many animal-centered variables as possible is a way of giving animals indirect participation and achieving animal-centered design with minimal direct wearer involvement, particularly during the formative stages of the design.

Thus, our research focused on developing a framework, moving the field of animal biotelemetry design beyond limited existing guidelines and checklists. The framework would conceivably focus designers' thinking on the goal of wearability during the design process by fostering a thorough discussion, and supporting a holistic requirements analysis that would lead them to establish wearability requirements both in a creative and systematic fashion. The WCF was intended as a flexible resource to inspire designers while

supporting their systematic thinking during the design process, thus enabling them to account for as many wearability dimensions as possible. Thus, we firstly developed the WCF, and then we investigated whether it was a useful tool to guide and inspire designers towards designing for animal wearability.

FRAMEWORK DEVELOPMENT METHOD

The components of the WCF were deduced from pertinent text excerpts, passages, and quotations in relevant literature: extracts related to device-induced impacts, tag features associated with negative effects, design guidelines aiming to minimize these effects - on the one hand - and animals' needs, characteristics, activities and environments - on the other hand. This raw material was selected from 8 representative papers, manuals, and technical reports from the biotelemetry literature [6][11][19][20][23][24][29][34]. These sources were identified by initially searching on Google Scholar for critical articles on the use of biotelemetry using the keywords: 'biotelemetry' and 'impact'. Then, from the first relevant source identified [6], a snowball-like search was performed to find all other related sources.

We then drew a parallel between bioteletrists' guidelines ([6][11][19][20][23][24][29][34]), which focus on animal wearers' needs, and UCD's central value that a design must conform to user needs [9]. Specifically, bioteletrists advocate for body-attached tags to be more consistent with animal wearers' physicality, behaviors, and lifestyles to reduce adverse effects (improving their experience as wearers). Likewise, UCD champions focus on users' capabilities, needs, and tasks to deliver a positive user experience (UX) with the technology. Thus, systematically designing for wearability should yield wearables that impinge less, just as systematically designing for usability should yields products positively experienced by users [22]. In developing the WCF to support good wearer experience (WX) design, we made reference to the conceptual scaffolding that in UCD supports good user experience design. Initially, we based our WCF on the model from Preece *et al.* ([27], pp. 19-30), who promote the use of conceptual tools such as design principles, usability goals, and user experience goals to design for good user experience. The authors refer to these as "*concrete means*" that "*orient designers towards thinking about different aspects of their designs*" [p. 25]. We abstracted and reoriented these UCD drivers for WX design, to provide designers with an equivalent set of concrete, orienting items for thinking systematically about animal wearer experience.

To systematize the process of text interpretation across our sources, we conducted an abductive thematic-like analysis. We selected text passages related to tag wearability (e.g. device impacts, animal characteristics, recommendations for improving the design) and sorted them into one or more predefined conceptual 'containers' derived from the welfare guidelines (i.e. perception, obstruction, acceptance, and animals' characteristics, activities, and environments).

While reading the documents, we also found excerpts providing additional information that was relevant for describing WX (e.g. devices' features, components and attachments). This abductive process, whereby passages expressing similar concepts were placed in predefined categories (deductive stage) or used to generate new categories (inductive stage), produced consistent patterns from which we derived the elements of the WCF. As an example of how we applied this process, here is a quote from one of our sources [6] and how we used it: "*Electronic devices may emit acoustic frequencies or light spectra to which animals are potentially sensitive. For example, some mammalian species use acoustic signals for communication and foraging and may modify their behaviour*" [p. 1478]

The passage conveys that the perception of acoustic and light frequencies may generate a sensory and behavioral impact, which affects the wearer's experience in a negative way. In order not to generate this impact, devices should not be perceived acoustically or visually, since the stimulus exerted cannot produce impact if the device is not perceived. The text excerpt was deductively coded as 'perception'; at the same time, 'sensory abilities' was inductively recognized as a new conceptual 'container'. Thus, from this passage we inferred that *sensory imperceptibility* is an important design principle for animal wearability, which then became an element of the framework and one of its key principles identified through this analytical process. Additionally, the quote specifies the kind of sensory capability (*hearing*, and *sight*) and activities involving those sensory capabilities (*communicating* and *foraging*). Thus, the passage also allowed us to identify animal characteristics and activities relevant to the application of the principle. In summary, from this excerpt we derived the principle of sensory imperceptibility, as well as hearing, sight, animal communication and foraging as important characteristics and activities relevant to it. To develop the structure and content of the WCF, we conducted this kind of analysis on all our sources (i.e. [6][11][19][20][23][24][29][34]).

THE WEARER-CENTRED DESIGN FRAMEWORK

The resulting WCF consists of seven main interconnected components: general values and principles that inform wearability and that apply to the design of any biotelemetry wearables; and wearability parameters against which to identify requirements for the intended wearer group and the type of device to be designed. Animals' wearability requirements are traded off with human users' requirements and systems' capabilities and constraints, to ensure feasibility. Below, each component is explained in detail.

Knowing the prospective wearers (a)

It is essential that biotelemetry designers acquire biological and contextual information about the species and individuals of interest, if a wearer-centered design is the goal. As designers may not have the necessary knowledge, the WCF suggests possible sources of relevant information, such as consulting species-specific literature, observing prospective

wearers, including animal experts and carers in the design activities, and using ethograms (descriptions of behaviors exhibited by an animal species).

Design values (b1) and principles (b2) for wearability

These are 'conceptual triggers' ensuring that interfaces provide certain features ([27], p. 26). For wearability, the WCF proposes one design value and three design principles.

Annulment of effect is the key value, reflecting the ethical and scientific imperative to nullify tags' potential negative effects. If this cannot be achieved, any effects should be minimized and under no circumstances should it be acceptable that the effect is deleterious, especially if it endangers the wearer's life (e.g. some types of tag attachment might get caught and cause entanglement jeopardizing survival). This value was universally expressed in all the biotelemetry literature, where it is stated that all effort must be taken to minimize the burden of the transmitter and the attachment [34], and ensure that the "*tagging and presence of the device do not deleteriously affect the individual*" [8]; also, those "*who tag animals have a moral as well as a practical obligation to ensure that there is no adverse effect on their subjects*" ([19], p. 123).

The three principles proposed by the WCF pertain to the sensory, physical and cognitive experience an animal might have due to the presence of a tag. They are grounded in the observation that animals have a physical interaction with biotelemetry devices, but do not actively use or engage with these for their own purposes. In this case, we argue, good wearer experience means having no experience at all. Indeed, all existing welfare guidelines suggest that tags should be designed so they do not get in the way of the animal's daily experiences, activities or social interactions. Assuming that an experience can be sensory, physical or/and cognitive, the WCF proposes the following:

Sensory imperceptibility means that ideally a device should not be perceived by any of the wearer's senses. It refers to the whole range of possible senses (e.g. electro-receptive animals can sense the electric fields emitted by the tag [18]) and the whole spectrum of possible sensitivity (e.g. birds such as raptors may perceive colored devices at a much greater distance than humans do [16]). Since experience is primarily mediated through the senses, if the senses cannot detect a tag, there is no experience of it.

Physical unobtrusiveness means that a tag should not impede movement or access to locations. It relates to locomotive abilities (e.g. swimming or flying can be limited by unsuitably attached tags) and environmental features (e.g. tags may impede smooth movements in dense vegetation [19]). Even if a tag is perceived by the wearer, if it is not obtrusive, the experience is likely to be less intense. On the other hand, obtrusion is likely to intensify any sensory experience the wearer might have of a tag.

Cognitive acceptability means that the wearer should not express the need to remove a tag. A tag whose presence the

wearer does not accept can cause behavioral abnormalities such as stereotypes (detrimental compulsions arising when individuals cannot express natural and strongly motivated behavior, [14], p. 81). A tag may be perceivable and obtrusive, but the wearer may still find it acceptable. On the other hand, if a tag is unacceptable to the wearer, the experiential impact can be significant whatever its perceptibility or obtrusiveness.

Interactors (c)

This component reflects the fact that animals are part of wide ecologies, social networks and activities [29]. Hence, wearability principles and values do not just relate to the wearers themselves; they also pertain to other individuals significantly interacting with them. Ecological and social contexts need to be considered from the perspective of all related interactors. The WCF identifies two classes of interactor: the *wearers* and their *significant others*. The latter include social relations (e.g. off-spring, sexual mates, social group members) and a-social relations (e.g. prey, predators), whose interaction with the wearer could be significantly altered due to the tag. For example, potential mates might perceive the tag of an individual, experience it as physically obtrusive, or find it cognitively unacceptable, preferring non-instrumented partners instead (e.g. see [5]). As the users (e.g. wildlife researchers, pet guardians, even poachers), humans too are significant others as the technology gives them the means to interfere in the wearers’ life.

Animal variables (d)

This component accounts for interactors’ characteristics, activities and environments, consistent with their biology and context. It implies that animals have species-specific and individual capabilities and that they live in diverse environments performing a range of activities, all of which is key to determine wearability requirements. The component derives from Gould and Lewis [9]’s stance that “users’ [in our case, interactors] *goals, tasks and needs should early guide the development* [of user-centred systems]” (in: [10], p. 401) and is adapted to help designers understand interactors’ needs. The WCF requires designers to consider both the wearer and their significant others’ characteristics, environments and activities.

Device design (e)

This component refers to the physical and functional aspects of a tag as the object of wearer-centered (re)design. It serves as a reminder of the various aspects of a device, which need to consider the wearer’s and their significant others’ characteristics, activities and environments with regards to a range of features, components and types of attachment.

Wearability and usability requirements, and technical constraints (f1, f2, f3)

The WCF focuses on animal wearer needs in order to facilitate the identification of wearer-centered requirements (f1). However, human users have their own needs and technological possibilities may be limited. Thus, the WCF also accounts for the need to consider user requirements (f2)

and technical constraints (f3), although identifying these requirements and constraints is outside the scope of the WCF. The needs of different stakeholders (animal wearers, their significant others, and human users) and technological capabilities should all inform a requirements analysis that addresses potential conflicts in order to achieve practical biotelemetry solutions that are wearable and functional.

Design trade-offs (g)

Wearer-centered biotelemetry should be imperceptible, unobtrusive and acceptable to wearers, allowing them to perform their daily activities and behaviors undisturbed. While entirely neutralizing technological impacts may not be possible, this component encourages designers to analyze any requirement conflicts and negotiate the best possible trade-offs between wearability and usability requirements, given available technological capabilities. These trade-offs result from the balancing between what kind of data human users need to collect and what is an acceptable impact for animals, given what technologies are currently available.

Figure 1 illustrates how the different components of the WCF work together.

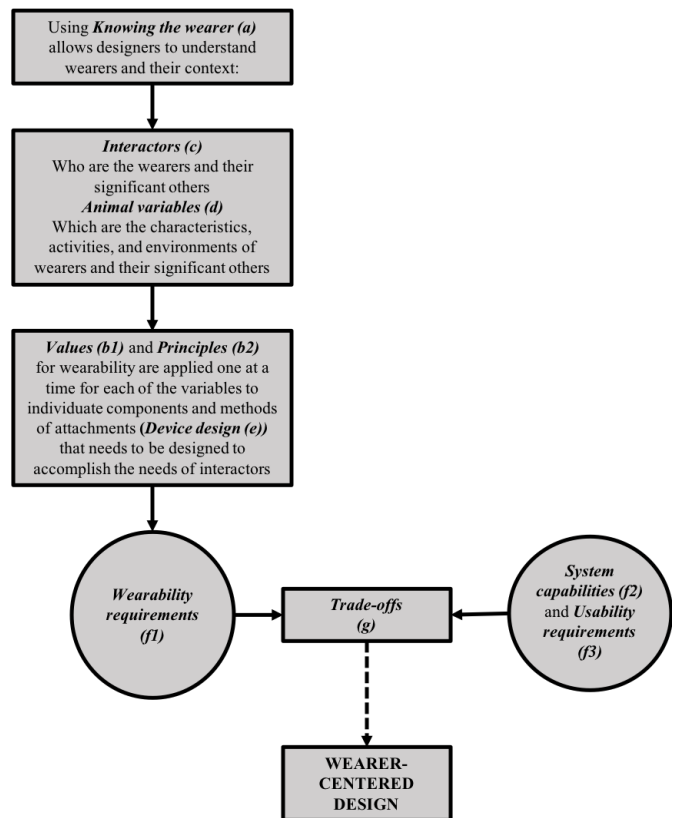


Figure 1. Components and connections of the WCF.

EVALUATION OF THE FRAMEWORK

Recalling Blackwell and Green [3], the direct recipients of the WCF are designers who would use it to carry out wearer-centered design activities creatively and systematically. To assess the WCF’s usefulness, we conducted three one-day workshops during which three Teams (Ts) of four designers

each used the framework to establish design requirements for a tracking device for domestic cats. We chose participants (Ps) according to three categories of stakeholder and grouped them homogeneously: computer scientists (T1: P1, P2, P3, P4), biologists (T2: P5, P6, P7, P8), and cat carers (T3: P9, P10, P11, P12). The homogeneous teams' composition aimed to explore any possible effects of the participant's background on the application of the WCF, as a way to assess whether their background or the WCF (or both) influenced the workshop discussions. The workshops followed a predefined template [1] to facilitate a collaborative 'quick&dirty' requirements analysis and prototyping activity in a relatively short time, using a range of low-fidelity prototyping materials and a dummy cat as a model. There were four phases: *introduction* (participants were introduced to biotelemetry impacts and the WCF); *instruction* (participants learned how to use WCF components); *exploration* (participants applied the WCF to the case study); *crafting* (participants built a low-fidelity mock-up based on identified requirements). A cat expert was present in the room to answer questions on cat biology and behavior. Participants were asked to share and discuss thoughts, design ideas and prototype details. Their activities were video- and audio-recorded, and their dialogues transcribed for analysis.

Thematic analysis of data

To understand how the WCF had been used, we conducted a thematic analysis [4] of the dialogues' transcripts, where themes were determined by any direct or indirect reference to the WCF. We wanted to know whether the designers' ideas, as expressed through their dialogues, were informed by the WCF. We coded direct references to words used in the WCF, but also coded seemingly relevant words or segments that did not have explicit correspondence in the WCF, in case concepts deemed relevant by the designers might have been missing from the framework. Having read the transcripts, we generated initial codes, collected them into preliminary themes and reviewed these by reading all related extracts to check for consistency. In case of inconsistencies, we re-worked the themes, discarding existing or creating new ones. Once consistency within each theme was reached, we created a thematic table. Finally, we defined each theme and determined whether the WCF had been used to establish each team's set of wearability requirements.

Our analysis took an abductive approach at the semantic level, looking at explicit meanings in the designers' words (i.e. what designers actually said) rather than anything inferred, with regards to both direct and indirect references to the WCF and its components. Cases of direct reference appeared where designers named the WCF or any of its components during discussion; for example, pointing to the WCF's component 'Interactors', a designer stated: "*this is for getting us in the context*" (P9, T3). Cases of indirect reference appeared where designers discussed a concept that we deemed elicited by the WCF, but the WCF or its components were not named; for example, the segment "*Is there an area on the cat's body that gets touched least from*

other animals" (P2, T1) does not directly name the relevant dimension ('significant others') in the WCF but indirectly refers to it.

Clearly, some designers' ideas were more likely elicited by personal experience and knowledge, rather than the WCF. For example, "*As you are a cat owner, how easy is to take stuff from the neck of the cat, to take the collar off and charge it*" (P8)..."*I would prefer to leave it so that the cat gets used to it*" (P7)". The idea expressed here is to habituate the cat to a device, which is not a WCF's concept and, actually, could be seen as inconsistent with the basic principles underpinning the WCF (which imply that the technology should adapt to the user [30] and not the other way around). Similar dialogues, expressing ideas that contrasted with the WCF dimensions or that could improve subsequent versions of the wearer-centered framework were inductively coded while reading.

ANALYSIS FINDINGS

We identified two main themes: WCF dimensions informing the designers (divided into seven subthemes); elements influencing designers other than the WCF (divided into two subthemes). For each of these two themes, we considered differences between teams (computer scientists, biologists, cat carers) to see if differences in participants' background might have led to different responses.

Theme 1: WCF dimensions informing the designers

The designers' discussions in relation to various dimensions of the WCF included the physical, sensory and behavioral characteristics of cats, and often referred to perception and acceptability aspects. We identified seven subthemes:

Subtheme 1 - Considering deleteriousness

Workshop participants conferred with each other several times about the imperative not to harm or impact cats and the need to consider their safety. Some of their comments were: "*could that put the cat in harm's way?*" (P10)", or "*actually, I was thinking: we were talking about the cat going to the wood, maybe getting caught. So, it is worth to think about a safe release*" (P6)". Designers discussed how to minimize the burden of a tag on the body; for example, P3 proposed distributing the device's electronic components on the body: "*what I am trying to do is to not put everything on the cat's collar but rather to distribute around the body, so that he does not feel much weight*". In every team, participants also had the idea of transferring part of the technology from the body to the environment, to alleviate potential impacts; for example, P9 stated: "*placing a radio station or a kind of station around the area where you know the cat goes, so you can download the positions of the cat without affecting the cat welfare. There's nothing on the cat, or at least there is something on the cat, but it's really lightweight*". These considerations reflect both the general imperative not to harm wearers, which should apply regardless of context, and context-dependent ways of implementing the WCF core value and related principles. For example, all teams implemented non-deleteriousness through safety measures,

such as break-release mechanisms or stretchy material to prevent strangulation. This suggests that designers complied with the value ‘annulment of effect’ (including non-deleteriousness and minimization of effects) and that their thinking was informed by this component of the WCF.

Subtheme 2 - Considering perception

A continuously emerging topic among participants was the need to avoid interactors perceiving a device. Codes identified related to wearer’s olfactory and auditory perception; sensory capabilities of cats, their prey and predators; visual perception of the device by other individuals; the need to hide a device and render it ‘invisible’; the need to minimize device-induced stimulation; and the concept that not wearing anything would solve many perceptibility (as well as other) problems. For example: P1 proposed that “*magnetic levitation is to have the bulky bit not attached to the cat*”; P8 suggested that “*the device has not to make any noise, including ultra and infrasound, no odor material has to be used*”; P2 argued that “*if there is a color that prey recognize very easily, you do not want to put it on the cat [...], we need some camouflage fur*”; P5 declared “*I have been thinking how to make the device less visible*”. Transferring tags to fixed ambient stations was also seen as a possible way of achieving sensory imperceptibility. All these discussions refer to sensorial aspects and we ascribed their occurrence to the influence of the WCF principle of sensory imperceptibility.

Subtheme 3 - Considering acceptability

Designers discussed the tolerance of cats to devices, e.g. P12: “*my cat, a couple of times had fleas, and I put a flea collar, and he stayed there with the back legs trying to push the collar away*”; the cats’ potential non-acceptance of a device on the body, e.g. P8: “*if you put something to a place the cat cannot see or reach but they can feel it, as they are curious animals, I do not know how they could react, if they know there is something, but they cannot see or touch it. It may be drive them crazy*”; and things that cats do not like, e.g. P2: “*the cat won’t like anything rubbing or pulling or chafing*”. Designers also considered comfortability as a way to increase the acceptance of a device on the body, e.g. P7: “*maybe, you can use that part of the animal to attach it firmly, not giving that much discomfort*”; and discussed how keeping the device always attached would reduce intrusiveness, e.g. P7: “*I think it is worse for the animal to have it remove it and put it again and then remove it. If you can leave everything as it is, and then you are able to get what you need is better for the animals. If you detach the device, you are moving the equilibrium*”. This shows that they were concerned about the possibility that cats might not accept wearing a tag (including the fact that detachment and reattachment would remind the animal of the object’s presence), which suggests that their thinking was informed by the WCF principle of cognitive acceptability.

Subtheme 4 - Considering significant others

Designers continuously referred to conspecifics, prey, predators, and other animals interacting with cats. For

example, P2 stated: “*what about cat leadership? If someone was the leader of the group and they saw something, one of the members all of a sudden notice the device. [...] I was just thinking about the fact that if there is an animal that gets groomed more, like an alpha-male or alpha-female...If an alpha male gets groomed more than any other animals... [this could be disruptive]*”. Likewise, P8 noted: “*it is important that other animals do not investigate. The device has to be inconspicuous enough for prey and predators, so if [the cat] is hunting mice we do not want something that gives his position*”. Participants in T3 also considered humans as potentially harmful interactors. For example, P10 said: “*other people [can interact]. That can be a bad thing, some people can harm cats*”. All this suggests that the related WCF component raised designers’ awareness about the fact that, when designing wearer-centered devices, the wearer’s interaction with other individuals should be considered.

Subtheme 5 - Animal variables discussed by designer

Designers considered locations and features of a device with respect to the activities of cats, e.g. P1: “*I would not put anything on the fur because the cat will groom it*”; body parts’ movements, e.g. P3: “*it is possible to cover something from here, but the legs will lose the movement*”; interspecific communication, e.g. P8: “*it is not a good idea to put the device in body parts important for communication*”; personality, e.g. P3: “*...but it depends from cat to cat also, no? Like for aggressiveness, not every cat is aggressive*”; habits, e.g. P12: “*but what if the cat roams free outside his house?*”; context, e.g. P8: “*cats can use cat flaps [and have to pass through it]*”; hunting strategies, e.g. P2: “*when [cats] try to not be seen, like stalking [a prey] is important for cats*”; living environments, e.g. P7: “*this cat is having an active life in the wood [nearby his house]*”; mating activities, e.g. P3: “*[cat females] do not attract the male with the body color*”; physical characteristics, e.g. P2: “*it does not work on short-hair cats*”; physiology, e.g. P9: “*what if he is molting? That’s a problem I guess, when there is the changing skin and fur*”; sociality and interaction with other cats, e.g. P7: “*their conspecifics would recognize [the tag] and they would discriminate the animal for that*”. This shows that the designers considered various animal variables, putting wearer characteristics, activities, and environments at the center of the discussion, consistent with the WCF ‘animal variables’ component; and it suggests that the framework informed their discussions.

Subtheme 6 - Trading-off

Sporadically, designers mentioned technological capabilities that might constrain wearer-centered design, e.g. P8: “*weight and stuff is going to depend on the kind of device and how the device operates*”; user priorities, e.g. P8: “*incising the cat’s skin to put inside just a GPS, I would not do it, but if it is for a [cat life-saving] pacemaker, yes*”; and they reasoned about the feasibility of implementing some of the requirements established, e.g. P2: “*but you need to think about the cable, they need to be long enough for when you stretch and pull the whole collar, so that they do not break*”.

These excerpts show that designers discussed what might be desirable, what constraints there might be and what might be feasible, consistent with the WCF component related to trade-offs, which plausibly influenced their thinking.

Subtheme 7 - Knowledge about the wearer

Designers were made aware that they could consult a cat expert in the room for queries about the species' biology. Having no knowledge of cats, T1 (computer scientists) made use of the cat expert 'tool'. For example, P1 and P2 respectively asked questions such as "*which range of color do [cats] see?*" and "*is there an area on the cat's body that gets touched least from other cats?*". Instead, both T2 (biologists), which had a cat guardian among its members, and T3 (cat carers) discussed the biology and behavior of cats sharing personal knowledge and experience, preferring to question one another rather than the expert. For example, P7 mentioned "*I don't know if you have ever had a cat, but this is the only part he cannot reach when grooming*"; P11 shared their knowledge that "*electro sensing is an interesting [variable] because apparently, [cats] can hear the buzz of 240-volt electrics. They can detect that*"; and P8 asked the cat guardian in their team: "*as you are a cat owner, how easy is to take stuff from the neck of the cat?*". Here we found the first notable difference between teams: the WCF component 'knowing the wearer' influenced T1, who asked the expert, while the other teams considered the advice of cat-caring colleagues sufficient. But, although personal experience and knowledge can be useful, they can be biased and insufficient, issue which we discuss in more detail below.

Theme 2: Elements influencing designers other than the WCF

During the analysis topics emerged that were not aligned with the WCF. These were collated into two subthemes, and regard discussions about user requirements and the difficulty of aligning designer thinking and animal perspective:

Subtheme 1 – Human needs

Although the aim of the workshops was establishing wearability requirements, T2 and T3 also discussed the needs of (human) users, which in some cases they prioritised over animal wearer requirements. For example, P6 declared: "*I would incise the skin [to insert the device] if it is worth, if for example I am losing [my cat] very often and I want absolutely to know where it is, I may decide to go for it*". When T3 discussed the texture of the case, P10 focused on the user's need to ensure that they would not lose the device as a consequence of a cat's attempt to remove it: "*I was thinking to keep that smooth, because otherwise, when you've got cats who manage to pull it off...*"; P9: "*can they grasp it?*"; P10: "*yes, they might pull it from here*". Especially T3 (cat carers) discussed functionality and data-gathering aspects. For example, they initially conceived a design featuring small electronics distributed around the collar to minimise protrusion. But when they realised that their design allowed for extra-room, they imagined using the available space for adds-on to augment its tracking

capabilities, thus eroding the optimal wearability they had reached. They then discussed what widgets might provide additional data for users. P9 started: "*it will be interesting to add some more stuff now that we realised [that] we have more space*"; to which P12 answered: "*what about temperature sensors? It could be a nice add-on to consider, because you can track the cat movement, but then you might correlate with behaviour outside and the temperature*". P9 even thought of features that would make the device more sellable: "*commercially speaking, every cat and every owner of a cat has different needs [...] so in this way you can personalise the band and then you can change colours. You can play with all this kind of options to sell it*".

Here we find the second notable difference between teams, which might have come from their background: although all three teams established wearability requirements by making use of the WCF, the computer scientists (T1) seemed to focus on establishing requirements for the wearer, as per the given task; on the other hand, the biologists (T2) and (especially) the cat carers (T3), who were potential or actual users of biotelemetry, also discussed user requirements, sometimes weakening the wearability requirement debated only minutes earlier. The wearer-focused performance of T1 might be due either to computer scientists' familiarity with using design frameworks, or to their continued consultation of the cat expert (which might have provided an indirect reminder of the given task), or both. In contrast, T2 and T3 based part of their requirements analysis on their own knowledge of the species, which might be why they diverted from the given task: the personal experience of animal guardians can bring to the fore various human needs that range from protecting the cat to discovering more about their roaming habits, thus side-tracking designers towards user requirements and diverting them from the wearer perspective that the WCF aims to promote. Indeed, our findings suggest that this was a background-related issue. This highlights the need for design instruments that can inform a systematic requirements analysis towards a given design goal, especially when designers are challenged to design technologies from (other) animals' perspective. However, it also shows limitations in the current version of the WCF, which was not always effective in inducing designers' thinking to consistently recognise animal wearers as the central stakeholders.

Subtheme 2 – Difficulty of aligning with animal perspective

The WCF has its foundations in the basic UCD principle that technology should adapt to interactors. However, the biologists (T2) turned the concept around: the cat should get habituated and adapt to a device; they assumed that, those devices that are already in use must be appropriate. For example, P6 proposed always leaving the collar on the cat's neck with the battery hanging off it like a pendant, for easy detachment. When P7 argued "*but [the pendant] can be annoying*", P6 defended their idea saying "*why not, I have seen cats with ID tags*". Along the same lines, P8 proposed "*a neck-based solution, because domestic cats, most of them, are already wearing collars, so they are already used to*

them". When others pointed out that an existing design does not necessarily afford wearability, P8 responded: "but if you are designing a device that is designed to monitor the animals, it is really difficult to shape the technology on the animal. It has to be a device that is imposed to the animal".

Another difficulty in aligning with the animal perspective emerged with the cat carers (T3), who in a few instances minimised a potential side effect of wearing a device, bringing their personal experience as evidence. For example, P11 reported that their cat had worn a GPS in the past and commented about its size: "I looked at [the device] and thought: that's quite a significant weight. My cat would hate it, but absolutely not bothered by it whatsoever. Most cats would not be bothered". This is in contrast with empirical evidence from Paci *et al.* [26] which demonstrated, through systematic observations of cats during their daily activities, that cats can have adverse reactions towards a body-attached device. P11's ability to observe their cat while this wore the device was limited, since the animal was fitted with the GPS soon before leaving home and released upon returning home. Hence, P11 did not have evidence to support their assertion and, from the enthusiastic tone of their voice, they appeared more likely focused on satisfying their monitoring needs.

Overall, for T2 and T3, our findings highlight two difficulties in aligning with the animal's perspective. The first is evidenced by the discussion of the biologists, who thought about habituation as a way to accomplish wearability and referred to conventional devices as acceptable solely based on the fact that these are already worn by cats. The second is evidenced by the discussion of the cat carers, who tended to minimise potential effects, founding their considerations on personal experience as users of biotelemetry.

DISCUSSION

The thematic analysis method adopted to examine the workshop dialogues allowed us to understand whether and to what extent designers were informed by the WCF during their requirements activities. Our findings suggest that seven of the framework's components informed the designers' thinking. From subthemes 1 to 6 of theme 1, designers of all three teams used a WCF dimension, by directly or indirectly referring to it. The most discussed items were the two design principles of *sensory imperceptibility* and *cognitive acceptability*, which were discussed with the aim of developing the device so it would be imperceptible and acceptable to both wearers and other individuals interacting with them. Clearly, designers took onboard the notion of *significant others*, since throughout the whole discussion they regularly referred to conspecifics and other species interacting with the wearer. Thus, the *interactors* dimension informed the requirements elicitation process during the workshop. Behavioural activities, physicality, intraspecific communication, physiology, personality, hunting and mating strategies, habits, and living context and environments were *animal variables* considered by the teams when establishing wearability requirements. This shows that designers placed

the wearer at the centre of their requirements analysis, both at a species-specific level (e.g. considering the impact of a device on cat-universal behaviours such as grooming) and at an individual and context-specific level (e.g. considering the problems that could arise from the roaming habits of a domestic individual). The value *annulment of effect* was generally expressed by all teams in terms of not harming the cat, of minimising the effect of a tag, and of safeguarding the animal's integrity. These arguments were aligned with specific aspects of the WCF's key value. Finally, although sporadically and not in so many details, the need to *trade-off* requirements was also discussed, showing that this WCF component stimulated reflection in this area.

None of the teams had a focussed discussion about physical *unobtrusiveness*. Only T1 mentioned (once) the importance of not using a harness because "the legs will lose the movement" (P3); and T2 mentioned that "[the device] has not to obstruct the hiding and running" (P8). Although these two insights might have been influenced by the principle of physical unobtrusiveness, we did not consider them sufficient evidence to claim that the designers used this particular principle of the WCF, since they were only briefly mentioned. However, this does not exclude that, implicitly, the designers might have considered the obstruction of movements related to the perception and acceptance of obtrusions more generally, whereby unobtrusiveness would have been implicitly achieved by designing imperceptible and acceptable devices.

Concerning the *knowing-the-wearer* component, this was used only by the team of computer scientists (T1). This indicates a limitation in the use of this specific component of the WCF when biotelemetry users are in the designers' teams, since it seems that the participants' experience and needs as users were considered more than the knowledge and expertise of an animal expert. However, precisely because designers of any degree of expertise might have biases inherent to their own knowledge, or to the knowledge they think they have, arguably it is important that they systematically refer to this component to avoid such biases. Thus, the limited use of the knowing-the-wearer dimension highlights the need to find a way of enabling designers to make systematic use of it.

Overall, with six items used by the designers, one partially used (i.e. by only one team), and one not used (at least explicitly), we deem that the workshop participants engaged with and were informed by the WCF regardless of their background.

However, our findings suggest that, when using the WCF to establish wearability requirements, other factors influenced the designers' thinking. These are mainly ascribable to: 1) the experience of some of the designers as users (who occasionally put their needs above those of cat wearers), and 2) the difficulty of taking the perspective of an animal wearer (e.g. thinking that ID pendants do not annoy cats because they wear them anyway and can easily get habituated to

them, even though they do not choose to wear them; or thinking that a potential side effect is not important, if the signs of an animal's discomfort are not easy to detect for a human). The findings also show that such influencing factors were not shared across all three workshop teams; in fact, paradoxically, only the biologists and cat carers discussed user needs, or deemed acceptable that wearers would need to get habituated to the device, or underestimated its potential impact.

Since design frameworks enable flexible and creative thinking, inexperienced designers such as those in T2 and T3 might have lacked specific instructions to help them operationalise the WCF. As evidence of such a difficulty, at the end of T3's workshop, P12 commented that it would have been useful to receive more precise directives: "*[the WCF] it's more of an anthology, like the whole landscape of all the variables and things to consider. The only thing is that, maybe, I think a kind of protocol could be like a companion to [the WCF], like a step-by-step guide*". This suggests that the current version of the WCF could be complemented by an execution protocol enabling any designer to conduct a focussed, consistent and systematic wearability requirements analysis, regardless of their background. Such a protocol might complement the WCF, providing specific guidance on how to work through the elements of the framework without incurring the limitations of prescriptive guideline-based approaches. Arguably, with a protocol at hand, the team who took cat knowledge for granted (T3) would have been prompted to work through the knowing-the-wearer component more systematically.

Overall, the thematic analysis shows that the WCF was an informative instrument for each team. In fact, the majority of the dialogues focused on wearers and each workshop produced mock-ups that had features consistent with the WCF dimensions. We report the case of P8 as evidence that, although there were limitations in the use of the WCF, this did not prevent the framework from usefully supporting the design process. This participant defended their proposal to design a neck-based solution by saying that cats are used to wearing collars and, therefore, they can get easily used to them. As mentioned above, P8 reinforced this concept by stating that, because it is difficult to shape a technology on the animal, a device needs to be imposed on the animal. However, when it came to presenting their idea of a wearer-centred device, P8 proposed the following wearability requirements: "*we know cats rub their head, groom their head, they can use cat flap, so the device has to be a reasonable size to pass through. It is important that other animals do not investigate. The device has to be inconspicuous enough for prey and predators, so if he is hunting mice, we do not want something that gives his position. Cats run and hide so [the device] has not to obstruct the hiding and running. The device has not to make any noise, including ultra and infrasound, no odour material has to be used, it is not a good idea to put the device in places important for communication. The sensitiveness of the skin*

has to be considered; the device must not have taste. This is what I caught [from the WCF]". This shows that, although P8 had some preconceptions, this did not prevent them from ultimately establishing requirements consistent with the cats' characteristics, activities, and environments.

In conclusion, although the version of the WCF that we evaluated presents some limitations, the systematic analysis of designers' dialogues shows that the tool was useful and informative, fostering the designers' innovative thinking and helping them strive for (feline) wearability. Our findings suggest that the informing power of the WCF was greater than the influence of designers' personal knowledge (and sensitivity). Although some of the designers' reasoning appeared to be inconsistent with the values, principles and dimensions of the WCF, the themes and subthemes emerging from their dialogues show that most of the designers' thinking was in fact aligned with those elements. This evidences the significance of the WCF as an informing instrument when designing for wearability.

CONCLUSIONS AND FUTURE WORK

This research delivers the first holistic wearer-centred design framework for animal biotelemetry and animal wearables more broadly. Drawing from theories about the efficacy of frameworks to achieve systematicity in interaction design, the WCF is conceived as an aiding tool to systematically elicit wearability requirements. Such a process is essential to understand how a biotelemetry product could achieve good wearability and wearer experience. Informed by, and extending, the fundamental tenets of UCD, the WCF proposes essential values, principles and dimensions relevant to wearability, providing a conceptual roadmap that helps designers focus on animal wearer stakeholders without stifling creativity.

Thanks to the level of conceptual abstraction of its elements and to the modular organisation of the process it represents, the WCF is potentially adaptable to diverse design contexts and wearer species (whether non-human or human animals), fundamentally improving on rigid design guideline-based approaches currently used in biotelemetry design. Indeed, the WCF allowed the designers in our study to focus on animal stakeholders in relation to their sensory (e.g. hearing, sight), physiological (e.g. energetics), morphological (e.g. animal body shape, size), behavioural (e.g. kind of movements), and environmental variables (e.g. aquatic, terrestrial organisms), and to those of their significant others. Arguably, being able to identify requirements, and predict the potential impacts of prospective applications as accurately as possible, before entering the iterative design cycle to develop a wearable device, is of critical importance for wearer-centred design, as a process and as an outcome. Nevertheless, what we have proposed here is not intended as the ultimate WCF but as the first framework of its kind, which will need to be iteratively refined and incrementally improved with the acquisition of new knowledge.

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