Towards a Wearer-Centred Framework for Animal Biotelemetry

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Introduction

The emerging discipline of Animal-Computer Interaction (ACI) aims to understand the relation between animals and technology in naturalistic settings, to design technology that can support animals in different contexts and to develop user-centred research methods and frameworks that enable animals to take part in the design process as legitimate contributors [11]. Given existing interspecies differences and communication barriers, measuring the behaviour of animals involved in ACI research can be instrumental to achieving any or all of these aims, as a way of gauging the animals' patterns, needs and preferences. Indeed, measuring behaviour is a common practice among ACI researchers, who take various approaches to this task [5,15,17,24]. In this respect, the use of biotelemetry devices such as VHF tags and GPS trackers, or bio-logging and environmental sensors has a significant potential [22].

At the same time, biotelemetry has been used for many years in many areas of biological research. Biotelemetry is used to improve the quality of physiological and behavioural data collected from animals and in an attempt to reduce researchers' intrusion in the animals' habitat [2]. However, there is evidence that carrying biotelemetry tags may influence the bearer's physiology and behaviour [20]. Such impacts interfere with the validity of recorded data [14] and the welfare of individual animal wearers [1,3,13]. Neither of these effects are compatible with the animal-centred perspective advocated by ACI, on both scientific and ethical grounds. Our analysis of current body-attached device design and biotelemetry-enabled studies points to a general lack of wearer-centred perspective. To address these issues, we have developed a framework to inform the design of wearer-centred biotelemetry interventions, in order to support the implementation of animal-centred research methodologies and design solutions in ACI and other disciplines.

Background

Tracking movements and measuring vital parameters remotely in animals through biotelemetry tags has allowed the acquisition of ecological, physiological and behavioural information usually inaccessible with other observational methodologies [2]. Since the 1960s, body-attached devices have been used for the study of targeted species in their natural environment, the refinement of experimental procedures, and the implementation of biodiversity conservation strategies [2,18]. Although the use of biotelemetry has revolutionized data-gathering practices in animal biology and ecology, side effects caused to the wearer by the device itself can interfere with the phenomena that are being monitored, thus producing unreliable and biased data. For one example, when studying the foraging behaviour of penguins using transmitters, the tag attached on the body can increase drag, thus reducing the swimming speed and altering the very hunting patterns being investigated [23]. Impacts on individuals can be physically manifested, such as those occurring on the site of the attachment (e.g. fur abrasion, limb swelling, or wounds), or less obviously perceivable to researchers, such as alterations of physiological parameters (e.g. variations in the metabolic activity and body temperature). Changes in the normal behaviour can be apparently unrelated with the presence of the device (e.g. decrease in foraging behaviour) or clearly derived from it (e.g. abnormal grooming in the attempt of removing the foreign body) [9].

Therefore, although measuring behaviour can play a key role in ACI and other research as a way of understanding otherwise non-accessible aspects of animals' habits, needs and preferences, the use of biotelemetry can have implications for the scientific validity of recorded data as well as serious consequences for the welfare of the animals involved in research procedures. To reduce such device-induced impacts, animal welfare scientists have proposed guidelines and recommendations for improving the experimental designs of studies that employ biotelemetry. Namely, they have pointed out the need to re-design both body-attachment methods and tag features, such as weight, shape and colour in a way that better conforms to the wearer [1,3,13,23]. Arguably, whereby negative effects induced by a device are minimized or removed, the quality of collected data can be improved as well as the welfare of the animal being monitored.

However, although in principle such guidelines aim to bring the perspective of the animal to the attention of researchers and designers, when it comes to application details they often lack the very perspective they advocate. For example, in one of their recommendations, researchers discourage the use of the red hue in device components, suggesting that this particular colour can be interpreted as blood by predators or conspecifics [3]. Indeed, this may be the case if said predators or conspecifics are able to see colours in the same way that humans do, and more importantly, if they use sight as the guiding sense towards blood, and colour as blood's characterising feature. However, many mammal species have di-chromatic vision [4] and many such predators are driven to prey by scent rather than sight. For example, wolves have a highly sophisticated olfactory system they use to track prey, but a scarce ability to detect red objects, perceiving them in shades of grey instead [12]. We agree that a red harness or tag encase could generate an impact (for example, by disrupting the camouflage of an animal). However, we argue that design recommendations should be informed by criteria that systematically extend beyond the human perspective (e.g. associating the colour red with blood and colour as a salient marker of blood). However, to date there is no design framework that can help researchers and designers to systematically account for and reconcile the often diverging perspectives of the animal wearer and of the human user, and the design requirements that derive from both. For example, ecologists often use coloured tags for marking the animals they are studying because they need to easily identify individuals during field observations; but this can be detrimental for the animals if they become easily detectable to ill-intentioned humans, potential predators or prey. To address this gap, we have developed a *wearer-centred* framework with the intent of bringing the wearers' perspective into the process of designing biotelemetry devices.

Designing for wearability

In Interaction Design [16] it has long been established that good interactions are designed 'around' users - their characteristics, those of their activities and those of their environment – systematically informed by established design principle (e.g. perceivability, affordance). The same user-centred perspective characterises designers' approach to novel forms of interaction enabled by ubiquitous computing technology, whether these are intentional or unintentional, explicit or implicit [7]. Although these include physical interactions resulting from the use of, or contact with, wearable technology, a design framework to support the design of wearer centred devices is still lacking. Developing such a framework is our aim, particularly with reference to the design of biotelemetry for animals, in order to improve their *wearer experience* and therefore reduce the negative aspects related to the device presence.

Providing good user experience is a main goal of user-centred technology, with the fundamental assumption that the technology the user interacts with is directly relevant to them and their activities. But what is the equivalent of a 'good experience' when the technology one interacts with is not directly relevant to one's intentions and activities? This is arguably the position in which animal wearers of biotelemetry find themselves in when they physically interact with technology that does not serve their own purposes but those of someone else. In this case, we argue that paradoxically a good wearer experience amounts to having 'no experience' of the device: in other words, good wearable biotelemetry (for animal wearers who are not users) is one that does not get in the way of the animal's daily experiences, activities or social interactions, one that is not experienced at all. To this end, we propose that the design of wearable devices should be informed by *design principles for wearability* pertaining to the animal sensory, physical and cognitive experience, namely: *sensory imperceptibility*, *physical unobtrusiveness*, and *cognitive acceptability*. Sensory perceptibility refers to a wider range of senses in comparison with those of humans (e.g. electro-receptive animals can sense the electric fields emitted by the tag [8]) as well as to a wider spectrum of sensitivity (e.g. birds such as raptors may perceive coloured devices at a much greater distance than people do, thanks to their very acute and pigmented vision [6]). Physical obtrusiveness is linked with locomotive abilities (e.g. swimming or flying movements can be limited by a tag attached in an improper location) and environmental features (e.g. dense vegetation can impede smooth movements of instrumented animals) [9]. Cognitive unacceptability refers to the psychological condition of those animals that, being aware of the device, do not accept its presence, which can lead to the development of atypical behaviour such as stereotypes (detrimental compulsions that may arise when a wearer cannot express its natural behaviour because of the tag). We propose that, when designing tags, considering the abovementioned principles in relation to the animal's biology, and consistent with the way in which the animal may experience the device, can help ensure that the devices' features do not generate an impact on the wearer.

Furthermore, because individual animals are part of wider social ecologies, these principles do not just relate to the wearers themselves, they also apply to other individuals significantly interacting with them [20]. These *significant others* include potential prey and predators of the wearer, or conspecifics such as sexual mates or members of the same social group, whose interaction with the wearer can be significantly altered due to the device. For example, a potential mate might perceive the tag of an individual, experience it as physically obtrusive, and find it cognitively unacceptable, thus preferring non-instrumented partners instead of the tagged individual. Therefore, in order to design devices that are imperceptible, unobtrusive and acceptable, researchers need to carefully consider the sensory, physical and cognitive characteristics of the wearer, and those of their significant others, and how their environment and activities influence those characteristics.

Below we discuss an example to illustrate how our framework can be operationalized. We show how our proposed wearability principles, considered from the perspective of all stakeholders (wearers, significant others and human users) in relation to their sensory, physical, cognitive, behavioural and environmental characteristics, can inform a systematic requirements analysis. We propose that this can in turn lead to the identification and development of wearer-centred design solutions. For our illustrative example, we consider a North-America population of *red foxes* (*Vulpes vulpes*) as species of interest and *hearing* as design-informative variable for the principle of *sensory imperceptibility*. In order to be *aurally imperceptible* as not to influence critical and delicate activities (e.g. by interfering with mating calls, alerting and dispersing prey, or disrupting ambushes), a device should not produce any frequency audible by the animals instrumented [1], or by their *significant others* (i.e. their conspecifics, their prey, and their predators). This particular requirement is not incompatible with those of human users (e.g. researchers), since in this case there is no interest for ecologists in detecting instrumented animals through acoustic signals. The possibility for a biotelemetry tag of emitting ultrasounds hearable by animals have been demonstrated by studies on bat dataloggers which revealed the emission of ultrasonic bands in the measure of circa 33,000 Hz [21]. In this respect, the framework asks designers to assess the presence of detectable radiation from the device in relation with the aural capabilities of all the animal species that are likely to be involved or affected (i.e. instrumented animals plus their significant others within the geographical context and distribution area in question). In this simplification, the wearer species, foxes, have an audiogram within the approximate range of 51-48,000 Hz [10] (for comparison: humans' audiogram is commonly 20-20,000 Hz). The audiogram of foxes' significant others varies: their typical prey, mice, have an aural sensitivity of circa 1,000-91,000 Hz [19]; their potential (but not regular) predators living in the studied area, coyotes (*Canis latrans*), are likely to have an aural sensitivity of circa 67-45,000 Hz (although their exact hearing range is not known, it is likely similar to that of canids such as dogs [19]). This means that in order to meet the hearing requirement, a device used on foxes should not emit auditory signals within the frequencies of 51-91,000 Hz, which is the combined minimum and maximum frequency hearable by at least one of the three species. If the envisaged tag does not produce any noise within this range, then the audible aspects of the *imperceptibility* principle are fulfilled. On the contrary, if the technology used generates a resonance, the device design should be revised and technologies that do not produce ground noise in the 51-91,000 Hz span should be used (or designed) instead. Should this not be possible due to current technological limitations, trade-offs should be considered following a scale of importance, where importance is determined by the severity of the expected impact produced by the electronic tag on the wearer. To continue with our example, as we mentioned, coyotes are accidental fox predators while mice are regular fox quarry. Therefore the predatory impact of coyotes on vulpines is less significant than fox hunting failure on mice, which can lead to starvation, especially because mice rely on their very high sensitive hearing system to escape from predators, whereas coyotes' hunting behaviour on foxes is principally driven by smell and sight.

The same assessment process should be carried out for each known significant other (e.g. mice are not the only prey foxes rely upon) and for all the relevant variables associated with the biological and environmental characteristics of the animals in question. More specifically, these are related with the sensory, physiological, morphological and psychological characteristics of animals, their physical and social environment, their living conditions, daily activities, behaviours, and movements.

To validate our framework, we are currently designing evaluation studies comparing a range of off-the-shelf biotelemetry wearables designed for felines with the purpose of observing which tag features, and to what extent, they are liable to produce side effects on the wearer (for example, fur abrasion on the site of attachment, increment in grooming, or noise intrusiveness). The findings will serve as an initial validation of our framework. As a complementary form of validation, we will then apply the framework to inform the design of prototype tags, which we will evaluate against off-the shelf devices. The comparison between the impacts produced by the commercial products and our prototype will provide insights as to the validity of the framework. To begin with, we will work with cats as the model species of choice, with a view to extend the work to other species. Our experimental designs will be assessed and approved by the Animal Welfare and Ethical Review Body of the Open University and will also conform to the University's ACI Research Ethics Protocol.

Conclusions

Biotelemetry has played an important role in the development of behavioural science, and biological sciences more generally. Similarly, it could play a key role in ACI. However, we argue that, if biotelemetry is to truly contribute to the kind of animal-centred research that ACI aims for, the perspective from which this technology is designed needs an essential and systematic shift. We propose that our wearer-centred framework, and the solutions that can be derived from its application, can significantly increase the potential of biotelemetry in ACI, both as a part of animal-centred applications and as a methodological instrument to conduct animal-centred research.

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