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Animal-computer interaction and beyond: The benefits of animal-centered research and design

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Animal-computer interaction and beyond: The benefits of animal-centered research and design

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Editorial: Animal-computer interaction and beyond: The benefits of animal-centered research and design

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Editorial on the Research Topic
Animal-computer interaction and beyond: The benefits of animal-centered research and design

Animals are increasingly exposed to interactive technologies and involved in technological interactions. Ambient and wearable devices are now frequently used by humans to monitor animals' states and behaviors within conservation or husbandry practices, and a growing number of animals engage with interactive or technological systems as a part of their activities in research laboratories, on farms, in zoos and in domestic environments.

The field of Animal-Computer Interaction (ACI) investigates how interactive technologies affect the individual animals involved; what technologies could be developed, and how they should be designed in order to improve animals' welfare, support their activities and foster positive interspecies relationships; and how research methods could enable animal stakeholders to participate in the development of relevant technologies. A fundamental tenet of ACI is that the technologies being designed, the methods employed for their development and the ethical underpinnings of those methods should be animal-centered, meaning that the characteristics, needs and wants of the animals involved should be of primary consideration and should directly inform design processes and outcomes. This perspective has key advantages, for example, ensuring that animals' interactions with technologies are positive and effective, and addressing growing societal concerns over the treatment of animals.

This Research Topic collects contributions from different perspectives, which highlight possible animal-centered approaches in research and design, as well as challenges that animal-centered approaches might pose and how these might be addressed. Bringing together novel contributions that demonstrate how animal-centered technologies, research methods and ethical frameworks could benefit research and practice in different domains - including farming, animal conservation and welfare, or animal research - this e-collection provides a resource for researchers and practitioners whose work involves animals and for whom the applicability of animal-centered technologies, methods or frameworks may be relevant.

Frameworks that aim to support animal-centered design processes have the potential to enable animal agency and enhance their welfare, as discussed by Webber et al.. In their proposed framework, the authors combine the "Five Domains of Animal Welfare" model and the "Coe Individual Competence" model, providing a structured approach to defining and refining animal-centric objectives to design technologies that can promote positive animal welfare in managed settings. Throughout the process, animal-centered design involves paying close attention to the sensory, cognitive and physical characteristics of the animals in question. In this regard, drawing together academic perspectives from ecology, neuroscience, anthropology, philosophy, interaction design, and arts, French argues for expanding the aesthetic dimensions of design beyond the limits of human capability to encompass other species' sensory modalities and include non-human aesthetic sensibilities. Likewise, Carter et al.'s work highlights the importance of considering animals' ergonomics when designing artifacts that they are expected to interact with. Examining canine working trials, the authors measure vertical forces and apparent joint angulation at landing in dogs traversing a scale of different heights, suggesting that the maximum scale height should be reviewed to minimize impacts on the physical health and welfare of participating dogs. However, the impacts that technological interventions may have on animals are not limited to physical interactions and, in this regard, Paci et al. discuss the importance that privacy has for animals. The authors draw from observations of privacy-related behaviors in different species, finding that animals use a variety of distance regulation and information management mechanisms to secure their own and their assets' safety, and to negotiate social interactions. Thus, they argue that the design of interactive systems needs to be informed by animals' privacy requirements.

Given the interspecies communication barriers and power asymmetries characterizing human-animal relations, understanding, let alone prioritizing, animals' requirements poses significant, emergent and often unexpected ethical challenges. To help researchers deal with such challenges, Ruge and Mancini propose an ethics toolkit for clearly and systematically articulating the ethical stance both of researchers and of the projects researchers work on, to support moment-by-moment decision-making. An implication of animal-centered research and design is that decisions related to processes and outcomes should prioritize animals' interests, with regards to both research outcomes and processes. Exploring the applicability of such a perspective to all animal research, Mancini and Nannoni propose an ethical framework for conducting research *with* animals, highlighting the principles of relevance, impartiality, welfare and consent, and provide a scoring system to help researchers and delegated authorities assess research procedures, with a view to shifting research practices toward more animal-centered approaches.

Alongside the abovementioned proposals, contributions based on novel technological applications demonstrate the potential benefits of animal-centered research and design, for example, to analyse animals' behavior and achieve a more objective understanding of their abilities and needs. Using sensor-instrumented dog toys to test dogs undergoing advanced training to become service dogs, Bryne et al. discovered that a measure of average bite duration could help predict a dog's success as a service dog. Therefore, they suggest the use of instrumented toys in addition to current behavioral assessments. Similarly, Menaker et al. demonstrate how, consistent with questionnaire-based assessments, the application of unsupervised machine learning techniques could help cluster dogs' responses during standard behavioral tests and, thus, support the early exploration of behavioral data before forming and testing behavioral research hypotheses. Moreover, machine learning can be applied to understand animals' interactions with environments shared by multiple individuals. To this end, the facial recognition system developed by Brookes et al. measured how individual members in a troop of seven zoo-housed gorillas used cognitive enrichment equipment, effectively recognizing individual gorillas. To support the automatic, real-time evaluation of cognitive enrichment interventions, the authors propose the integration of sensors that could record the animals' detailed interaction with specific elements of the equipment.

Machine vision combined with Internet of Things (IoT) systems have significant potential also for managing and optimizing animal farming conditions. To support automatic processing within Black Soldier Fly and the domestic cricket farming, Hansen et al. used object detection and classification techniques to count and size fly larvae and to sex crickets, as well as IoT technology to monitor various environmental parameters and thus maintain suitable conditions. Furthermore, Neethirajan suggests how novel uses of technologies such as deepfake could help improve the welfare of farmed animals if used to generate large video datasets on which to train machine learning models that can accurately monitor animal health and identify their emotional state; and maybe even enable interventions that could ameliorate animal behavior, for example by displaying digital conspecifics. Completing this series of contributions, Bendel looks into future developments of partially and fully autonomous machines and robots, discussing how they could be designed to avoid harming or to protect animals. The author divides these systems into passive (e.g., systems that detect the presence of animals), active (e.g., systems that feed animals) and proactive (e.g., fully automated systems that protect animals); he discusses how these could be designed, providing numerous examples for each category.

Overall, the 12 contributions in this Research Topic provide a rich overview of cutting-edge animal-centered design approaches and applications of animal-centered technologies within domains as diverse as animal farming, research, conservation, and welfare. Readers will find discussions on the benefits that the proposed approaches and technologies have or could have for the welfare of animals, for the activities in which they are involved, and for human-animal relations, as well as discussions on challenges to the applicability of animal-centered perspectives and how such challenges might be addressed.

Author contributions

Both authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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METHODS
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Welfare Through Competence: A Framework for Animal-Centric Technology Design

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Digital technologies offer new ways to ensure that animals can lead a good life in managed settings. As interactive enrichment and smart environments appear in zoos, farms, shelters, kennels and vet facilities, it is essential that the design of such technologies be guided by clear, scientifically-grounded understandings of what animals need and want, to be successful in improving their wellbeing. The field of Animal-Computer Interaction proposes that this can be achieved by centering animals as stakeholders in technology design, but there remains a need for robust methods to support interdisciplinary teams in placing animals' interests at the heart of design projects. Responding to this gap, we present the Welfare through Competence framework, which is grounded in contemporary animal welfare science, established technology design practices and applied expertise in animal-centered design. The framework brings together the "Five Domains of Animal Welfare" model and the "Coe Individual Competence" model, and provides a structured approach to defining animal-centric objectives and refining them through the course of a design project. In this paper, we demonstrate how design teams can use this framework to promote positive animal welfare in a range of managed settings. These much-needed methodological advances contribute a new theoretical foundation to debates around the possibility of animal-centered design, and offer a practical agenda for creating technologies that support a good life for animals.

Keywords: animals, animal-computer interaction, animal-centric design, animal welfare, animal technology, interaction design, digital enrichment

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INTRODUCTION

Digital technologies offer new ways to ensure that animals in human care can lead a good life across a wide range of contexts. These contexts include, for example, zoos, farms, domestic settings, kennels, stable facilities, veterinary hospitals, animal shelters, research facilities, and wildlife sanctuaries. Such sectors are rapidly increasing the use of animal-centric devices such as wearable tracking devices, digital enrichment, automated feeders, robotic gates, and milking machines. In many settings is also common for carers and other humans to use technological devices as part of animal management and care, which may impact on animals and on human-animal interactions. These include data gathering devices, veterinary equipment, communication systems including screens and audio-visual equipment. However, in designing for animals' physical and mental wellbeing, a significant challenge lies in "centering" the animal—that is, identifying and prioritizing design objectives from the animal's viewpoint. Historically, design for animals has been guided by the drive for efficiency, economic gain, the preferences and goals of human carers, and by tradition or common practice, rather than by understandings of animals' ancient evolutionary nature and welfare needs. For example, although zoos have a long history of creating naturalistic environments, their design is often heavily influenced by visitor experience objectives, the practicalities of cleaning and animal management, and by the practice of imitating or improving on existing exhibits at other zoos. In the animal production sector, technological innovation may respond primarily to industry standards and to commercial pressure to increase efficiency and productivity.

Animal-centric goals are essential as a focus in design projects, to ensure that technology interventions' outcomes promote life-long mental and physical wellbeing for animals. The emerging discipline of Animal-Computer Interaction (ACI) proposes that design of technologies can achieve an animal-centered orientation and uncover new opportunities for technology to contribute to a good life for animals, by adapting the processes and methods of interaction design, as used in human-centered innovation projects (1–3). However, a core challenge of this approach lies in identifying what animals "need" or "want" (2). On the other hand, animal welfare scientists and designers of environments for animals (such as zoos, shelters, farms, and kennels) have a strong understanding of what is required to address animals' essential welfare needs but may miss opportunities to deploy design practice as a way to learn more about animals' preferences and about the potential benefits of digital technologies to animals. Increased understanding of animal sentience has highlighted the importance of enabling animals to be active agents in their lives. This emphasizes the need for opportunities for animals to develop independent competence within managed settings, which technology can support in novel ways. Our aim is to build on and advance ACI research toward a methodology that includes animals as key collaborators in multi-stakeholder design projects. To date, recommendations for conducting animal-centric design projects have been fragmented, and have not addressed the critical issue of how animals' wellbeing goals can guide a project from its outset. The purpose of this paper is to address this gap by proposing a framework for designing technology to promote a good life for animals, which integrates interaction design practice with models of animal welfare and design for animal competence.

A Good Life for Animals

To successfully design for animal wellbeing, a clear understanding of what constitutes a good life for animals is required. The concept of animal welfare can be considered equivalent to quality of life and wellbeing; an animal's welfare status is informed by many facets of its life and can vary from very poor to very good (4). The subjective experience of an individual animal is influenced by how the conditions in which it lives impact its affective state (5–7). That is, what does the animal need to do to cope and thrive in life, and how does that make the animal feel? Considering positive welfare, or a good life for animals as "enjoying good health (having what they need) and having access to what the animals themselves want, while also liking what they have" provides a modern, animal-centered perspective on what is meant by *animal welfare* (8).

Recent advancements in animal welfare science demonstrate evidence from areas such as neuroanatomy, comparative cognition, and physiology that has established the sentience of animals. This means that vertebrate animals and a growing number of invertebrate animals (e.g., octopus and lobster) can consciously experience awareness and different feelings such as pain, joy, frustration, loneliness and comfort. Understanding that animals are sentient requires us to identify the needs of animals as a significant moral obligation. This is particularly true for animals kept under human care, where environmental, social and behavioral opportunities are often restricted (9, 10). This is reflected in the recent recognition of animal sentience in legislation globally, and shifting community attitudes of concern toward animals and the industries that manage or interact with them (11). These new understandings of animals' sentience imply that humans should ensure that the animals they care for enjoy a good life, going beyond the minimization of negative experiences such as harm or discomfort. As part of this shift toward ensuring positive experiences, there is growing attention to the value of exercising agency, building competencies and appropriate levels of challenge as important contributors to wellbeing of animals in human care (12–14).

Historically, the management of animals has been anthropocentric. Across modern animal care settings, the attitudes and consequent behaviors of people responsible may not align with the animal welfare evidence base or animal preferences (15). In response, some people have proposed that the animals must change to cope with the settings people have placed them in; that there is a need for animals to be *resilient* to cope with welfare challenges and *robust* to maintain productivity without compromise (16). An alternative strategy, which aligns with the change in community attitudes toward animals, is to seek new ways to care for animals in managed settings that prioritize their wellbeing. Where practices relating to animal care and management have been shown to conflict with community expectations, industries have experienced significant interruption or termination of their social license to operate (17). For example, community concerns about animal welfare played a substantial role in the reshaping of zoos (18) and have recently had considerable impact on the use of exotic animals in circuses (19) and greyhound racing (20). Similar shifts are now occurring in public attitudes regarding farm animal welfare (21), which has substantial implications for the sustainability of animal production (22, 23). The importance of promoting positive welfare has relevance for the horse racing sector (24) and for working dogs, as reflected in official standards for security and detection dogs (25). Taken together, these points highlight the need to provide all animals under human care with a good life, by creating environments, equipment and systems centered on animals, aligning with community expectations and modern scientific understanding of critical factors such as animal sentience.

Designing for Animal Wellbeing

Sectors in which animals are managed, notably zoos and farms, have a history of designing built environments to meet essential welfare needs. Standards of care for animals' environments have traditionally been based on the "Five Freedoms" principles of animal welfare, which arose from the livestock-focused Brambell Report (26, 27). The Five Freedoms principles aimed to provide animals with "freedoms *from*" negative conditions and suffering: 1) Freedom from hunger and thirst and malnutrition (through ready access to fresh water and adequate diet to maintain full health); 2) Freedom from discomfort (by providing an appropriate environment that allows for shelter and rest); 3) Freedom from pain, injury or disease (by preventative health care and/or provision of rapid diagnosis and treatment); 4) Freedom to express normal behavior (through provision of sufficient space, resources and social interaction); and 5) Freedom from fear and distress (by providing conditions and treatment which avoid mental suffering). These principles guided the provision of a minimum baseline of acceptable welfare which should be met in the design and management of farms and other settings.

As scientific understanding and societal concern regarding animal welfare have grown in recent decades, new methods to consider and assess animal welfare have emerged. These modern methods have influenced the provision of environments and resources in some settings, including good, modern zoos (10, 28). The current animal welfare models recognize that animals should feel well, be biologically functional and lead reasonably natural lives (29, 30). The assessment of animal welfare is today most commonly informed by the structured Five Domains of Animal Welfare Model (7). The Five Domains offers a systematic way to assess indicators of internal and external physical and functional states, environmental conditions and how these then influence the subjective mental experiences of animals. Unlike the older Five Freedoms, the Five Domains Model combines "freedom *from*" and "freedom *to*" by considering both negative and positive mental states. This model provides a valuable tool for assessing and remedying existing facilities and programs, but does not specifically address the issues of promoting animal competence, generating animal-centric design requirements or including animals in design practice.

There has been increasing recognition that species-specific strategies and interventions are needed to improve the lives of animals. Such strategies include being required to "work" for their food (31), creating opportunities to exercise highly-motivated natural behaviors, variation of the environment and addition of sensory stimuli, and allowing animals some degree of independent control over their lives. Many of these strategies can be achieved through "environmental enrichment," which takes many animate and inanimate forms, including "occupational" enrichment such as food puzzles, control of the environment and physical exercise; "physical" enrichment from interacting with complex environments including structures and appropriate substrates; "sensory" enrichment, including visual, auditory, and olfactory stimuli; "nutritional" enrichment through variation of delivery, food type and challenging presentation; and "social" enrichment comprising interactions with other animals and with humans (32, 33). In recent decades, zoos, aquariums, and similar facilities have pioneered the design, creation, and evaluation of enrichment (34, 35). The use of enrichment has demonstrated benefits to animal welfare for animals living in a range of contexts, including laboratory, farm, zoo, aquatic, and kennel environments [e.g., (15, 32, 36–38)]. Important considerations in the design and provision of enrichment are that it should be relevant to the animal's "behavioral needs" (39), and context (40), and that it should provide appropriate levels of challenge (41). Enriched and challenging environments play an important role in enabling animals to gain competence, including flexible problem-solving skills and mastery in specific tasks (12). To develop competence and exercise agency, an animal must be exposed to novelty, broad sensory experiences and opportunities for learning through interaction. Through gathering environmental information, exposing themselves to risk and training their capabilities through exploration and play, animals build the ability to solve problems that are meaningful to them, with respect to their ecological niche (12). Indeed, opportunities to develop competence may play a significant role in addressing ethical and welfare concerns associated with keeping animals in managed settings (14).

The potential for technological devices to contribute to animal wellbeing was explored as early as the 1970s, notably by Markowitz and colleagues at Portland Zoo. As cognitive enrichment for primates housed in barren environments, Markowitz created installations which required animals to push specific buttons or levers in response to artificial stimuli such as lights, or work to obtain tokens which could then be exchanged for food rewards (42). Operant training was used to shape animal behavior and teach animals how to play the games (42). In cognitive research programs, primates and other animals have long used technologies such as joystick-controlled computers and touchscreen interfaces (43, 44), and there are claims that this type of activity can be enriching for animals (44). In recent years, researchers have explored the potential of using sensor-based technologies to provide animals with greater variety, and more opportunities for active interaction and agency in their environment (45–48) and to offer substitutes for natural behaviors, such as hunting live prey (49). In parallel, there has been a rapid uplift in the potential for conducting digital monitoring and tracking of animals in zoos, farms and other settings, using animal-attached sensors, bioacoustics (50), video-based analysis (51, 52), and other technologies embedded into animals' environments. Technologies such as precision agriculture systems are generally grounded in the needs of human stakeholders and the aims of improving efficiency and productivity, but can also contribute to animal welfare goals (53), and be designed with consideration of the needs of animal stakeholders (54).

The Challenges of Animal-Centric Design

With the increasing use of digital technologies for and with animals in a range of settings, there is an urgent need for technology design methods which can account for and respond to the needs and interests of animals and, at a minimum, ensure that there are no negative impacts on animal welfare. The field of ACI addresses this challenge, investigating how animal-centric digital technologies can best contribute to a good life for animals, and to develop relevant methods and theories to achieve this. A commonly cited aim, formulated by Steve North, is that ACI would "build only what they [animals] want or need" (55). Researchers from animal sciences have drawn attention to the breadth of opportunities that interactive technologies offer for enhancing animal welfare (56). However, there is a risk that such interventions can introduce unintended harms, or inadvertently promote misconceptions about animals' needs, if they are created without inclusion of appropriate expertise and careful attention to the genuine needs and interests of the animal (59). Limited attempts to include the perspective of the "non-verbal other" (60) in design entails the risk of attributing desires to an animal which correspond with preconceived notions of what animals need or want (59). North has also drawn attention to the risk of "unconscious projection of personal design priorities and enthusiasms" onto "voiceless co-designers" (55) as part of a call for robust, interdisciplinary methods for ACI design and research.

As an interdisciplinary field, ACI has applied a variety of theoretical and methodological lenses to the question of how we can elicit and respond to animals' requirements in designing digital technologies. Mancini's manifesto proposed that user-centered design methods, commonly used by interaction designers and human-computer interaction researchers, could be used alongside methods and knowledge developed in animal sciences, to access an animal's perspective (1). One approach for formalizing an animal-centric design process, the "Agility, Welfare as value and Animal eXpert involvement" model (AWAX), was devised by van der Linden and Zamansky (61). The AWAX process is initiated with specifications created by a technical team, rather than starting with what is known about the animal to identify design opportunities and objectives. French et al. draw on their experience in designing for elephants and other animals to propose a deck of "Concept Craft Cards" which are intended to support designers in envisioning ACI interventions, with prompts related to aesthetics, species characteristics, values and user experience (62). To leverage scientific and zoo-based knowledge in defining design objectives, Veasey proposes the "Animal Welfare Priority Identification System" (APWIS), an approach based on the Delphi method, in which animals' needs are identified and weighed by a panel of species experts and specialists (63, 64). It remains unclear however, how animals' needs might be incorporated into an iterative design project, or revisited as new knowledge emerges through the design process.

ACI designers face substantial challenges in imagining how an animal will respond to new interactive opportunities (65), and in crafting experiences which will be aesthetically interesting to animals (62) and be of ongoing interest and benefit. Many ACI researchers seeking to enhance animals' lives have found that animals respond to novel interventions with disinterest (66), fear (67), or active destruction (68). Such investigations can be costly and time consuming if they entail extensive work to ensure that hardware components are safe and sufficiently robust for animal use (48, 68) or require considerable training for animals to use them successfully (67). Even ACI installations which are initially used successfully can fall into disuse, suggesting that they require modification to provide ongoing meaningful benefits to animals (46, 69). This suggests that there is a need for methods which will guide designers in identifying appropriate solutions while minimizing effort and cost spent on exploring alternatives which might not be beneficial or successful.

There remains a need for structured approaches that guide interaction designers, animal scientists and carers to systematically explore animal wellbeing design opportunities, convert them into animal-centric design objectives, keep them in focus and refine them through the course of a design project. It is notable that the interdisciplinary nature of animal-centric design means that methods and tools should be accessible to interaction designers, animal experts and carers, and should help teams to communicate and collaborate despite differences in methodological backgrounds. In this paper, we draw on our cross-disciplinary experience of designing and evaluating interventions for animal welfare, and extend the prior work of designers (62), animal welfare experts (63), and computer scientists (61) to present the Welfare through Competence framework (WtC), grounded in interaction design practice, animal welfare science and expertise in world-leading zoo design. This framework is offered as a guide and support for teams of practitioners and researchers aiming to create technologies that contribute to a good life for animals.

MATERIALS AND EQUIPMENT

In this section, we introduce the existing models of animal welfare and competence, design for animals and interaction design that we employ as a foundation for animal-centered design. As a contemporary model of animal welfare focused on identifying positive welfare outcomes, we adopt the Five Domains model developed by Mellor, Beausoleil and colleagues, most recently presented in Mellor et al. (7). We complement this with the Coe Individual Competence Model (70, 71), which provides designers a structure for thinking about the long-term needs of animals in managed settings and which emerged from extensive design work in zoos and sanctuaries. The third model we deploy is the interaction design cycle, an approach to iterative, user-centered prototype-based design widely used by design practitioners and human-computer interaction researchers.

The Five Domains of Animal Welfare Model

The Five Domains of Animal Welfare Model (7) is widely recognized as a paradigm for systematic consideration of how animals' wellbeing relates to their lived experiences. The Model assesses indicators of welfare across the physical and functional domains of (1) **Nutrition**, (2) **Environment**, (3) **Physical Health**, and (4) **Behavioral interactions**, which together inform the final domain, (5) **Mental State**. In addition to placing Mental State at the center of animal welfare considerations, the Five Domains provides a Model that observes positive states with equal emphasis as negative states. In assessing an animal's welfare, the Five Domains Model relies on behavioral and physical indicators and resource provision to infer animal wellbeing. This acknowledges that animal welfare is experienced subjectively at the level of the individual; we must rely on these indicators as the absence of validation and consensus mean that we are not yet able to directly measure an animal's subjective welfare (72, 73). The success of the Five Domains Model is evidenced by its widespread international adoption, including by organizations such as RSPCA UK and the Zoo and Aquarium Association Australasia. It is a valuable tool for the systematic examination of the different aspects of an animal's present experiences. However, it does not provide a process for envisaging possible futures or generating solutions to deficiencies, other than identifying improvement in mental state as an indicator of success. While not a fault of the Five Domains Model, suggested solutions to compromised welfare tend to be framed as: "What can people do for the animals to improve their welfare in this domain?" rather than empowering animals to competently improve their own welfare as they prefer.

The Coe Individual Competence Model

The Coe Individual Competence model (71) was developed to provide a practical agenda for designers of managed animal facilities and enrichment to create environments which enable animals to develop competence as part of positive animal welfare. Competence can include broad capacity to address challenges and novel problems, as well as mastery in specific tasks (12). This model responds to the growing body of research which attends to competency and agency in animal wellbeing (13), and the significance of factors such as novelty, predictability, complexity, challenge and sensory experience (12).

The Coe Individual Competence model calls for animals to be offered opportunities which entail (1) **Choice**, (2) **Control**, (3) **Variety**, and (4) **Complexity,** which all contribute to the development of (5) **Competence** (71). With a focus on *freedom to* rather than *freedom from* as also described in the Five Freedoms principles, the Coe Individual Competence Model provides a structure to identify enrichment opportunities that can contribute to animals' ongoing development of physical, social, and mental capabilities for living a good life. Ideally, levels of competence can be compared to, but not limited to, species-typical natural behaviors recorded in the wild. For example, zoo-housed orangutans should have the strength and dexterity to be agile climbers as wild conspecifics are, but may also become competent to use symbolic language on a touchscreen computer interface if they wish. This approach is based upon providing animals with an enabling environment, and supportive training and conditioning opportunities, to develop necessary levels of competence and agency to benefit from the increased opportunities listed here. We have defined each of the foci of this model for clarity as follows.

Choice

Choice entails having opportunities to select between two or more options. Choice is provided by enabling animals to make decisions and encouraging animals to exercise agency (13). As well as being inherently rewarding (14), opportunities to choose can enable animals to address their physical, homeostatic needs, as in the case of having nutritional choices (74), and to develop the competencies they may need to access desired resources in future (13). Managed settings often restrict animals' freedom of movement and other behavioral choices (e.g., social interaction and breeding opportunities), but can be designed to provide greater access to preferred environments and experiences as compared to wild settings (14). Choice is often based upon relative, rather than absolute preference. Choices offered to the animal should remain within the limits of what may be helpful and not harmful.

Control

Increased control or agency has been proven to improve welfare (13, 75). It entails giving animals the power to influence (limit, order, or direct) behavior, actions, environment, or the course of events, enhancing individual capacity to cope with novel problems. Control is provided when animals can actively decide when, how, where and/or with whom to interact without external interference. While many animals under human care lack opportunities for control, they can derive inherent benefit from features specifically designed to allow them to say, activate showers, trigger food delivery, or change lighting (42, 70, 76). Exercising control and agency is intimately linked to developing competency, in that it enables animals to gather knowledge, develop novel behaviors and enhance skills through exploration and play, instrumental or social learning, and communication (13). The term "competency-building agency" has been used to denote a level of agency which may not deliver immediate outcomes but enhances animals' capacity for, say, more efficient foraging, or addressing future challenges (13). It should be noted that an animal choosing *not* to use an enrichment feature or other intervention is also exercising agency. Coe (77) has suggested that the organisms with the greatest degree of choice and control have the greatest degree of relative freedom.

Variety

Variety involves experiencing quality or states that are diverse. In the wild, animals move through a varied spectrum of environments to meet their needs and are likely to encounter changes with the seasons and over time. Variety entails novelty and is a prerequisite for building competency (12). Facing new objects, situations, events and challenges encourages "inspective exploration" and "inquisitive exploration," and enables animals to develop flexible problem-solving abilities (12). For animals in human care, variety can be introduced by incorporating a range of physical and sensorial features, making alterations over time, or by providing access to multiple, different spaces. Variety can also take the form of different foods, varied social opportunities, and opportunities to exercise a variety of behaviors—for example, using different foraging strategies.

Complexity

Complexity involves engaging with many interrelated parts (e.g., objects, ideas, activities, environments, etc.) that may be connected in intricate and complicated ways, with no simple solution. Complexity is provided when animals find situations or tasks challenging to analyse, understand or solve and rewarding to achieve (41). The challenges presented by rich, complex and unpredictable environments demand ongoing learning. From an animal's perspective, a complex environment that is also variable is highly probabilistic: repeated attempts and intense engagement may be required to access resources, and this provides a setting where animals can build mastery and perhaps come to detect hidden contingencies (12). Animals evolved to prosper in an often-changing complexity of physical and social environments, and welfare can be compromised through boredom leading to frustration and a lack of physical conditioning and mental acuity (32).

Competence

Competence is gained by animals who achieve the functional abilities (physical and mental, innate, and learned) to be able to realize desired outcomes effectively and efficiently. In an evolutionary sense, the successful wild animal is *de facto* physically, mentally, and socially **competent**, exercising **choice** and **control** amid a wide **variety** of **complex** physical and social environments to achieve success. We suggest that offering animals in human care opportunities to engage and gain skills in these areas will help them to better manage their own lives through increased agency and competence (73). Competence requires the development of capacities along several dimensions: physical, social, cognitive capacity, knowledge acquisition (12). It allows for problem-solving and achieving desired outcomes in the short and long term. Developing competence is life-long and incremental, and need not be rushed. Competence along any of the above focal dimensions (exercising Choice or Control, and responding to Variety or Complexity) may take time to acquire, depending upon the physical, social and management environments. Progress toward competence can be evaluated using the Five Domains Model. Competence to achieve a high level of physical, mental, social, innate and learned abilities may be considered the measure of the self-actualized animal (71) in nature or in managed care (78). Competence is the set of demonstrable characteristics and skills that enable increasing agency and self-determination for the animal resulting in a good life.

Time and timing (occurrence, frequency and duration) is a factor or opportunity for consideration in each of the competence focal categories (79). For example, **Choice** of timing, frequency and duration of enrichment occurrence; **Control** of timing of occurrence, frequency and duration; **Variety** and **Complexity** of timing options could all support development the animal's **Competence**. Ideally, enrichment opportunities should be scheduled to coincide with the species' natural circadian rhythms rather than caregiver working hours. However, success of interventions also requires that they be feasible for animal caretakers to implement—a factor which is associated with workplace satisfaction and caretakers' mental health (80).

The design of interventions for animal competence should account for the prior experiences and competence of the animal, and should consider how competence can be augmented over time. As part of this, it is important for designers to consider how new animals will be introduced to environments in which ACI interventions have been deployed; for example, habituation, training and incremental introduction may be required. In addition, it is important to consider the exit process for animals who will be removed from an enriched environment to one in which they have lower levels of choice, control, variety or complexity.

The Interaction Design Process

Building on the approaches suggested by ACI scholars (1, 55), we adapt and extend interaction design methods, which are widely used to create user-centered digital technologies such as interactive websites and mobile applications (81). The process of interaction design entails learning about the future users of a digital product, using these insights to define what should be built, creating prototypes (rough representations or approximations), and evaluating these prototypes. A key aim of interaction design methods is to gain input and feedback from potential users and other stakeholders throughout the process. The steps are often portrayed as a design "cycle" which should be conducted iteratively, on the basis that information gained through testing early prototypes can give designers important new understandings of what should (or should not) be built, and how to build it successfully (82). This iterative approach to design contrasts with "waterfall" development methods in which all research and requirements gathering is performed upfront, before design takes place (83).

Interaction design commences with understanding users, or developing "empathy," and learning about the problem space, i.e., the nature of the goals and issues faced by potential users, the limitations of existing solutions, and the context of use. This information, collectively, is used to *define objectives* for the product, i.e., to determine what should be built. Designers are encouraged to undertake creative *ideation*, generating multiple alternative ideas about how the objectives could be addressed through e.g., brainstorming. Ideation, especially if conducted in collaboration with future users and stakeholders, can lead to new insights about the problem, enabling the team to refine the objectives. From these candidate ideas, one or more will be selected as the basis for *prototyping*. As part of the iterative process of learning, the first prototypes are created with the intention that they will be thrown away, and so should be low-cost and quick to create. Early prototypes may include storyboards (84), paper prototypes (85) and "Wizard of Oz" solutions, in which the role of a future system is played by a human operator (86). These are often referred to as "low fidelity" prototypes (87): they look very different from the envisaged product they represent, but can still allow people to give valuable feedback about what a product will deliver, and how it will be used. Later on (after a few iterations of the interaction design cycle), design teams are likely to turn to software and interactive devices to create "high fidelity" prototypes, which look and behave more closely like the envisaged product (85).

Evaluation of prototypes can result in many different forms of insights, which may be used to redefine the objectives, to generate new design ideas, or to inform subsequent prototypes. Evaluation conducted in early iterations of a human-centered design project often takes the form of workshops, focus groups and walkthroughs, aiming to validate the overall aims of the project and learn more about alternative design directions. Through user evaluation, teams may well learn more about the users and the problem space. Subsequently, "formative" evaluation of higher fidelity prototypes is likely to focus on improving usability and the "user experience" (82, 88), but it generally becomes more costly to make significant changes to a product proposal (83). Late-stage evaluation of candidate products may also investigate the effectiveness of alternative designs in terms of, say, productivity (in the case of a workplace application), or learning outcomes (for an educational tool). "Summative" evaluation seeks to establish the effectiveness of a final candidate product and is often conducted with users immediately prior to a product being deployed (89, 90).

There exists great variety in the way that interaction design processes have been defined by institutions such as Stanford's d.School, Google and IDEO (91–93). Processes vary in terms of the number of steps (commonly, 4–6 steps), the terminology used, and graphical representations. We have adopted a simple design process, employing terminology often encountered in interaction design and allied fields of user experience and human-computer interaction. A graphical representation of this process is shown at **Figure 1**. This diagram represents a broadly cyclical process entailing four activities: *define objectives, ideate, prototype, evaluate*; and also shows that information and ideas can flow in different directions between the four activities.

Many ACI scholars have recognized the potential benefits of iterative, user-focused interaction design methods as a means to include the "voice" of animals in creating a product, and "center" animals' needs, and thereby avoid misguided, and anthropocentric design directions (3, 65, 94, 95). However, our own experiences and those of other ACI designers indicate that there are several challenges to including animals in interactive, prototype based design processes (96). Firstly, animals cannot verbally express their goals and desires, and so designers often struggle to identify and prioritize animals' essential needs to inform design objectives (57, 59). Secondly, prototypes can be rapidly destroyed by animals (97), so may need to be replaced repeatedly or constructed in highly robust fashion, which can be costly and time-consuming. Thirdly, it is problematic to make inferences about how useful or suitable an intervention is to animals based on their initial responses (98) as their early interactions are likely to be shaped by the impetus toward inquisitive exploration (13) and the "novelty effect" (99), or by neophobia or startle responses (67). Fourthly, methods of evaluation used in animal care sectors can conflict with iterative design approaches in which prototypes are repeatedly changed in response to formative evaluation (96). Our aim is to adapt interaction design methods to overcome these challenges, providing a lightweight, learning-focused process (as set out in Section Applying Interaction Design Process) for ACI design teams to maximize attention to animals' needs in the context of the WtC framework.

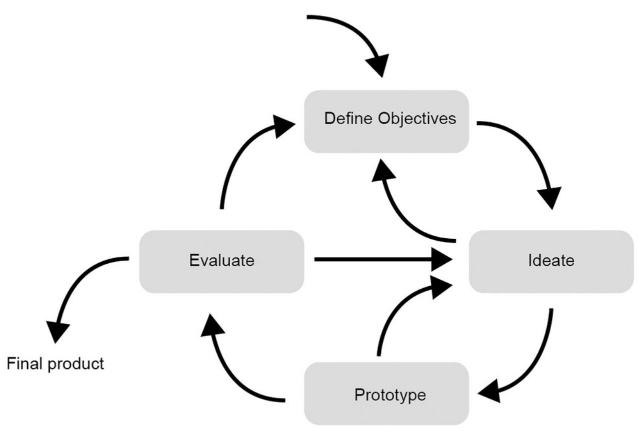

FIGURE 1 | An iterative interaction design process.

METHODS

Responding to the challenge faced by ACI designers in identifying what it is that animals want and need, we present the WtC framework for design centered around a matrix which synthesizes the Five Domains model and the Coe Individual Competence model. The framework prompts designers to identify animal-centric design opportunities using the matrix, giving consideration to the individual animal, its group population, the context and the animal species. The WtC Animal Objectives Canvas, represented in **Figure 2**, provides a structured approach to define animal-centric design objectives as input to a technology design project. We describe how these objectives can be included in an Interaction Design process shown at **Figure 3**, in such a way as to validate, refine or redefine the animal-centric objectives and revisit them through the course of a design project.

The Welfare Through Competence Design Opportunities Matrix

Synthesizing the Five Domains and Coe Individual Competence models into a matrix, as shown in **Table 1**, provides a basis to assess and identify opportunities for a good life for animals. We propose that designers can systematically explore animal-centric design opportunities by considering how each of the competence foci (per the Coe Individual Competence model) can contribute to each of the Five Domains of animal welfare. For example, designers might first consider how each of the Competence foci can play a role in supporting an animal's welfare in the domain of nutrition, as follows:

- Considering the focus area of **choice** and asking what food and feeding options would the animal have in the wild might reveal opportunities for providing greater, more natural choice of food such as seasonally available variations (while still ensuring that the animal has a nutritionally complete and balanced diet) or feeding schedule (single predictable feeding or multiple random feedings), which would the animal choose? Which would be best suited to its evolutionary adaptations?
- Designers would then progress to consider goals related to animal **control** in the domain of nutrition. How would the animal choose to control food recourses and availability choices within a healthy diet? For example, would the animal prefer to control a food delivery mechanism itself rather than having the same food delivered by a caregiver?

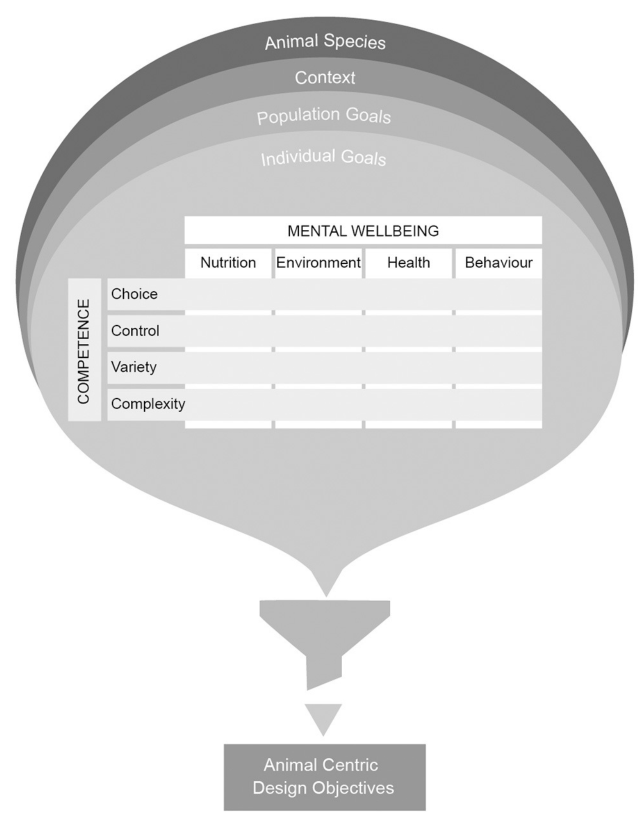

FIGURE 2 | The welfare through competence animal objectives canvas.

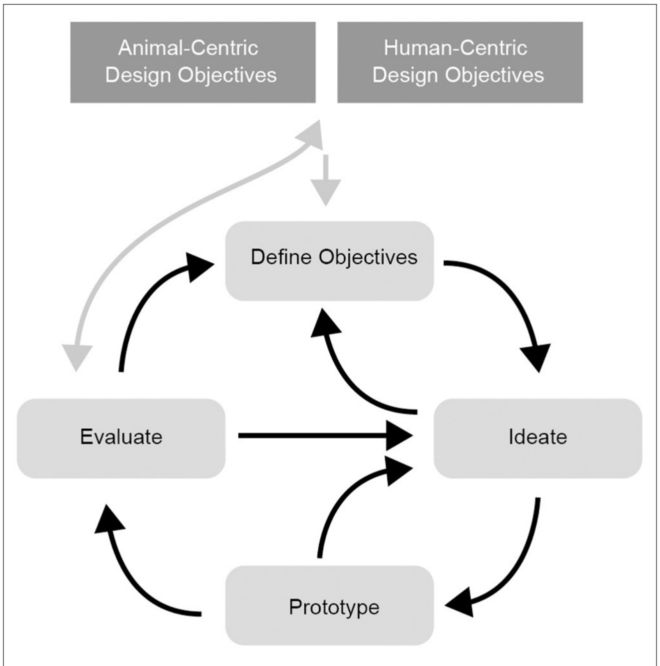

FIGURE 3 | The welfare through competence interaction design process.

TABLE 1 | The welfare through competence design opportunities matrix.

		Mental wellbeing			
		Nutrition	**Environment**	**Physical health**	**Behavioral interactions**
Competence	**Choice**				
	Control				
	Variety				
	Complexity				

- Opportunities for **variety** in nutrition might be considered next, including mechanisms for varying the schedule, location, type and quantity of food available from day to day, or according to the season (while ensuring that nutritional needs are met). Designers might consider aspects of timing, including the frequency with which a given food is presented, and varying the interval between feeding events.
- In considering how **complexity** can be provided in the domain of nutrition, designers might identify opportunities for feeding schedules in which the mechanism of exercising control over feeding varies, as well as the type of food, thereby gradually increasing the level of variety and challenge that the animal experiences over time. Feeding in social settings also opens opportunities for experiencing and navigating complexity as the animals would in the wild. Increasing complexity can be an important dimension of incrementally augmenting animals' competence, and so careful consideration should be given to the rate at which greater complexity is introduced to provide optimal levels of safety and challenge.
- Taking a broader view, consideration would also be given to other intersections between **competence** and nutrition, which might lead designers to identify opportunities to promote behaviors, skills, physical strength, dexterity or speed that the animal's wild counterparts must possess to obtain food in native habitats.

Contextualizing and Prioritizing Design Opportunities

The WtC Animal Objectives Canvas (**Figure 2**) provides a tool for gathering the information required to effectively fill out the WtC Design Opportunities Matrix, and for prioritizing the opportunities to define objectives for a design project. In considering each component of the matrix, designers should take account of **the animal species,** the **context,** the **welfare goals of the population** and the **welfare goals of the individual animal.** In this context, "goals" refers to the needs and wants of the animal and are associated with improved welfare outcomes. Through this process some components will be responsive to high priority welfare needs of the animal. Conversely, some components may not be relevant to the needs of the animal.

Animal Species

Species-specific needs, goals and capacities should play a large role in identifying and selecting design opportunities. Designers should take account of the motivated behaviors, cognitive capacities, and environmental preferences of the species, as well as their abilities and preferences in terms of physiology, sensing, locomotion, and interaction with objects. For many species, there are known welfare challenges with managed care. For example, spatial considerations to enable captive snakes to adopt straight-line body postures (100); elevated positioning of features for arboreal animals (101); optimal enrichment provision for different life stages (suckling piglets, weaning piglets, and fattening pigs) of group-housed pigs on farms (37); and supporting Asian elephant herd dynamics in zoos with larger and more complex habitats (102). Designers should take account of these species-specific characteristics through reference to relevant literature and species experts with emphasis on characteristics observed in the wild.

Context

Design opportunities should take account of specific environmental factors which impinge on the animal's wellbeing. These may include contextual opportunities and constraints such as diurnal or nocturnal illumination, microclimate, space, physical structures and substrates, which may influence the extent to which an animal can express highly motivated behaviors such as exploring, play, and foraging behaviors such as rooting and digging, or hunting. The extent of environmental complexity and variety have been demonstrated to influence the degree of cognitive stimulation and challenge that can be provided to the animal (96, 103, 104) [See Coe and Hoy (70) for examples of contextual, built-in environmental enrichment]. Per Mellor et al. (7), the visual, auditory, and olfactory environment may have either a positive or a negative impact on wellbeing; for example, for some species, the sounds and presence (including position overhead) of humans or other species may elicit fear (105, 106). However, environments which offer visual and auditory variety, especially access to distant views, sounds and smells, may be enriching. Opportunities for design can be identified and prioritized by considering the ways in which the animal's environment 1) may negatively impact on wellbeing, 2) constrains existing welfare provisions, 3) already meets welfare needs.

Population Goals

Characteristics of the group that an animal is part of will shape welfare goals at several levels. Animals housed in groups are likely to have common welfare needs, goals and constraints. Accordingly, animal welfare is often considered at the group or population level (107, 108). The social characteristics of the group may also impinge on the welfare status of the group as a whole: factors such as the number of co-housed individuals, social hierarchies, ratio of male vs. females, and age composition of the group may impact welfare.

Individual Goals

The welfare needs of an animal, and ways in which those requirements can best be addressed, are also shaped by individual factors such as the animal's age, sex, personality, social relationships, and prior experiences. Older animals may have fewer opportunities for positive experiences due to declining physical or cognitive abilities, associated behavioral change or physical pain (109). Aging and life-stage have been found to significantly impact on the extent to which animals make use of enrichment (46, 110–112). As animals age, they may require tailored husbandry, enrichment and training, informed by ongoing monitoring of physiological, behavioral and cognitive changes (109). Sex has been associated with differences in welfare factors such as fearfulness (113) and participation in enrichment sessions (110). Personality traits such as aggressiveness, fearfulness, and risk-taking can impact on an animal's welfare and this may also be relevant in the case of traits such as sociability and nurturing behaviors (107). Many opportunities for improving welfare through animal-computer interaction may stem from the ability to use computational approaches to gather information about individual animals and automatically personalize interventions to individual animals.

Defining Animal-Centric Design Objectives

The design opportunities identified and prioritized using the WtC Design Opportunities Matrix can be distilled to define design objectives: clear, measurable, specific statements of what a design intervention is intended to achieve in terms of animal wellbeing. The animal-centric design objectives, balanced with human-centric objectives, will provide input to the first cycle of an interaction design project. In many projects, selecting a single, high-priority design opportunity from the matrix will provide greater chances of overall success. As an example, identifying opportunities to increase environmental variety for zoo-housed primates might give rise to the objective to *create an interactive enrichment installation allowing animals to access a range of visual or audio stimuli*, as in the case of the Kinecting with Orangutans project (114) and the SakiTunnel installation (69). In some cases, secondary objectives may be included through this filtering process. For instance, a project to create interactive installation for primates might include secondary goals related to increasing primates' environmental control or promoting greater complexity of behavior (115). However, design teams should be aware that including too many disparate design objectives can lead to a lack of focus, and risks overloading a project with unrealistic aims.

A core challenge in projects of this nature is to explore how animal-centric and human-centric design objectives can be achieved simultaneously, through careful design. The interests and constraints of human stakeholder involved in the care of animals will need to be included as human-centric design objectives. Many design tools and processes exist for establishing human-centered design objectives and defining project objectives as they relate to an organisation's strategic goals. This framework therefore does not address that aspect of the design process. For example, in designing for zoo-housed primates, ACI researchers have identified the need to consider the varied requirements of zoo personnel and visitors (116), such as eliciting visitors' empathy for animals, while also providing meaningful education and enjoyment (114).

Animal-centric and human-centric design opportunities should also be used to define evaluation criteria. Through this process, designers are likely to identify several criteria for success, which may reflect the overarching goal of creating positive outcomes for animal and human stakeholders or, at a minimum, seek to ensure that the intervention has no negative impacts.

For example, an initial summative evaluation of Kinecting with Orangutans measured its behavioral impacts, finding that the installation had no negative welfare impacts (46), while impacts on visitor perceptions of the animals were examined separately (114).

Applying Interaction Design Process

Below, we describe a step-by-step process for using the WtC framework as part of an interaction design project. The process is offered as a way for teams of designers and animal carers to collaborate in creating interactive technology which prioritizes animal welfare objectives. This process responds to the real-world issues and conceptual challenges of designing for animals that we have encountered in our own work, and which are reported in the literature. We suggest that teams should conduct multiple iterations of this process cycle to gain greater clarity about animal needs, and include animal and human stakeholders as design participants.

Step 1: Understand Animals' Needs and Wants

1. Collate information to understand the needs and preferences of the animal, the context and current welfare provisions. The WtC Animal Objectives Canvas (**Figure 2**) provides a guide to collating such information to understand animals' needs and how they might be addressed. This approach can be used to address welfare needs in one of the Five Domains, or to address a known issue, or within a project that has broader goals, and which might impact on animal wellbeing. A broad, rapid survey of the types of knowledge held by different fields and practitioners can be valuable as a first step and allows for subsequent "deep dive" into the topics most relevant to design directions pursued as the project progresses.

    1.1 **Animal Species.** Gather information on the needs of the animal species and known welfare challenges in managed settings. This can be in the form of scientific and reliable popular publications; accounts, video recordings and data on wild populations and their habitat use; information from independent species experts such as veterinarians, animal welfare scientists and animal carers. Designers might employ a modified Delphi process, as suggested by Veasey (63, 64) to gather expert opinions on the relative importance of the behavioral and psychological needs of wild species in captivity. It is essential for designers to gather rich information from varied sources about the species' needs, behaviors and relative importance of welfare goals to avoid the pitfalls of creating products which have little value to the intended users (57, 117).

    1.2 **Context.** Gather information about the existing or proposed environment and its known impact on animal welfare. This might be collected through site audits of animal welfare (for example using the Five Domains methods), or through observations or reports on the animal environment. Designers can build on existing knowledge about how to address animal welfare challenges in sites such as zoos (35) working dog kennels (118), farms (119), and slaughterhouses (120). When designing for zoos, note that context includes both on-display areas and off-display areas (121). To understand opportunities and constraints on changes to the animals, collect information about the physical space in which the animal is housed, in terms of dimensions, physical structures and substrates, air flow, and temperatures. Additionally, information about the visual and auditory environment and other sensory aspects (e.g., odors from cleaning chemicals) might also be relevant to the animal. Understanding routines, schedules and protocols for feeding, health checks, cleaning, enrichment, training and other forms of interaction with familiar humans is important. Further, collecting details about any other activities which entail changes to the animal's environment, such as relocations, introduction of other animals, or changes to the presence of humans. For these events and routines, record occurrence (for example, any events which trigger them), frequency and duration or, ideally, obtain baseline data covering such factors.

    1.3 **Population Goals.** Gather information about the welfare needs of the group or population in which the animal is located. This might take the form of formal animal welfare audits and plans, or informal assessments from carers or handlers. Understanding the history for a specific population, for example through interviews with carers, can offer insights into important social dynamic nuances and previous enrichment successes or failures. This in turn, may influence identification of preferred opportunities and strategies. Peer reviewed literature can also provide insights into the welfare needs of other groups of the same species housed in similar settings. To identify related design opportunities, collect information on the social interactions between conspecifics, including the nature of such interactions, and whether they entail positive or negative experiences for the animals involved.

    1.4 **Individual Goals**. Gather information about the welfare needs of the individual animal. This might include the outcomes of existing animal welfare audits and reports. Where possible, up-to-date "baseline" assessments of the animal should be conducted, which will be valuable when evaluating success. Another option is to include light-weight assessment techniques, such as the qualitative "free choice profiling" approach proposed by Wemelsfelder et al. (122). To understand the design opportunities and constraints pertaining to an individual animal, gather behavioral data such as the animal's current activity levels, use of enrichment, interactions with conspecifics, human carers and others, and feeding preferences. This may be obtained through direct observation, interviews with carers and video recordings—including hours when carers are not present—which can be analyzed by carers, species specialists or welfare specialists. Comparing an individual's behavioral data with that of conspecifics from the same or different site may be revealing. Consider the likely physiological, behavioral and cognitive impacts of maturation or aging, and other future changes such as pregnancy and rearing young.

Step 2: Identify Animal Centric Design Opportunities

2. Consider in turn each of the focus areas defined by the Coe Individual Competence Model (Choice, Control, Variety, and Complexity), to identify ways in which the animal's situation might be changed for the better, if a design solution could be successfully realized.

   2.1 Consider how enhancing **Choice** might improve the animal's situation within the welfare domain currently under scrutiny. This might include interventions which allow the animal to choose between a wider range or frequency of options, or throughout a 24-h cycle and not just when care staff are present (123, 124). Consider how increased choices could enhance the animals' ability to communicate preferences, or expand the areas of life in which the animal can exercise control, engage complexity and build competence (14, 125).

   2.2 Consider how greater **Control** for the animal might allow for better welfare outcomes in this domain. An important consideration is whether an animal can be given continuous control over basic aspects of their situation, including freedom of movement between cooler/warmer, dryer/damper, lighter/darker, open/enclosed/novel/familiar spaces (76, 126). Interventions which allow appropriate levels of control over when and how to access essential provisions such as water, food, shelter, conspecifics, and enrichment might play an important role in addressing welfare needs (70, 127). Systems which allow animals to control their environment (e.g., lighting, temperature, water or sprinklers, sound, breeze) and activities to train animals to use such systems would also be examples of designing for greater animal control (70).

   2.3 Consider how increased **Variety** of opportunities can be offered, Variety may be considered in types of food, varieties of environments, methods of physical conditioning opportunities, or companions (74). Variety also may be considered in other dimensions or combination of dimensions such as times of day, frequency, duration, and location of activities or rest areas or changing seasonal conditions for example.

   2.4 Identify ways in which **Complexity** can be introduced through combinations and permutations of existing, or new, interventions. This might include complexity of environments and multisensory stimuli (128). Social interactions with larger animal groups and housing with other species are inherently complex. Complexity of nutrition can include variation by time and by seasonally changing natural conditions, which has been shown to be beneficial to animal health. Complexity should be considered carefully when introducing mental challenges, such as cognitive enrichment: designers should ensure that appropriate levels of challenge are provided to individual animals, and that complexity is incremented at an appropriate rate to build competence without causing detrimental levels of frustration (129).

   2.5 Consider, more broadly, how an animal's **Competence** can be augmented through design and deployment of interventions. In this, consider timing and building on the individual animal's prior experience. It may be valuable to consider at this stage how the prototyping process will be used to introduce animals to novel apparatus, new forms of interaction, and new behavioral opportunities.

Step 3: Define Animal-Centric Design Opportunities

3. Prioritize design opportunities and distill them to define animal-centric design opportunities.

   3.1 Prioritize the opportunities identified, according to likely positive impacts on the animal's overall wellbeing.

   3.2 Select a small number of opportunities, ideally 1 or 2, to be addressed in the design project.

   3.3 State design objectives unambiguously, in a framing which makes it clear which animal needs are reflected, and the overarching rationale for the design objective.

   3.4 Identify evaluation criteria associated with the selected design opportunities. Determine how evaluation will be conducted, by whom, and how the design team will know if the aims have been met.

Step 4: Define Project Design Objectives

4. Identify initial design objectives for the project, and evaluation criteria.

   4.1 Identify human-centric design objectives. We anticipate that organizations may have access to existing processes for conducting human-centered design and eliciting organizational requirements for design projects. We note that it is important to consider the goals and constraints impinging on caregivers, organizational stakeholders and perhaps other groups (e.g., the broader public). It is valuable to acknowledge how existing systems, organizational or societal values and commercial considerations constrain the range of options, and discuss how the design thinking might be expanded if these limitations did not exist. There is also a need to consider how design might impact on human attitudes to animals. For example, in zoos, interventions can be designed to support educational aims and promote positive attitudes to animals (114, 130). But technologies can also inadvertently foster misunderstandings about animals' needs or negatively impact caregiving (58, 131).

   4.2 Identify potential conflicts between the goals of human and animal stakeholders and determine how these tensions will be managed. In some settings, such as agriculture, the conflicting pressures of organizational drivers and competing perspectives of different stakeholder groups can mean that attempting to make changes to improve animal welfare presents a "wicked problem" (132). Iterative design thinking can provide a valuable approach to addressing wicked problems (133), allowing for reframing problems and identifying novel solutions as well as new ways of working which respond to conflicting goals (134).

4.3 We suggest that it is valuable to be explicit about which stakeholder will benefit from a stated project requirement. For example, user stories provide a useful framing for articulating design objectives from the perspective of a specific stakeholder, making clear how the goal is relevant to their overall wellbeing or objectives. User stories follow a prescribed format: "As a [stakeholder type] I [want to], so that [....]".

Example: "As manager of a primate colony in a biomedical research facility I want to find entertaining and diverting activities for macaque monkeys so that they are quiet and calmly occupied while they are isolated and closely confined during lengthy biomedical testing procedures".

Step 5: Ideate to Identify Alternative Solutions

5. Gather ideas and inspiration for alternative design approaches from multiple sources and conduct a range of ideation activities to explore the problem from new perspectives. When conducting ideation, project teams should make use of the information that has been gathered about the animal's needs and wants at Step 1. Alternative solutions are likely to start by responding to the design opportunities identified at Step 2, but may extend more broadly as new ideas are gathered, and as new insights about the problem space are generated.

5.1 Practitioners who work primarily in animal sectors can benefit from learning about the capabilities of emerging technologies by reviewing white papers and technology sector magazines, or through connecting with university researchers. Inspiration may be drawn from technological interventions in other domains: for example, interfaces for primates have been inspired by installations in public spaces and for young children. Learning some of the ways wild animals use their habitats is often inspiring.

5.2 Ideation activities can include brainstorming in groups or individually, sketching, storyboarding, soliciting ideas from a wide audience, mind-mapping and deliberately exploring problematic ideas ("worst possible idea" brainstorming). A deck of cards, such as the "Concept Craft Cards" created by French et al. (62) can support groups to generate ideas by prompting them to consider different aspects of a problem and alternative approaches. Several guides and templates for conducting ideation activities and "design thinking" are available online, from organizations such as the Stanford d.School, Google and IDEO. Including a wide range of stakeholders in ideation activities can help to broaden the thinking and examine the problem from alternative perspectives.

Step 6: Develop Prototypes

6. Create and deploy prototypes to investigate the likely effectiveness of a proposed intervention and barriers to its implementation.

6.1 At early iterations of the design process, create "low fidelity" prototypes such as non-working hardware prototypes and partial prototypes to gain feedback from animal users and stakeholders. Early prototypes can be rapidly created with the aim of determining whether the proposed design objective will contribute to animal wellbeing as envisaged. One approach is to use the "Wizard-of-Oz" technique (96, 135), in which a human operator provides the interactivity or effects which will be delivered by a computerized system. This approach will help designers to avoid spending excessive time and resources on developing a solution which is not attractive to animals or does not meet their interests. In addition, early prototypes can be designed to minimize animal training needs and put aside non-functional requirements (such as robustness and longevity) in order to quickly and cheaply determine whether the animal will benefit from the changes or behavioral opportunities that the intervention delivers.

6.2 A key tenet of the interaction design process is that prototypes should be created to be thrown away. When designing with animals, this means that prototypes should also be designed so they can be safely destroyed by the animal users. Designers should therefore repurpose materials and objects which are known to be safe for the target animals, and avoid deploying computing components which could be chewed or ingested. Using familiar objects and materials is also likely to reduce the impact of the "novelty effect" and neophobic responses on animals' initial interactions. When prototyping for animals, "decomposition" (96) provides an approach to examine different aspects of design separately. For example, physical hardware components of a proposed device can be constructed and given to animal users to see if they are usable, and ascertain whether animals will need to be trained in how to operate them.

6.3 At later iterations of the design process, deploy "higher fidelity" functional prototypes which progressively approximate more closely the fully working ACI intervention. Designers should defer investing in high-cost, high-complexity prototypes until sufficient evidence has been gathered that the design objective will have a positive impact on animal wellbeing, and that the proposed design will be effective in achieving that goal. This approach allows design teams to be responsive to data gathered during the design process, including making fundamental changes to the design approach, and shifting the design objectives if required.

Step 7: Evaluate Against Design Objectives

7. At each iteration of design, prototypes should be evaluated against the design objectives established in Step 4. Evaluation can reveal new insights about the needs and preferences of animals and humans. This knowledge, if captured, can be valuable in its own right, and also inform future design projects.

7.1 "Formative evaluation," conducted throughout the project, can allow designers and stakeholders to improve on the design. In early iterations of the process, Wizard-of-Oz and prototype decomposition techniques can allow for evaluation which focuses on assessing (a) to what extent the design objective provides a valid pathway to enhancing animal welfare and (b) to what extent the design is likely to be successful in meeting the design objectives. Qualitative evaluation with stakeholders, such as video review and focus groups, will allow designers to learn more about the needs of animals and humans, and about potential barriers to successful deployment. This approach allows for refining or changing the design objectives 1) if initial goals impractical or unachievable, 2) if better opportunities are discovered, or 3) if animals' responses to prototypes reveal new directions for design.

7.2 In later stages of the project, once design objectives and the overall design approach have been validated, evaluation can be expanded to assess and improve on other aspects of design such as usability (for animals), functionality, performance, ease of deployment (for human carers), robustness, reliability, and maintenance requirements.

7.3 At a final iteration of the design cycle, a complete working prototype should be used to conduct a summative evaluation, to collect data about the extent to which the intervention is successful in achieving the design objectives. This data will provide a baseline for ongoing evaluation of the long-term effectiveness, and provide a valuable resource for other organizations seeking to deploy a similar system. Evaluation which seeks to make claims about the effectiveness or welfare impacts from the animal's perspective should use appropriate methods, informed by animal behavior and welfare science (56, 98). It is likely that a reliable, robust prototype will be required for this evaluation, and that design changes should not be made once the study has commenced.

ANTICIPATED RESULTS

The WtC framework can be used by diverse sectors to guide design with and for animals and capture learnings. Here, we present three scenarios to illustrate how the framework might be used to support design projects in zoos, animal production, and companion animal care.

Application in Zoos and Sanctuaries

The WtC framework can be used by zoos and sanctuaries to enhance and capitalize on their existing expertise in designing and creating animal enrichment, and to support effective reuse in other settings.

Scenario: Designing to elicit birds' natural behaviors in acquiring food.

A zoo holding passerine (perching) birds seeks to encourage the birds' natural behaviors and problem-solving abilities for locating and extracting food. The birds' natural habitats are relatively complex and varied, presenting diverse challenges in locating and extracting food, but existing zoo enclosures lack such opportunities.

TABLE 2 | WtC design opportunities matrix used to identify opportunities for increasing natural feeding behaviors of passerine birds housed in a zoo.

		Mental wellbeing			
		Nutrition	**Environment**	**Health**	**Behavior**
Competence	**Choice**	Opportunity to choose between alternative foods	More and different features related to foraging to choose from	Reduce self-harming behaviors (e.g., overgrooming) through increasing foraging	Choice in food acquisition behavior
	Control	Agency in feeding, including timing			Agency in acquiring food, including timing
	Variety	Wider variety of foods	Greater variety in environmental features related to foraging		Greater variety of food acquisition tasks
	Complexity	Complexity of diet, including weekly or seasonal variance	Greater complexity of environmental features related to foraging	Muscular fitness for food acquisition	Greater complexity of food acquisition tasks

Bold border indicates opportunities identified as high priority for animal welfare.

The WtC Animal Objectives Canvas prompts designers to weigh the needs and attributes of the species, the individual animal and population, as well as the zoo context and the behavioral opportunities it provides. In the wild, most passerine birds live in relatively complex naturalistic environments which present diverse challenges for obtaining food. Many bird species, including those of the corvid (crow) and psittacine (parrot) families are naturally intelligent and curious. **Table 2** shows an example of how the WtC Design Opportunities Matrix might be used in addressing this scenario, identifying how greater choice, control and variety and complexity can all contribute to offering richer behavioral opportunities related to "working" for food. The matrix also reveals how this goal intersects with environmental, health, and behavioral domains of welfare. To meet the behavioral needs of intelligent birds housed in an environment which lacks complex foraging opportunities, designers might decide to prioritize design opportunities related to increasing the complexity of food acquisition tasks, as highlighted in **Table 2**. By working through the WtC Animal Objectives Canvas, designers will have acquired a deeper understanding of relevant characteristics of the animals and their environment, and will have identified additional needs which might be incorporated as secondary design objectives. The WtC Interaction Design Process will guide designers to consider how the objectives might be met using alternative technologies, such as computerized puzzle feeders, automated scatter feed devices.

TABLE 3 | WtC design opportunities matrix used to identify opportunities for enabling cows' self-grooming behaviors.

		Mental wellbeing			
		Nutrition	Environment	Health	Behavior
Competence	Choice		Choice of objects and surfaces to interact with in the environment	A choice of ways to meet grooming and scratching needs	Ability to choose between grooming-related behaviors
	Control		Agency over when and how to interact with different objects and surface	Ability to groom and scratch at will, e.g., in response to itches or for stress reduction	Freedom to perform grooming and scratching behaviors at any time
	Variety		Wider variety of grooming related objects and surfaces	Ability to groom all parts of the body	Allow for greater variety of grooming/ scratching behavior. Allow for individual preferences
	Complexity				

Bold border indicates opportunities identified as high priority for animal welfare.

Application for Animal Production

For livestock production, the WtC framework can be used to incorporate animal welfare objectives into the design of computerized systems, now being widely deployed as part of precision livestock farming initiatives. This will support the sector in paying increasing attention to positive animal wellbeing as a contributor to productivity, and to public concerns about farm animal welfare. In addition, ACI interventions can be used to capture data about animals' interactions and movements, supporting the inclusion of animal welfare and behavior metrics in precision farming systems.

Scenario: Designing to enable cows' self-grooming behaviors.

Self-grooming is an important natural behavior in farm animals such as cows, which is vital for health and which appears to be enjoyable and highly motivated, especially when animals are restrained (136). *In environments such as freestall barns, cows make extensive use of fences, walls and pen objects for scratching and grooming. However, such objects are not sufficient for all self-grooming behaviors that cows want to perform* (137).

Using the WtC Animal Objectives Canvas would prompt designers to consider the ways in which cows' self-grooming is important for physical health, is part of social behaviors, and may be a self-soothing behavior for coping with stress. Freestall barns generally offer little structural variety, and are likely to offer cows few objects for scratching against. Additionally, the size, texture and shape of such objects might not be sufficient to allow for satisfying scratching of different body parts. **Table 3** shows an example of how designers might use the WtC Design Opportunities Matrix to address this scenario. In this example, opportunities have been prioritized (as highlighted in **Table 3**) for offering greater control and variety for self-grooming to contribute to physical health and mental wellbeing, which will inform the animal-centric design objectives. Through the WtC Interaction Design process, the design team might examine how these objectives can be reconciled with the need for efficient, easy to clean facilities. Ideation might lead designers to explore how mechanical brushes can be improved on to provide access to a wider variety of textures and surfaces, or provide a wide variety of pressure and speed of brushing by responding to pressure and movement.

Application in Companion Animal Care

With growing interest in digital technologies for pet care and enrichment (such as video call systems and robotic toys), the WtC framework can guide the design and use of devices to deliver wellbeing benefits to domestic animals based on specific needs and objectives. Applying the WtC framework can help allay concerns that some pet care devices are designed primarily to appeal to the concerns and motivations of owners, rather than addressing genuine wellbeing issues affecting companion animals.

Scenario: Improve pet dogs' experience of their sound environment.

For some pet dogs left alone during the day, external sounds can be a source of stress or distress. For others, sound can be an important form of varied environmental stimulation, and individuals have distinct preferences in music genre, for example (138). *While free-ranging dogs can select or modify their own sound environment, for example by moving to a different resting place, dog companions confined in homes or yards are unable to do so.*

Using the WtC Animal Objectives Canvas to investigate this issue reveals several ways in which pet dogs can benefit from wider variety of audio stimuli. For dogs housed in urban or loud environments, external and unpredictable noises may be stressful, so a sound environment which masks such noises may be beneficial. For other dogs, sound may be a form of enrichment in another wise monotonous setting. Seeking out alternative sound environments may constitute a valuable form of environmental exploration for dogs who are confined. **Table 4** shows an example of how the Design Opportunity Matrix might be used to address this scenario, and indicates that in this instance designers have given greatest priority to animals' control over their auditory environment. As part of a design project with the objective of allowing dogs to change their auditory environment, designers might explore the possibility of using different types of sensors (e.g., proximity sensors, activity monitors) to provide dogs with alternative sound environments which the dog can choose between by moving from one area to another, and which vary according to the dog's level of movement and wakefulness.

DISCUSSION

The WtC framework, by providing a practical approach to centering animals in technology design projects, will prove useful to ACI researchers and practitioners who seek to improve animals' lives. In our presentation of the framework, we

TABLE 4 | WtC design opportunities matrix used to identify opportunities for improving pet dogs' sound environment.

		Mental wellbeing			
		Nutrition	**Environment**	**Health**	**Behavior**
Competence	**Choice**		Choose between alternative auditory environments or stimuli		Ability to choose environments suited to e.g., resting, sleeping, interactivity
	Control		Ability to change the auditory environment	Ability to minimize exposure to distressing auditory stimuli	Ability to rest, sleep, interact etc. when desired
	Variety		Greater variety of auditory stimuli, less predictability		
	Complexity		Greater complexity of auditory environment to avoid habituation		

Bold border indicates opportunities identified as high priority for animal welfare.

provide definitions, processes and examples which will support collaboration and the exchange of ideas and approaches between the various disciplines, expert and stakeholder types involved in successful animal-computer interaction design projects. This paper also delivers a robust response to long-running debates in the field of ACI about the feasibility of including animals as stakeholders, by outlining a design process which can capture and respond to the interests of animals, in turn offering them a good life.

Enabling Animal-Centric Design Practice

While interaction design and "design thinking" approaches are now widely used for human-centered innovation, the WtC framework provides a much-needed structured approach for project teams to include current understandings of animals and their needs. The framework enables interdisciplinary collaboration on this topic by providing a conceptual frame for understanding the different types of knowledge that can be brought to bear in an ACI project, for sharing those different forms of knowledge across the team, and for understanding how they intersect with each other and support the project. In addition, the WtC Animal Objectives Canvas provides a tool to guide teams in identifying what it is they need to know about the animal and its world, while the design process indicates how that knowledge can be applied and further developed through the project.

There is considerable divergence between the aims and practices of different animal sectors, and between the needs and objectives of the human stakeholders that interact with them. Furthermore, we anticipate that many organizations will have established processes for eliciting, documenting and validating project requirements, which will provide input in the form of human-centric design opportunities and objectives of the WtC interaction design process. While the WtC framework can capture and respond to diverse sectorial needs, we recognize that for some organizations, it will be most beneficial to use the WtC Animal Objectives Canvas as inputs to IT project management processes.

Advancing ACI Debates and Scholarship

A core strand of ACI scholarship engages with the question of "to what extent design processes can reflect the needs of animals as stakeholders and users?" (59), and how human-centered interaction design methods can be adapted to achieve this (1, 3, 55). Attempting to place animal stakeholders at the heart of design work raises a range of methodological challenges (55), including the issue of identifying appropriate design objectives, aligned with the animals' interests and welfare needs (2, 59). In this paper, we have proposed a framework which offers a new pathway to progress this dimension of ACI theory, building on animal welfare science theory and design approaches developed in zoos and sanctuaries. This provides a structure that addresses methodological issues of ACI design and provides a foundation that can support designers to avoid the pitfalls of anthropocentrism (59) and inadvertent negative welfare impacts (57).

The framework expands ACI's interaction design methods by building on well-established concepts of animal welfare science and design techniques developed over several decades in zoos and sanctuaries. As we have illustrated, the WtC framework provides a model which can be applied in any animal management setting. The model we offer foregrounds animal-centric objectives, acknowledges that human stakeholders may have competing objectives, and indicates how both sets of objectives can be incorporated into an interaction design project. In this way, the WtC framework constitutes an important advance for the field of ACI by providing a methodological basis for design projects that are well-informed about target animals, their species and context, to be able to contribute to a good life for animals.

Enabling Interdisciplinary ACI Research and Education

Creating technological interventions for animal wellbeing is inherently interdisciplinary work, which can entail collaboration between designers, computer scientists, species specialists, animal welfare scientists, carers familiar with the group and individual animal, and other stakeholders with knowledge of the context and organizational aims. Several ACI scholars have drawn attention to the need for ACI scholars to work closely with specialists in animal behavior and welfare (56, 57, 98), and to understand how to elicit and apply different types of expert knowledge about animals (96). The WtC framework provides a structured approach to achieving this and offers practical guidance to researchers and technologists who are new to animal-centric design. Conversely, the visual components of the framework (**Figures 1**, **2**) also supports ACI researchers to communicate with scholars from other disciplines about the interaction design process. This illustrates how animal centric knowledge can be incorporated into interaction design, and how design work can lead to deeper understandings of animals' needs and wants, as well as the production of a technological artifact. Our hope is that this approach will enable non-ACI specialists to envision ways in which technology and animal-centric design can further their efforts to increase the welfare of animals in their care.

The WtC framework supports ACI scholars to resolve tensions between iterative interaction design processes with the empirical methods of animal-related sciences. While rapid prototyping favors innovation and responsive design, these agile approaches are not compatible with the qualitative, ethological evaluation methods generally used by animal behavior and welfare researchers to assess the effectiveness of an intervention (96). To address this, the WtC design process proposes a distinction between lightweight "formative" prototyping, conducted to inform subsequent cycles of design, and rigorous "summative" prototyping, which might deploy ethological methods to assess the effectiveness of a finished artifact. An important facet of the framework is the focus on defining and refining animal-centric design objectives, to guide both formative and summative evaluation and ensure the project retains sight of the animal welfare goals.

With computer science and design students showing increased interest in ACI, important challenges for educators are to sensitize students to animal welfare in iterative development, and to offer guidance in methods for eliciting animal-centric requirements (55). The WtC framework provides a structured foundation and step-by-step process which responds to this need, offering a tool for training ACI students in applying interaction design principles to animal-centric work, and a foundation for cross-disciplinary projects with animal scientists in any managed animal setting.

Future Research to Expand the WtC Framework

Envisaged benefits and contributions of the WtC, as discussed above, will be expanded with further data about the design journey of projects undertaken using these tools. The WtC tools and process provide structured prompts for design teams to capture project objectives, decisions, and readjustments, as well as the results of prototype evaluations. Technology interventions often entail unexpected outcomes and unanticipated consequences (139), and documenting projects' design journeys and lessons learned will provide valuable insights for future design projects, for ACI research, and for enhancing the WtC Framework and associated tools.

An important aim of the WtC framework is to bring to the fore the tensions between human-centric objectives (including organizational aims and commercial considerations) and the animal-centric design objectives that emerge. However, techniques for addressing issues of ethics and power in ACI (59) are left to the discretion of designers. As the WtC framework is adopted by different animal sectors, it will be valuable to investigate how specific tools and approaches can aid designers in identifying solutions to provide animals with a good life which simultaneously address the needs of human stakeholders and organizations.

CONCLUSION

The WtC framework integrates existing, best-practice models and process, to create a structured guide for designers to create interventions that respond to animals' needs and wants, and mitigate the risk that human-centric aims prevail over the interests of animals. In the WtC Animal Objectives Canvas, designers are provided with a novel tool which leverages contemporary theory and best practice to aid them in understanding what animals need to live a good life, and for identifying relevant design opportunities and objectives. We provide a structured approach for iterative interaction design that can lead to deeper understandings of what animals need and want, allowing for refinement of animal-centric design objectives as well as creation of a technology product. The WtC framework is presented to provide a practical tool that can support collaboration and communication in interdisciplinary teams, providing a foundation for better design. Acknowledging the diverse needs and practices of different sectors that involve animal management, the WtC framework is widely applicable and flexible to satisfy the needs of different animals, organizations, and settings, and can be complemented with other organizational toolsets and protocols.

By presenting a framework that integrates models of animal welfare, design for animal competence, and interaction design process, this paper responds to core challenges and debates related to animal-centric technology design. Crucially, the WtC framework contributes new thinking and conceptual approaches to the core ACI challenge of centering the animal in design, supporting a good life for animals.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

The conceptualization of this work and development of the WtC framework we present was shared predominantly between SW (45%) and MC (35%). JC contributed to the framework development (20%) by providing feedback and expertise on the Coe individual competence model. Writing and preparation of the manuscript was conducted predominantly by SW (60%). MC wrote sections of the manuscript (30%) pertaining to animal welfare science. JC provided writing contributions (10%) to sections of the manuscript on animal enrichment and zoo-based design. All authors contributed to the article and approved the submitted version.

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Expanding Aesthetics

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This paper seeks to expand traditional aesthetic dimensions of design beyond the limits of human capability in order to encompass other species' sensory modalities. To accomplish this, the idea of inclusivity is extended beyond human cultural and personal identities and needs, to embrace multi-species experiences of places, events and interactions in the world. This involves drawing together academic perspectives from ecology, neuroscience, anthropology, philosophy and interaction design, as well as exploring artistic perspectives and demonstrating how these different frames of reference can inspire and complement each other. This begins with a rationale for the existence of non-human aesthetics, followed by an overview of existing research into non-human aesthetic dimensions. Novel aesthetic categories are proposed and the challenge of how to include non-human aesthetic sensibility in design is discussed.

Keywords: aesthetics, design, inclusivity, multi-species, perception, Animal-Computer Interaction, animal centered computing, more-than-human design

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INTRODUCTION

"What's it like to be a human
the bird asked
I myself don't know
it's being held prisoner by your skin
while reaching infinity
. . .
That's funny said the bird
and flew effortlessly up into the air"
- From the poem Funny by Kamienska (1).

Humans have historically claimed five senses - sight, hearing, touch, taste and smell. Each of these has a corresponding aesthetic dimension, in that humans have identified facets of each sensory experience and learned to adjust the aesthetic qualities of designed artifacts so that they give greater pleasure. This has resulted in the development of creative arts such as painting, music, textiles, cooking and perfumery. However, there exist other aesthetic dimensions that are not perceptible to humans because we lack the necessary sensory organs. One example of this is electromagnetism, a phenomenon that humans seem not to be able to detect without using technology. There is increasing evidence that a wide range of animals perceive and utilize electromagnetic fields for global positioning and migration (e.g., birds, sea turtles, wolves, butterflies), and to detect prey and predators and mates (e.g., sharks, skates, rays).

All human senses have a restricted range, because like other species, we evolved to be able to discriminate the sensory information that would maximize our potential for fitness in a specific setting. Too much unnecessary information would be sensory overload for our brains. Even sight, the sense that is most commonly associated by humans with aesthetic quality, has built-in limitations for our species. By contrast, zebra finches possess a tetrachromatic color spectrum, which means they can see extra colors that we can currently only imagine; hedgehogs and eagles can perceive ultra-violet light. These adaptations provide important benefits to their owners, contributing to survival and welfare.

Expanding aesthetics is about exploring the qualities of non-human sensory experiences, despite not necessarily being able to perceive the sensory information in the same way ourselves. As an example, even if it is possible for a human to sense the same stimulus as a bear, our perception of the stimulus and its associated meaning are inevitably different, because of our distinct life experiences. Moreover, we know that many other species have different sensory apparatus to humans and are able to perceive and interact with the world using different modalities. Yet we can use technology to support the capture and analysis of non-human sensory information, and it is possible to take an anthropological approach to gain deeper understanding of the context. This paper also includes some literary references, a reminder of how human imagination has been captivated by the idea of embodying the "other" and on occasion, striven to explore unknown dimensions of being.

Technology has been used extensively to enable humans to interact with the world and perceive phenomena that we are incapable of discerning with our own neurobiological systems. Prosthetics, false teeth, ear trumpets and eye lenses have been around for centuries, supporting proprioception, touch, hearing and vision. The investigation of new dimensions of perception experienced by other species is a more recent area of research that is developing as we make progress in understanding non-human animals. Modern technology includes seismic sensors that can pick up vibrations, algorithms that can translate and applications that can visualize acoustic signals, biochemical tests to identify constituents of a substance, infrared and ultraviolet cameras, pressure sensors and more. Building awareness of non-humans through a range of multidimensional sensory apparatus can help humans to understand the complex needs and pleasures of other species.

Since humans dominate the global ecosystem, it is critical for us to understand the implications of our ubiquitous presence and associated technologies, so that we can design to live equitably with others. Additionally, the knowledge derived through expanding our perceptive and aesthetic capabilities may have relevance beyond the original contexts. The insights accrued may allow us to appreciate what constitutes a joyful moment for a non-human animal and in discovering how to facilitate that, experience the confluence of cognition and emotion that constitutes joy for ourselves. We may become empowered - delighting in gaining new perspectives, with our perceptions enhanced by technology.

Many technology-enabled systems designed for animals have a very specific context – for example, zoo or lab enrichments, systems for livestock, indoor games for domesticated companion animals – which means there are multiple opportunities for designer practitioners to explore the aesthetics of the devices they create. The field of Animal-Computer Interaction (ACI) emphasizes animal-centered design and associated ethics (2) and this paper aims to contribute an aesthetic dimension to the field in the form of a review of current knowledge and some suggestions for exciting future research.

The content is divided into three sections: The first of these offers a rationale for non-human aesthetics, considering how different disciplines have tried to interpret and understand the aesthetic experiences of other animals. The second section offers an overview of existing research into non-human aesthetic dimensions and suggests some novel aesthetic categories relating to patterns of behavior. The third section relates to the challenge of designing for non-human animals and discusses how researchers from a broad range of disciplines might inspire each other through sharing their ideas and perspectives.

RATIONALE FOR AESTHETICS

> "*Aesthetics could well be an important part of the evolution of life, and consciousness, on Earth, allowing organisms to better interact with the universe surrounding them.*" - Thompson (3).

Do non-human animals experience aesthetic pleasure? And if so, how and why? Possible answers to these questions draw together research from multiple disciplines, including neuroscience, anthropology, philosophy and ecology.

Philosophical Theory

According to Berleant (4), "*aesthetic appreciation is … a complex multi-sensory perceptual engagement by means of a cultivated sensibility*." He explains that aesthetic sensibility requires sensory awareness, perceptual discrimination and the ability to discern intensity, evoking cognitive, emotional and potentially physical responses. This perspective is supported by the work of Berlyne (5) who concluded that in conjunction with perception, discrimination and emotional sensitivity, learning and hedonic value are critical psychological processes associated with aesthetic appreciation.

Applying this definition to non-human animals, it follows that aesthetic sensibility relates to an animal's ability to perceive a phenomenon or experience, to be able to discriminate between that and other phenomena of a similar sensorial type, to have the capacity to enact a preference choice, and for this judgement to be motivated by immediate personal experience. This means there is a reward associated with different sensory episodes at the time of experiencing them, and that therefore the potential exists for more or less pleasurable environments and experiences.

Evolutionary Rationale

At a neurobiological level, Skov (6) states: "*…liking emerges when certain patterns of neural activity in reward structures assign a measure of hedonic value to perceptual representations*." In other words, we see, hear, smell, taste or feel something that gives us a positive response and we store this information. Skov continues: "*…biological organisms can only come to form preferences for the parts of the surrounding world they can perceive, and these parts themselves are a result of the individual species' evolutionary history*."

Interest in the biological determinants of aesthetic preference has led to several distinct theories, some of which are grounded in the use of sexual selection as an indicator of aesthetic choice. A brief description of each follows.

Evolutionary Biology (EB) proposes that all traits are directly or indirectly linked to fitness, thus being honest signals to potential partners – this means that the quality of the trait (e.g., size of horns, volume of croak) genuinely corresponds to the reproductive quality of the mate with that characteristic. More often, the chooser in this scenario is the female, because she produces fewer gametes (eggs) than the male (sperm), so logically she should be more selective. Thus, EB states that all aesthetic preferences associated with partners are in fact related to reproductive success. The same reasoning can be applied to all aesthetic preferences about everything, if lifestyle choices are also driven by an evolutionary mechanism aiming to ensure both individual and species welfare and longevity (6).

However, it could also be argued that such an explanation undermines the value of cognition and free choice. As Abram [(7), p.50] says: "*Consider a spider… however determinate one's genetic inheritance, it must still… be woven into the present, an activity that necessarily involves both a receptivity to the specific shapes and textures of that present and a spontaneous creativity in adjusting oneself… to those contours*" (See **Figure 1**: Orb-weaver spider.). Static camouflage, on the other hand, is considered strong evidence of natural selection [since (8)]. Cott (9) identified various forms of predator and prey camouflage that provided concealment in pursuit of food or safety, thereby contributing to fitness.

FIGURE 1 | Orb-weaver spider in London garden, UK.

Supporting EB as the underlying mechanism for all brain function, Pinker famously dismissed music as "*auditory cheesecake*" (10). His super-stimulus hypothesis claimed that music was "*pure pleasure technology*" and therefore "*biologically pointless*", comparable with pornography. This position has been criticized by other researchers (11–13) who point out that music has adaptive value, since it conveys information between minds and enhances communication and emotional skills.

Another model, based on work by Fisher (14) contests that aesthetic preference is a self-reinforcing phenomenon that occurs as traits become preferred in the population. More individuals with those traits are born, thus increasing the frequency of those traits, usually through selection for the male line. Selection for traits happens over several generations. Prum (15) suggests that in this case, preferred traits are merely "*attractive*" rather than utilitarian; in other words, they are not preferred because they denote fitness in a mate. In human society, this might account for the emergence of trends.

Sensory Bias – (16, 17) suggests that preferences evolved as responses to the environment and were subsequently also used by the neurobiological system that directs sexual choice. Dutton's Savanna Hypothesis (18), based on Orian and Heerwagen, (19) attributes human creative choices in painting and landscaping to evolved preferences for open spaces with visible water, animals and vegetation, because these provide the optimal conditions for human life.

Experiments have demonstrated that sensory preferences occur outside sexual selection (20), and that reactions to specific stimuli can be learned, which means they are based in cognitive processes, not only occurring as naturally selected behaviors. Moreover, preferences depend on context – they are flexible and can be influenced by both internal (e.g., hormonal) and external (e.g., competitive) factors. Different species are therefore likely to have different aesthetic preferences.

Association with intelligence – Watanabe (21) considers three aspects of aesthetic behavior: cognitive, hedonic and creative. *Cognitive* aesthetic behavior includes the ability to discriminate between options, requiring not only the ability to perceive differences, but also to make choices by recognizing and understanding these distinctions. This clearly identifies aesthetic sensibility as a cognitive process while also emphasizing that there is variety in any environment. Thompson points out: "*Intelligence has been strongly selected for throughout the evolution of life on earth, not only for hominids … but for much, if not all, of life... Aesthetics therefore has been strongly selected for throughout its evolution*" (3). In other words, although behavioral responses and variation in genotypes may be driven by evolutionary biology, there is an assumption that individuals retain the capacity to make meaningful decisions and to learn through their experiences.

Hedonic Ethnology

Watanabe explains *hedonic* aesthetic behavior as deriving from the neurobiological system that rewards pleasurable experiences (22). This has been exploited in training scenarios that use positive reinforcement (from humans) to shape behavior (of humans or non-humans). *Creative* aesthetic behavior might include activities such as decorating, crafting, tool-using, puzzle-solving, playing or performance. All of these creative activities are strongly based in cognition.

Watanabe claims that although human aesthetic creativity (for example, visual or auditory art) can have hedonic value for other animals, such behavior in non-human animals has no reinforcing property for their conspecifics. However, this seems to contradict other perspectives on aesthetic sensibility and the rationale for its evolution. None of the proposed theories discount the possibility that is gratifying to be the *subject* of an aesthetic experience offered by a creator who exhibits inherited preferred traits. Hogh-Olesen (23) states that as aesthetic expression and appreciation is inherent in human nature, it is therefore a primary impulse, requiring no external reward. Nonetheless, although humans spend a great deal of time on aesthetic activities that are apparently unrelated to fitness, these are not useless – the author clarifies that aesthetic skills are valid fitness indicators, providing mating opportunities, higher status and more collaborative offers. From a human perspective, even if we consider an artist to be highly attractive because of their particular skills, there is still pleasure in the moment of experiencing and acknowledging the artistry, beyond any personal connection with the artist. If humans can appreciate a sensory stimulus in and of itself, might not there be an aesthetic reward (experienced as pleasure) for other non-human animals in response to a particular stimulus in their environment, including a stimulus presented by a conspecific?

Balcombe (24) makes a strong case for hedonic ethnology, proposing that aesthetic preference may be distinct from evolutionary drive. He suggests that traditional explanations of behavior rooted in adaptation cause a lack of focus on alternative explanations that are related purely to pleasure. His perspective is that animals are sentient, emotional and aware, capable of experiencing many pleasures beyond those directly associated with fitness (nutrition and sex); these include comfort, visual beauty, play, touch and taste. This perspective is shared by Cabanac, whose research on sensory pleasure included an experiment with an African gray parrot (25). He demonstrated that the parrot was capable of learning words to discriminate between good and bad stimuli and moreover to apply this vocabulary to novel situations relating to types of food. Cabanac suggested that this demonstrated the parrot's aesthetic preferences in its current context, rather than being an evolved behavior.

Affective states (emotions) in non-human animals can be hard to assess but are usually measured in terms of valence (positive to negative experience), arousal (strength of response) and motivational intensity (how much the stimulus provokes a corresponding action) (26). There is wide agreement amongst neuroscientists and biologists that animals ranging from primates to fish experience emotions (27–30), and Balcombe is adamant that humans should not deny animals 'feelings' just because we are unable to prove their existence. Moreover, he cautions: "*Because many animals have more acute senses than we do, they may feel certain things more intensely than we do*" (31). As we shall discuss, there are many sensory aspects of life on earth that are imperceptible to humans, with corresponding pleasures for the animals that experience them.

Anthropological Perspective

Human culture encompasses aesthetic choices, according to Hogh-Olesen (23), who suggests they convey a "*unifying social marker*". Westphal-Fitch and Tecumseh Fitch (32) also endorse this idea, claiming that humans possess "*culturally coevolved aesthetics*", which explains the differences across populations. This point is picked up by Thompson (3), and expanded to include all animals, not only humans. He suggests that socially shared aesthetics are responsible for *collective intelligence*, helping to create different cultures within populations of species. Thompson's interest is folklore in anthropology, and the broadening of this field to encompass more-than human communities, part of a recent movement known as the "*animal turn*". Magliocco (33) expresses this shift in an anthropological context thus:

> '*Is folklore—meaning traditional expressive culture exhibiting variation over time and space—perhaps not a uniquely human phenomenon? Or can it be said to have derived evolutionarily from a set of behaviors common across a number of species? Is aesthetic performance … in fact common to many species, and ultimately rooted in perceptions of the natural world and experiences therein as "pleasant" or "unpleasant?"*'

Thompson makes the point that there is a lack of studies on the aesthetic perspectives of animals, due to a prevailing assumption that the human is the only species to have an aesthetic sensibility. On the other hand, Latini (34) suggests that the challenge for researchers is related to an anthropomorphic tendency to position non-human aesthetics within a human framing, such as "*providing common culture*" or even "*conferring evolutionary advantage*." However, as suggested, there is currently much interest in exploring the spaces and perspectives of other species (their "umwelten"), as humans become more acutely aware of our global impact during this epoch (often referred to as the "Anthropocene").

Ecology and Atmosphere

Lorimer et al. proposed a new concept – animal atmosphere – to describe the geographical space that non-human animals occupy; animal atmospheres are spaces with "affective intensities" of varying types, often derived from scents, patterns and rhythms that humans do not readily perceive or understand (35). The authors suggest that investigating these atmospheres offers researchers a window into "*a rich and underexplored diversity of ways of being in the world*."

Lorimer et al. explain how sensitive some animals can be to meteorological dynamics, such as perceiving minute changes in pressure, temperature, humidity, light and wind direction. These changes in atmosphere might be critical for motivating particular seasonal behaviors, such as hibernating, mating or migrating. Moreover, the non-human world is full of biochemical signals that we fail to appreciate, spectra that are outside our limits of perception and territories with invisible boundaries. The expansion of aesthetics to incorporate non-human sensory modalities and mindsets is therefore both topical (the animal turn) and highly relevant for Animal-Centered Research and Design.

The following section comprises an overview of current knowledge about animal perceptive abilities, and a speculative discussion relating to behavioral aesthetics and how they might be defined.

PERCEPTION, AESTHETIC SENSIBILITY AND BEHAVIOR

> *"It is entirely possible that behind the perception of our senses, worlds are hidden of which we are unaware."*
> – Attributed to Albert Einstein.

To illustrate the breadth of perceptual possibilities, the section *Sensory Aesthetics* introduces senses individually, while acknowledging Berleant's observation that: "*…sense perception is never simple sensation or pure perception...*" (4). Perception as a holistic experience occurring in a particular context is highlighted in the section *Behavioral Aesthetics*, which offers some suggestions for categorizing types of behavior that have intrinsic reward. Readers are invited to consider what aesthetic sensibility might mean in each context.

Sensory Aesthetics

Humans rely predominantly on vision to evaluate the world (36), but we know this is not the case across species. For some animals, vision is useful, but not a primary sense, while others can perceive more visual spectra than humans, so their sight provides them with dimensions unknown to us.

Visual

In his exploration of octopus evolution, Godfrey-Smith asks: "What could it be like to see with your skin?" (2016). He explains that the cephalopod nervous system is very different from the vertebrate configuration, in that perception and control is distributed throughout the body, instead of a control center being located in one location – the brain. Twice as many neurons exist in the combined arms of an octopus as in the brain. Although octopuses have excellent vision using their eyes, their limbs are able to dynamically and independently create camouflage. Their skin has millions of photoreceptors that both sense and respond to light, changing skin color and forming patterns in response to the environment. If the skin sense is communicated to the brain, octopus vision extends wherever the arms can reach; if it remains local, then each arm can see for itself.

Mantis shrimps are famous for having 16 color receptors in their eyes, and this allows them to perceive *polarized* light that occurs in different patterns underwater (38). Navigation on land using polarization has been documented in arthropods, but Powell and team developed a video camera that could capture polarized light underwater and render it visible to humans, showing that this information could be used both for geolocation and as a compass. Kelber, in his examination of tetrachromatic color vision in birds (39) states: *'Seeing the world "with bird eyes" is very difficult for humans with human* eyes.' Birds have four color receptors, compared with human three; the extra cone enables them to see *ultra-violet* (UV) light, whose wavelength is outside the human range of perception. Demonstrating the importance to animal welfare of exploring non-human sensory modalities and associated experiences is a recent study by House et al. that showed how rearing chickens in conditions with supplementary UV light lowered their stress and fear levels (40).

Infrared

Infrared waves are at the other end of the human visual spectrum, yet it is worth noting that *infrared sensing* is linked to the *somatosensory* system (see below), as it is the detection of temperature, rather than light. Pythons, vipers, boas and vampire bats all possess a heat sensing *pit organ* at the front of their heads, enabling them to generate thermal images (41). Combining thermal and visual images supports the snakes to detect prey extremely accurately. It is thought that vampire bats use this sense to detect specific locations for feeding, where the warm blood is closer to the skin surface of the prey (42).

In captivity, environmental sources of infrared (IR) are usually static, such as heat-lamp-enabled basking spots, whereas in the wild, IR radiation is a more dynamic feature of life. IR cameras can provide humans with a visual representation of this sense, expanding our perceptive repertoire (see **Figure 2**: Still from infrared camera.).

Somatic

Touch is thought to be the first sense to develop (43) and it is fundamental for interacting directly with the world: "*our primary conduit of both pleasure and pain*" (44). As an example of the connection between touch and positive affect in non-human animals, studies have shown that tickling captive rats induces them to chirp as if they were engaged in rough and tumble play with each other, thereby demonstrating their apparent pleasure (45). But tickling is not only a tactile experience; it also relates to the *performance* of an activity and the resulting sensory feedback for both parties. Godfrey-Smith explains: "*In everyday experience there are two causal arcs. There is a sensory-motor arc, linking our senses to our actions, and a motor-sensory arc as well.… The effect of action on what we sense next is surely important*" (37). Abram similarly emphasizes reciprocity through physical performance: "*…perception, experientially considered, is an ongoing dynamic…*" (7), p.81. Proprioception (kinaesthesia) is the awareness of bodily movement, but performance is the enabler of other sensory experiences, and has its own aesthetic dimension (46, 47).

In humans and other animals, somatic sensation arises from the body surface or internal organs and endows us with the sense of touch, proprioception, pain (nociception) and temperature (48). Linden (43) explains that in humans, there are two distinct systems for touch: (i) a discriminative sensory pathway that provides information about vibration, pressure, location and texture; (ii) an emotional pathway that processes pleasure, pain and social information related to the sensation experienced. It seems likely that the confluence of these signals is necessary for aesthetic appreciation, and moreover, that similar systems exist in other animals who share our evolutionary neurobiological roots. Research by Gibbon et al. (49) indicates that bees can modulate their nociceptive responses to prioritize feeding, which suggests that these are insects capable of perceiving pain. If so, does this point to a capacity for also experiencing pleasure?

Some species are acutely mechanosensitive, with specialized organs for tactile perception. Fish have a lateral line, which is a series of pores along the length of the body that can sense pressure changes, and by association, movement and vibration. The lateral line detects lower frequencies (less than 100 Hz) than the auditory system. It is thought to play an important factor in schooling, by providing information about neighboring fish and facilitating synchronized movement (see **Figure 3**: Whaleshark and shoal of golden trevally). In this way, the lateral line increases the ability to detect prey and also supports a mechanism for prey avoidance, since by swimming together, shoals of small

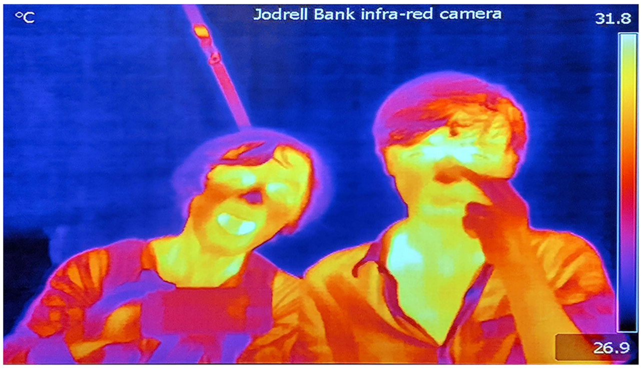

FIGURE 2 | Still from infrared camera at Jodrell Bank, Cheshire, UK.

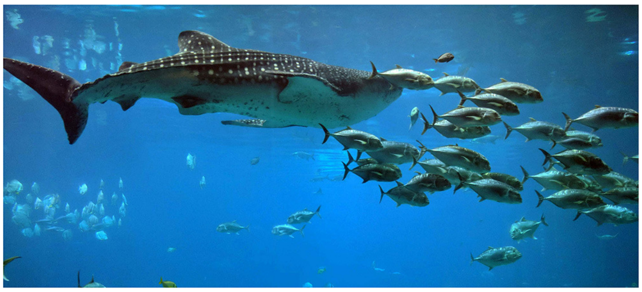

FIGURE 3 | Whaleshark and shoal of golden trevally in Georgia Aquarium, USA.

fish generate complex water movement that may confuse their predators (50).

In the case of sharks, their body movement gives them spatial awareness and navigational ability; they create waves that bounce back from obstacles and are detected by the lateral line, providing them with a pressure map of the surrounding environment (51). Crocodilians also possess a pressure sensor – a series of integumentary sense organs (ISOs) in their skin, which are highly concentrated around the jaw area. The ISOs are specialized for detecting touch, particularly in the context of water vibrations that predict and identify prey (52). These senses seem likely to contribute to the complexity and excitement associated with hunting.

On land, the star-nosed mole is a "*somatosensory specialist*", according to Catania (53). The mole's 22-fingered snout-star acts like a *tactile eye* and has a correspondingly large area of somatosensory cortex devoted to its representation. Snakes, meanwhile, can detect vibrations in the air and through the ground via their body surface, known as *somatic hearing* (54). In their work on tactile intelligence, Liu et al. point to the need for further research in this area: "*The inherent characteristics of tactile signals have not yet been fully explored*" (55).

Infrasonic

Large mammals, including elephants, giraffes, rhinos and whales (56–59), communicate using low frequencies that are outside normal human hearing range, below 20 Hz. This is known as infrasound and the sound waves generated can propagate through air, water and earth with less attenuation than higher frequency waves, thus are used for communication across long distances. We note that there is a strong link between tactile and auditory modalities, since both types of perception involve sensors that are triggered by vibrations.

> "*...you can touch the speaker cone and you will literally feel the infrasound, far below your hearing range. It's really surprising, like having a new sense.*" - From http://techlib.com/area_50/infrasound.htm by Charles Wenzel.

Elephants can detect infrasound through auditory perception via inner ears and also through somato-sensory perception of vibrations via mechanoreceptors in their feet. This may enable them to triangulate seismic information and thereby determine the distance of the sound origin (60). Low frequency vibration traveling along the ground maintains its integrity well, and O'Connell-Rodwell et al. believe that elephants can distinguish the rumbles made by their conspecifics from other background noise (61). Within their herd, elephants exchange these rumbles regularly, known as antiphonal calling (62); giraffes perform a similar aural activity at night, when they hum together (57). The exchanges seem to have social value, promoting cohesion and establishing personal identification within the herd (see **Figure 4**: African elephants at waterhole).

Ultrasonic

At the other end of the acoustic scale, ultrasound is beyond the upper limits of the human hearing range but perceived and generated by many other species. Detecting technology was first used by Griffin in 1944 to monitor bats' echolocation signals in the range 12–160 kHz, based on previous work by Pierce [in Brudzinsky, (63)]. The ultrasonic detection of rat chirps (50 kHz) mentioned earlier led to the discovery of their enjoyment of tickles; this exemplifies one way that improving human understanding of other species' aesthetic responses can potentially lead to better welfare.

Musical

> "*And the songbirds are singing,*
> *Like they know the score*"
> - Lyrics from Songbird by Christine McVie, Fleetwood Mac.

It is well established that animals communicate with conspecifics and also glean information by attending to acoustic cues in the environment, but do they produce or listen to sounds purely for pleasure? As Honing asks, in his quest to establish musicality in animals: "*Does a bird hear bird sounds as music?*" (64). According to musician Hollis Taylor, who has recorded songbirds for many years, the answer is yes (65); Gupfinger and Kaltenbrunner, who designed acoustic enrichment toys for gray parrots, describe their users as expert musicians (66); Hoeschele et al. point to entrainment (the ability to synchronize movement to a rhythm) and vocal learning as evidence of musicality in some birds (67). An example is Snowy, a cockatoo who performed spontaneous and diverse movements to music, demonstrating complex planning associated with dancing more than bobbing to a beat (68). Research with cockatiels (69–71) has shown that they improvise with musical toys, are capable of learning melodies and rhythms, and can spontaneously adjust their output so as to sing in unison with humans and other birds.

Recent research into origins of human music shows that our appreciation of tones and harmonies is an evolutionary development linked to our ability to perceive and understand human vocal sounds (72). This makes sense, as biologically having an attraction to sounds emitted by humans and also developing keen discernment of the underlying frequencies and harmonics enables us both to distinguish people by voice, and to interpret emotions, facilitating sophisticated communication. Dissanayake describes music as a "*behavioral and motivational capacity*", linking our musical development to affiliation through an evolved propensity to respond to other humans' rhythms and sounds (73). If this explains why humans appreciate human-made music, it also likely explains why human-made music holds little interest for the majority of other animals. There are some exceptions; Watanabe and Nemoto tested musical preference in Java sparrows (74), finding that they preferred Bach to Schoenberg and Vivaldi to Carter. While this does suggest that the sparrows have musical preference, the authors' conclusion that the birds prefer "*classical music*" is unfounded. Some musicians have attempted to compose *species-specific music,* notably for racehorses (75) and cats (76), claiming that it has a positive, calming effect. Truax and Vonk (77) emphasize the importance of assessing auditory preferences before introducing acoustic stimulation, which acknowledges the pervasive quality of sound as well as the potential for individuality. Honing has suggested that our attention as researchers should move away from music (interpreted by humans as melody and rhythm) and toward musicality – the ability to perceive relative pitch and regularity in beats (64).

Rhythmical

> *"And rhythm is all deliciousness; And joy is in the throbbing tide . . . and music is the exquisite knocking of the blood."*
> – From the poem The Fish by Rupert Brooke (78).

Thompson suggests that through aesthetics, an organism can "*involve itself in the mathematical regularities of the universe*", citing seasonal changes, cycles of day and night, soundwaves and rhythmical movement as some facets of life on earth that can be represented numerically with accuracy (3). Brando and Buchanan-Smith advocate for animal welfare that takes the patterns of natural life cycles into account (79), while Coe and Hoy (80) argue that abandoning schedules can offer captive animals a kind of relative freedom, allowing for control and self-sufficiency within a population. Captive environments need to be carefully managed, but for a wild animal, there is no such thing as a regular feeding time, for example, although natural activities, such as hunting and foraging, have their own rhythms and chronologies. A tightly managed lifestyle can lead to over-reliance and boredom, potentially contributing to stereotypical behavior.

FIGURE 4 | African elephants at waterhole in Etosha National Park, Namibia.

Temporality therefore has many facets. As well as relating to life cycles and rhythm, we notice that there is a connection between time and olfaction for animals with a good sense of smell.

Olfactory

Thwaites has claimed that animals have no sense of history and future (81). He states that only humans conceptualize the world using narratives and that this is what makes us unique. However, because humans primarily rely on vision, we perceive what is around us *at the moment.* For animals who rely on their sense of smell, such as elephants, dogs and bears, there is a connection between time and olfaction. Although our memories and imagination let us traverse time fluidly backwards and forwards, our olfactory limitations require us to live in the present with respect to our immediate perceptions. Dogs, on the other hand, inhabit a world of layered timelines, whereby their noses provide them with complex information about the history of the environment. Scents dissipate over time, so the intensity of a smell is a clue to its age. Olfaction thus provides an example of a sense that informs different species in different ways.

In land vertebrates, the olfactory receptor cells are located in the nasal cavity. Different species possess differing numbers of genes responsible for their activation. Sea dwelling mammals use a dorsal blow hole for breathing into lungs so they can open their mouths underwater. Bovet notes that olfactory activation genes are completely absent in dolphins, although still present in whales (82). Fresh water hunters, such as shrews and star-nosed moles, have adopted a different approach – they blow bubbles beneath the surface and suck them back in again quickly to capture the scent (83). Fish, meanwhile, breath through their gills, but also have noses and are extremely sensitive to waterborne chemicals; any toxic contamination has a negative impact on fish olfaction and subsequent behavioral responses (84).

Majid (85) suggests that a deficiency in vocabulary (in English language) may account for the common belief that human sense of smell is poor. Since humans share ideas and express thoughts through language, lack of words may affect our critical thinking around the topic of olfaction. Moreover, he claims that humans have higher odor sensitivity – meaning lower detection threshold – than animals such as dogs and pigs. In fact, in many cultures around the globe, languages are enriched with olfactory words, notably in hunter-gatherer communities where there is more contact with the natural environment and people possess more ethnobiological knowledge than typical city-dwellers. An example from contemporary western culture is Suskind's fictional account of a man gifted with exceptional olfactory skills, "*Perfume: The Story of a Murderer*", which was originally authored in French. The English translation is renowned for its literary evocation of odor, albeit using comparisons with known substances rather than a specific olfactory lexicon.

> *"This scent had a freshness, but not the freshness of limes or pomegranates, not the freshness of myrrh or cinnamon bark or curly mint or birch or camphor or pine needles, nor that of a May rain or a frosty wind or of well water ... and at the same time it had warmth, but not as bergamot, cypress, or musk has, or jasmine or daffodils, not as rosewood has or iris."* - From Perfume by Patrick Suskind (86) (reprint).

This all points to the need for flexibility in our approach to olfaction and suggests that researchers, writers and designers should not neglect olfactory attributes of systems, even if they seem difficult to describe and quantify.

There are two different pathways to the back of the nose, where the olfactory receptors are located – orthonasal, meaning via the nostrils, and retronasal, via the back of the throat. Dogs, for example, who detect scents orthonasally, can gain information and pleasure from sniffing the environment. Humans have a more developed retronasal pathway, which means we can enjoy the smell of food even more when we put it in our mouths.

Gustatory

For those animals that possess a sense of smell, olfaction is strongly associated with food. Olfactory stimuli are integrated with gustatory stimuli when we eat, so that the overall impression of taste is stronger. Humans can detect five tastes with their taste buds – sweet, sour, salty, bitter and umami. While we each have around 10,000 taste buds on our tongues, cows have around 20,000. The increased amount is thought to enable cattle to identify suitable food as they graze, spitting out toxins before ingesting; ruminants show the strongest preference for umami, followed by sweet taste (88). Catfish have 100,000 taste receptors, with concentrations around their barbels. This is an excellent adaptation for finding nutrition in dark, murky water (89). Probably the most advanced sense of taste belongs to the octopus, whose 8 arms each have around 280 suckers, every one with a sense of touch and of taste. There are approximately 10,000 taste receptors on each sucker (37).

According to Balcombe in (24), "*...the experience of food pleasure in animals is almost wholly unexamined*" (24). However, 12 years on, there have been studies with pigs (90), cows (88), fish (91), horses (92), cats (93); dogs (94) and tortoises (95). This demonstrates the contemporary interest in animal wellbeing, which highlights positive affective experiences as fundamental aspects of health and fitness (96, 97).

Multimodal

It is important to remember that all our senses are involved with the appreciation of food. Taste is somewhat limited in that it seems to consist of only five detectable tastes in various combinations. *Flavor,* on the other hand, is multimodal, including smell, sight, sound and touch (98). Sight relates to food presentation (e.g., color and shape); sound relates to qualities experienced during eating (e.g., crunchiness); touch relates to mouthfeel [e.g., texture, viscosity, temperature, chewiness, astringency and irritation – (99)].

> "*If a French crepe were to marry an English crumpet, the couple would probably become the proud parents of a Sri Lankan hopper. The hopper has the softness, delicacy, and pliability of the crepe teamed with the airy, hole-filled, puffy, and browned-on-the-outside quality of the crumpet.*" – From Eastern Vegetarian Cooking by Madhur Jaffrey, (100).

Perception usually involves multiple modalities perceived simultaneously, providing a holistic experience of an event (101). We are able to integrate the unimodal stimuli associated with a particular event, despite there being other stimuli present. Experiments have demonstrated a superadditive effect, such that the sum of the whole integrated sensorial experience is greater than the sum of the individual parts. In humans, the neurons that process an individual sense send their information to a convergence zone, where all matching perceptions are processed together. Neural convergence happens when there is more than one input neuron sending information to a single neuron; it has been established that the receptive fields around the input neurons (that each only respond to one kind of stimulus) must overlap in physical space in order for the super additive response to be invoked. There are many areas of the brain where this multisensory processing can take place, suggesting that our experience of the world is "fundamentally multimodal". Studies undertaken thus far with non-human animals indicate that their experience is similarly holistic – examples being cats (102), rodents (103), macaques (104) and flies (105).

The different sensory modalities we perceive can affect each other (101). Multimodal phenomena include perceptions combining to *enhance* a signal, such as the smell and taste combination previously discussed. Another example is found in human speech, where acoustic and visual stimuli support each other from the perspective of a perceiver who lip-reads to capture conversation in a noisy room.

Electro-Magnetic

Electro-magnetic field sensitivity is another phenomenon that most humans do not perceive. There is increasing evidence that a wide range of animals can detect and utilize electro-magnetic fields, to determine location and direction, and to detect prey and predators and mates. Animals sensitive to these signals can discern tiny changes in intensity or direction (106).

Clarke et al. showed that bees produce an electrical signal that facilitates pollination (107). The positively charged bee attracts more pollen dust and becomes a better transporter of pollen from flower to flower, but the charge is also detected by the plant. In response, the plant produces more volatile organic compounds (VOCs, otherwise known as scents) that attract more bees. In addition, flowers exhibit electric fields that endow different parts

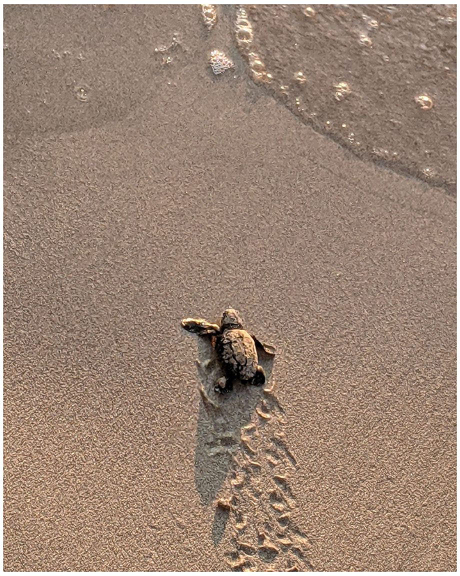

FIGURE 5 | Loggerhead hatchling heading for Mediterranean, Kephalonia, Greece.

of their anatomy with different charges; petal edges and stigma have a high charge, revealing the overall structure of the flower to an approaching insect.

Sharks have electro-sensory receptors in organs around their head and mouth. They are highly sensitive to electric fields and can detect muscle contractions in potential prey, as well as the Earth's geomagnetic field (https://www.sharktrust.org/shark-senses). Sea turtles (see **Figure 5**: Loggerhead hatchling) also use magnetic field information for natal homing (108). According to Clarke et al. (107), there are so many electric fields in the environment that "*signals in this modality could potentially be used by a broad range of species in an array of contexts*." The corollary is that any interference (such as electromagnetic pollution caused by wireless communication) can have a profound effect.

The range of sensory modalities covered here should give the reader an idea of the extent of aesthetic possibility that might exist for other species. As discussed earlier, action is inherent in all interactions with the environment that result in perceptions, since perception itself is dynamic, evoking a response from the perceiver to a stimulus. At some stage, there is a transition; movement changes from being a single instinctive action to becoming part of an established and recognized behavior.

Behavioral Aesthetics

Movement facilitates and enhances perception using other senses, and also offers embodied pleasure. Working with elephants led French et al. (47) to the idea of *performative aesthetics*, through observing the animals' preference for interacting with moveable features in their environment. This idea is now expanded to include a wider range of behaviors and phenomena that arguably have their own distinctive aesthetic dimensions for the animals involved.

An important aspect of behavioral aesthetics is that there is a narrative element to the activity that may be missing from a momentary sensory perception. Huron's ITPRA Theory (109) relates to the emotional responses evoked by events that unfold over time. It is a psychological theory of expectation that proposes five contributing systems: (i) the *imagination* required to predict the future in order to make choices in the present; (ii) the *tension* experienced preceding an anticipated event; (iii) an immediate response to the accuracy of the *prediction*; (iv) the feelings associated with the *reaction* to the event; (v) and the final *appraisal* when the outcome is assessed. The emotions experienced by animals during the performance of the following behaviors may fit well with this theory.

Aero-and-Hydro-Dynamic

"*Feet, for a flying bird, are an acknowledgment of inadequacy.*"
- From The Screaming Sky by Charles Foster (110).

An aesthetic experience that may be hard for humans to appreciate is the combined control and freedom of movement associated with traversing a medium that offers an upward force to counteract gravity. (See **Figure 6**: Swifts over Corfu.) The ability of an animal to flow in this manner through air or water has been called *buoyancy* for those that are expert fliers, swimmers and swingers. These animals have evolved to be able to move, detached from the ground, with minimum effort and maximum effect. To human observers, such activities appear to elicit joy, to the extent that we have historically tried to emulate the effects, and if not possible, gained pleasure from watching the aerobatics. Abram comments: "*I feel the stretch and flex of its wings with my own muscles, and its sudden swoop toward the nearby trees is a visceral as well as a visual experience for me*" (7), p.61. For animals who normally swoop, glide and go with the flow of their environment, it is often the case that captive conditions are too restrictive to allow for these kinds of movement; for example, aquaculture, which is globally the fastest growing food sector (https://www.fishwelfareinitiative.org/), faces criticism for subjecting fish to overcrowded conditions with associated health problems (111).

Hodgetts and Lorimer point out that mobility is shaped by each species' physical and cognitive characteristics, as well as their habitat (112). It may also be a collective experience, influenced by social factors.

Collective

"An evening murmuration is more than just the dance of starlings; it is a glimpse into one of the fundamental motions of life." – King and Sumpter (113).

Associated with flight but encompassing a different aesthetic, the phenomenon of swarming is exemplified by the murmuration of starlings and the energy of bees (see **Figure 7**: Honeybees). This kind of performance is a collective behavior that occurs

FIGURE 6 | Swifts over Corfu, Greece.

within a system composed of multiple entities that act independently while still maintaining a flow of information between participants (114). The resulting complexity of the system is an emergent property that cannot be predicted by just studying the components as individuals. In Vester Flights (115), Helen Macdonald tells readers: "*Turns can propagate through a cloud of birds at speeds approaching 90 miles per hour, making murmurations look from a distance like a single pulsing, living organism*."

Emergence seems to benefit both the individuals and the species. In human society, there are health benefits (practical and psychological) associated with being part of, and contributing toward, a bigger system. For a species that lives as part of a colony, collective behavior can give rise to extraordinarily complex results; termite mounds are a case in point, unique structures built cooperatively without any obvious blueprint. There seems to be communal intelligence amongst the participants of a collective behavior, which Sumpter attributes to a set of governing principles, including individual variation, positive and negative feedback, and catalysts (individual influencers) within the group (114). As Werber's fictional etymologist comments, in Empire of the Ants: "*It must be an incredible feeling to live the experiences of others and make them feel everything one feels oneself*" (116).

Playful

> "*Play is a process, not a static state of affairs.*" - From The Aesthetic of Play by Brian Upton (117).

Playing is also an activity, performed in a group or by an individual, that arguably has its own distinctive aesthetic, incorporating all the senses of the engaged animal. Upton values choice and agency as the primary aesthetics for play, a position that is challenged by Sharp et al. (118), who point out that making decisions that lead toward the accomplishment of defined goals is not necessarily rewarding. As Greaves comments: "*Very open-ended expressive-responsive movements of (animal) play do not primarily manifest as functionality. Yet they are prime occasions for aesthetic appreciation, both on our part and often on the part of animals themselves*" (119).

Non-human animal play may be easy to recognize but has proved difficult to define. However, as is the case with humans, there exist implicit behavioral rules that participants understand and communicate to each other; this is clearly seen within the frame of human-dog interspecies play (see **Figure 8**: Terrier and ball) and can be observed in play between other animals (120, 121). One of the "aesthetic ideals" of human gameplay explored by Lundgren et al. (122) is the idea of play emergence, which explains how complexity and interest often arise in social play, despite the rules of engagement being simple. Responses to the constantly changing playscape require players to be alert and cognitively flexible.

Animal play has been categorized as "object", "social" and "locomotor" (123). Locomotor and object play seem to map very clearly to pleasurable kinaesthetic and tactile experiences, exemplified by the exuberance of spring lambs and the mud-rolling of elephants. While there are welfare-related explanations for such activities – promotion of muscles development and skincare regimes – it seems likely that the play obtains satisfaction for the animal in and of itself. In other words, it is an autotelic activity, self-rewarding on multiple levels.

Flow has long been associated with the particular mindset that games can engender in players – characterized as an optimal experience that exhibits high levels of focus and enjoyment (124). For game designers, inducing a state of flow has often been seen as the ultimate challenge, summarized by Salen and Zimmerman as a call to "*design meaningful play*" (125). Although this sounds like a positive objective, there may be ethical issues associated with manipulating players, both human and non-human, so that they invest a large proportion of their time on a designed activity.

Recently, another optimal psychological state has been defined – *clutch*. This is also associated with heightened concentration and performance, most commonly in respect to athletes. In comparing the two states amongst people exercising, Swann et al. (126) comment: "*Flow occurred in contexts involving exploration, novelty/variation, and flexible outcomes, while the experience was described as enjoyable at the time and involved lower perceived effort. Clutch states occurred in contexts involving achievement and pressure. Exercisers perceived clutch states to be enjoyable afterwards but not at the time, and to involve intense effort.*" We argue that clutch pertains fully to the experience of hunting, included here as its own aesthetic category since it is such a fundamental aspect of predators' lives.

Predatory

Hunting is an activity that completely absorbs the brain and body so that the hunter is in a state of flow or clutch, with heightened perceptions and reflexes. For a predatory animal, hunting facilitates the multiple dimensions of pleasure associated with nutrition, including anticipation, identification and retrieval, ingestion and flavor, and the satisfaction experienced after consuming a meal (see **Figure 9**: Lion with zebra carcass). In the case of felids, for example, hunting comprises locating food, through traveling and detecting prey; capture, which

FIGURE 7 | Honeybees in Kent, UK.

FIGURE 8 | Terrier playing ball with human, London, UK.

FIGURE 9 | Lion with zebra carcass, Waterberg Plateau Park, Namibia.

might entail stalking, coursing, ambushing or scavenging; killing through disabling and dispatching; eating and subsequently processing (127).

Hunting can also be an important aspect of social life and welfare. For social species, pack hunting requires sophisticated communication and coordination amongst the group members, resolving itself in the sharing of the kill. As an example, neighboring groups of bonobos with overlapping territories in the Congo Basin have developed distinct hunting cultures, focusing on different prey to avoid competition between the groups for food (128). On a hunting expedition with dogs (searching for wild pigs), Keil describes how the animals' perceptions enhanced those of the human companions: "*A hunter immerses themselves in the multi-sensual immediacy of their world, attentive to how hunter and hunted affect each other... Chemical, electromagnetic, acoustic, meteorological and other material aspects imperceptible in an environment perceived by naked human senses, can be sensed by nonhumans*" (129).

It can thus be difficult to provide opportunities for captive predators to express their full repertoire of hunting behaviors, since the provision of live prey is not considered ethical in many places, space is restricted, and animals' autonomy is also limited. While there are undoubtedly many excellent examples of captive carnivore enrichment in zoos and wildlife parks around the world, this nevertheless remains a challenge.

Architectural

> "*A bird and its nest belong together so absolutely in our minds that the idea has gone beyond biology and become a motif in the work of poets.*" - Jurgen Tautz in Animal Architecture by Ingo (130).

There are many examples of animals that construct objects from found material or personal secretions, usually as shelters or traps. Notable structures are beaver lodges, which involve serious hydro-engineering and landscape architecture. The attention to detail accorded by beavers to designing, building and maintaining their lodges has been well documented, as well as the associated positive ecological effects on habitat and biodiversity (131, 132). As Laidre comments: "*...architecture changes the world...*" (133).

Birds' nests may be crafted by weaving, excavating and sculpting. The material varies with the environment and size of inhabitants, and the form derives from the function. While it is possible to acknowledge the artistry that goes into building these constructions, we cannot know if the builder derives a sense of satisfaction from a well-made nest. However, in many cases, nest-building is an act of courtship, and for bowerbirds, the selection process has favored visual complexity (134). The male places decorative objects around the bower, selecting specific colors, sizes and positions so as to create an impressive display. Endler comments: "*Great Bowerbirds are artists, judge art, and therefore have an aesthetic sense*" (134). An equivalent behavior has been documented in male puffer fish, who spend many hours constructing geometric circles in the sand to attract females (135).

Finally, this paper presents a small selection of creative methods that have been used by humans to explore the aesthetic dimensions experienced by other species. Not all approaches are directed toward an interaction design challenge, but they all involve imagination, innovation and background research. They may therefore be inspirational for future development in this field.

INTERACTION DESIGN: EXPLORING AESTHETICS

Understanding the users of a new system is a priority for interaction designers, but how can they gain empathy and insight into non-human experiences without relevant sensory modalities and world view? Useful methods deployed at the start of any project involving non-human animals include *ethnographic studies*, background *literature reviews*, and *collaborations* with species specialists and animal welfare experts. But is it possible to ask non-human animals for their opinions?

Although some animals can be trained to interpret some human speech, humans have made little progress in interpreting the vocalizations made by non-humans. There is also an assumption that the cognitive processes of non-human animals are less abstract than human thought and therefore less able to be expressed in a human-type language that is highly organized, symbolic and referential. In consequence, interspecies communication is often based on the communication of non-linguistic signals. It may be that different species can understand each other best through mutual observation of expressive behavior. Aspling et al. (136) refer to "*kinaesthetic empathy*" whereby meaning is constructed through bodily experience, and interaction between participants consists of physical movements (137).

However, in the case where human and non-human are not able to interact physically with each other, the provision of *choice* and enablement of *volition* are both crucial for allowing other species to express preferences. Having greater control over their environment is widely recognized as being beneficial for captive animals (2, 138–140), and it is therefore possible to apply this principle to the evaluation of design aesthetics. Ideally, two parallel events should be occurring – the choices made by designers that influence the experience offered to the animals, and the choices made by animal test subjects when they are offered a way to express their preferences. This suggests an iterative mode of development that values incomplete solutions as sources of inspiration and knowledge. In regard to preference testing, paired-choice testing has been criticized because participants may be forced into selecting the lesser of two unpleasant options, rather than necessarily selecting for a hedonistic experience (141). It is therefore recommended to create a range of options, including the option to avoid an experience altogether, as demonstrated in ACI projects with elephants (47, 142) and sakis (143).

To complement an experimental scientific approach, ACI designers have traditionally explored working methods that facilitate empathy and collaborative practice, including all the stakeholders associated with a new system. Another important feature of ACI is that technology has enabled the development of novel tools for designers, such as automated systems and machine learning (ML) algorithms for recognition of behavioral patterns. For example, ML has been used to support the investigation of musicality in birds, through synthesis of budgerigar songs from samples (144). Zamansky et al.(145) provide an overview of ACI research methods, emphasizing the benefits to the ACI community of remaining open to methodologies from different fields.

Literal Experience

A purely academic perspective can be quite limiting in regard to understanding the "other", which is why some artists and researchers have deployed more imaginative techniques in their quests to understand the experiences of non-human animals and appreciate their aesthetic sensibilities. For example, there are adventurous researchers who have attempted to personally embody the life experiences of their non-human subjects in real time. One such explorer is Foster (87), who recounts his lived experiences of being a badger, an otter, a fox, a red deer and a swift in "Being a Beast" (see **Figure 10**: Urban fox). Foster has inhabited the same environments as the selected species and suggests that as he possesses similar sense receptors, he is able to draw parallels between his responses and theirs to a given situation. However, he also acknowledges that because all the signal processing is performed in the brain, phenomenological sensations might be different: "*The universe I occupy is a creature of my head. It is wholly unique to me*" (p. 8). Foster is interested in personal autonomy, identity and otherness, and has chosen to share his insights using an evocative writing style enriched with poetic language. His work is underpinned by extensive research; for example, into species-specific sensory modalities and somatotopic maps. Although there are fanciful passages where he postulates about the dreams of badgers and the nonchalance of otters, his work has an authority derived from him trying to live authentically as creatures in their natural habitat.

Thwaites also attempted to emulate a non-human species, by choosing to become a goat for a week (81). He proposed to explore the physicality of a goat's experience as part of a herd and his research led to the development of a goat exoskeleton so that he could experience life on the hoof. Thwaites commented: "*When I strapped on four legs, I couldn't use my hands, so my mouth became my interface with the world*" [in Pilcher, (146)]. He used technology to facilitate his performance as a goat, to the extent of wearing a device that could digest grass.

Foster's work was undertaken in a personal and private manner, then reflected upon and shared to allow others to vicariously experience his pleasures, trials and subsequent

FIGURE 10 | Urban fox in Battersea, UK.

enlightenment. Thwaites' experiment was arguably an experimental performance art piece. Both were prepared to take risks in order to gain awareness of other species' sensibilities. They hoped that inhabiting the realm of the "other" would enable a deeper percipience of the possibilities and limitations associated with being a non-human animal; would help them to understand the animal's unique perspective; would allow them to assimilate the animal's natural environment in a corresponding way but through using their human senses. Yet after prolonged efforts, Foster claims he realized that he was incapable of creating a proper scent map because of his human dependency on vision. Both authors found their physical and perceptual limitations to be distracting during their intense engagement with their subjects' environment and lifestyle. In Art for Animals (147), which describes how contemporary artists have successfully included animals as participants and as audience members in their work, Fuller (148) highlights the problem faced by Foster and Thwaites, by asking: "*Is there a market for drugs that temporarily reconfigure nervous and perceptual systems to those of other species?*"

Fortunately, there are more practical and accessible methods for investigating non-human sensory experiences than Foster's and Thwaites' visceral adventures – for how many designers have a lifestyle that enables or motivates living in the woods for weeks eating worms or scaling a mountainside in prosthetics to chew cud?

Close Relationships

Many humans have developed a close bond with a companion animal, and dog owners' combined insights have been used as a resource by Aspling et al. in their study "Understanding animals: a critical challenge in ACI" (137). In particular, Aspling et al. focus on owners pretending to be their dogs and posting on social media, which gives an indication of the kinds of thoughts that the humans imagine their dogs would share (about physical surroundings, weather, toys, treats, social lives and emotions).

> *"it is not the taste of a leaf. that intrigues me. it is the crunch" "i heard there is a ball dropping later. does anybody have the details? i am interested in that"* - Thoughts of Dog, @dog_feelings, Twitter.

Helen MacDonald (149) painstakingly developed a relationship with a goshawk, Mabel. Although MacDonald never pretended to *be* a hawk, she describes the varying degrees of attachment and comprehension she felt as a result of her attentiveness to the "other" thus: "*I felt incomplete unless the hawk was sitting on my hand: we were parts of each other*." Subsequently: "*. . . her world and my world are not the same, and some part of me is amazed that I ever thought they were*." It is common for humans to feel strong affection for companion or tamed animals and vice versa (it seems); there are many narratives dealing with mutual understanding and apparently empathetic relationships.

Narrative

For a population that is increasingly urban, increasing interest in reconnecting with non-human species is reflected in contemporary media. Big budget nature documentaries continue to be hugely popular, using narrative to engage the public with other lives. However, there has been scrutiny of the selective editing required to construct these stories. As filmmaker Simon Cade says: "*. . . they just choose a few moments that provide the maximum emotional impact*" (150). A different style of documentary can be seen in "*Stray*" (151), filmed in Instanbul and shown entirely through the perspective of its street dogs. The creators state that the film "*explores what it means to live as a being without status or security*". Although this explicitly references the dogs themselves, the film also implicitly portrays human society, offering an example of animals being used as ciphers to explore human psychology.

Perhaps Aesop's Fables, a collection of folktales from Ancient Greece, is the earliest well-known example of anthropomorphism by storytellers. The behaviors of the animal protagonists are metaphors for human behaviors and the narratives are designed to express moral values. This tradition continues to the present day in children's literature, where one of the strengths of anthropomorphism is that it avoids the problem of human representation and therefore makes the text universally relevant. Fantasy fiction for older audiences also draws on folklore and mythology; popular modern examples include Pullman's "*His Dark Materials*" (152) and Martin's "*Song of Ice and Fire*" (153). Pullman envisages a world of people imbued with dæmons, who are human souls embodied as animals, similar in concept to spirit animals; skinchangers (humans who can enter the mind of another animal) are fundamental to Martin's plot. These human-animal connections reference the ancient tradition of shamanism that connects people with nature through interaction with spirits and is believed to have originated with hunting and gathering communities. A person's spiritual journey in this context is often facilitated by a spirit animal guide, but although the attributes of the animal influence their perceived guidance (e.g., a bear is emblematic of strength, an eagle epitomizes vision), the animals seem to be used symbolically.

Science fiction offers writers scope to experiment with different frames of reference. As a case in point, Tchaikovsky, in "*Children of Time*", writes from the perspective of an evolved spider, here seeing a human spaceship for the first time: "*Every detail is bizarre and disturbing, an aesthetic arising from the dreams of another phylum, a technology of hard metal and elemental forces*" (154). Tchaikovsky excels in evoking the spider's alien consciousness; she conceptualizes the world in spiraling networks of interconnectivity with her sisters, speaks with vibrations and is able to discuss maths with other species such as stomatopods and humans. Despite, or perhaps due to, being a fictional account, the work successfully introduces human readers to novel sensibilities. Nonetheless, Westerlaken, in Imagining Multispecies Worlds, brings home the importance of actually sharing a world space with other species for gaining empathy: "*Stories will always lack some of the sensorial engagement of the experiences themselves*" (155).

In contrast to a traditional linear narrative approach, completely new dimensions of experience are being explored through the use of immersive technology.

Immersion

In the world of games, "*Pigeon Simulator*" from TinyBuild (https://www.pigeonsimulator.com/) is described as a "physics sandbox roguelike" where players embody (antagonistic) city pigeons. Blue Twelve Media (https://stray.game/) are releasing an adventure game (also) called "*Stray*" in 2022, where the player is represented as a cat who interacts with the world from a feline perspective.

In human scenarios, there have been attempts to use VR (virtual reality) technology to enable people in caring roles to empathize more strongly with their patients. For example, VR has been used as a tool to empower nurses and family members, allowing them to experience the world as those in their care might experience it (156–158). However, Martingano et al. (159) discovered that VR seems to improve emotional, but not cognitive empathy, meaning that it can arouse compassion, but fails to help users understand the perspective of another. They suggest that cognitive empathy requires "*… more effortful engagement, such as using one's own imagination to construct others' experiences*." McFarland's view in (160) was: "*No film-maker, or virtual reality expert, could convey to us what it is like to be a bat, no matter how much they knew about bats*." While this view is apposite, McFarland acknowledged that although qualia are subjective qualities, if humans have experienced the same sensations as each other, they usually have a common understanding, despite each person being unique in their internal processing of the information (160).

Extending VR applications to support humans in their understanding of animals has already had some success. Recent ACI work in this area includes the creation and deployment of VR videos that express the visual experiences of (i) turtles and tortoises, (ii) cats and dogs and (iii) frogs and geckos (161). The focus is on showcasing alternative color spectra and dynamic vision, and the research motivation is to provide opportunities for humans to learn about animal vision in order to gain appropriate design perspectives. As humans are typically so dependent on vision, highlighting differences in visual perception between species may be a critical aspect of understanding the other.

Hook (162) developed a wearable horse-shaped head with lenses that enabled humans (who have bifocal vision) to view their surroundings as if their eyes were situated on either side of their head. This provided a typical prey species perspective, providing a much larger field of view. North (163) also explored the use of horse adaptations (robotic ears) worn by humans in order to further their understanding of horse communication using ear movement signals. Even though the ear movements are perceived by conspecifics as visual signals, North's work highlights the fact that interaction modalities vary from species to species. Hook describes his method for this project as *speculative design*, which emphasizes critical reflection around the future implications of a design, often using design fictions to provoke discussion (164). North, meanwhile, refers to his work as *science fiction autoethnography*.

Both these example projects by Hook and North required *expert crafting* in order to recreate the perception and anatomical features that are used by the animal, so that humans might gain deeper understanding of a horse's experience.

Craft

Crafting has a visceral, multisensory quality. It is related to fabrication or making, but with a stronger emphasis on exploring the materiality of the crafted object and the confluence of modalities that give rise to our perception of it. Craft has the potential to enhance the designer's sensory and intellectual appreciation of form and substance, which are attributes of an object that may have aesthetic appeal. In design work with elephants, French et al. (142) adopted a Research though Design *and Craft* methodology, where the crafting aspect was a fundamental aspect of negotiating an interactive enrichment design that would be appropriate for an elephant – not only designed according to an elephant's cognitive and physical abilities, but one that would be both pleasurable and engaging. The project started with ideas borrowed from game design and knowledge of an elephant's sensory modalities, then crucially, the researchers discovered that craft offered a physical way to mediate between designer and user through *mutual interactions with the same object*.

> *"Craft is the outputs from my brain through material practice by using my hands – the opposite to inputs such as reading, watching, listening … When we output something physically, we learn so much through all our senses."* – Mori (165) artist and metalworker (from Craft Council Stories, 2020).

Craft connects the designer with the aesthetic properties of the crafted object by promoting both cognitive and multi-sensory appreciation. Handling an object gives rise to insights regarding its aesthetic dimensions. Similarly, *tinkering* with electronics (included within the practice of craft) is more fruitful for developing an appreciation of the sensors and actuators used in interactive systems than using off-the-shelf solutions. Synthesized outputs are not objects – yet they can be concrete, perceivable experiences, such as sounds and vibrations. Therefore, they have aesthetic dimensions that are both discernable and potentially controllable by both humans and non-humans. The profound experiential knowledge gained from physical interaction with an object is something shared between designer and user, despite their reliance on different modes of perception.

These examples of creative methods used by humans to extend their aesthetic sensibilities and embrace the experiences of other animals hopefully serve to show how artistic perspectives can be inspirational for and complementary to scientific investigations in this field. Baker, in the introduction to Artist Animal, comments: "*…art has the potential to offer a distinct way of framing or unframing issues…*" (166). In this context, perhaps it is the *unframing* that is crucial, facilitating our ability to imagine a different way of knowing the world.

CONCLUSIONS

> *"We are human only in contact, and conviviality, with what is not human."* – David Abram (7) (reprint 2017).

Humans are gaining an improved ecological perspective on the environment and their co-inhabitants using a combination of science, technology and imagination. We observe and interpret, use tools to derive more knowledge, and create fictional or metaphorical narratives that attempt to explain our existence.

One aspect of the human quest to understand everything is our desire to understand other animals. Human society facilitates communication and shared intelligence between human individuals but gaining awareness of what it is like to be another species is more challenging and controversial, requiring a combination of scientific investigation, insight and imagination. Current studies indicate that aesthetics are fundamental aspects of the experiences of all living creatures and should therefore be taken into consideration by the designers of those experiences, as well as designers whose work occupies a multi-species-shared environment. A deeper awareness of the aesthetic experiences of non-humans can support human design endeavors by increasing sensibility to the environmental and ecological effects of human activities.

This paper has attempted to address ideas about different dimensions of being, by exploring and expanding notions of aesthetic sensibility. In *2. Rationale for aesthetics*, reasons for the existence of aesthetic sensibility were discussed from different disciplinary perspectives. *3. Perception, aesthetic sensibility and behavior* offered a review of current work on animal perception, pointing to sensory modalities that are important for designers to consider. This section also suggested some intensely rewarding behaviors exhibited by different species that may be good candidates for holistic aesthetic appreciation – being more than the sum of the individual senses involved. Finally, *4. Interaction Design: exploring aesthetics* comprised a collection of ways in which humans have engaged creatively with the sensory and cognitive experiences of other species. This was presented as a set of suggestions to support interaction designers to better understand their non-human users (intended or otherwise) and to design with confidence and respect.

Remaining open-minded and receptive to non-human perspectives and abilities has the potential to enhance human lives, by opening the doors to novel and mysterious aesthetic experiences. Through an exploration of difference, not only do we gain more insight into other species, but we may also learn more about the aesthetic sensibilities that we have in common. And indeed, by embracing alternative ways of being, we are extending inclusivity beyond human culture and personal identity.

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The author confirms being the sole contributor of this work and has approved it for publication.

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Understanding the Impact of Scale Height on the Kinetics and Kinematics of Dogs in Working Trials

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Working trials is a canine discipline that originated from police and military dog work. One aspect of working trials competition is for a dog to "scale" a 6ft high wooden wall. Concern has been raised in other canine disciplines that landing forces after traversing jumps may lead to soft tissue injuries. There is a paucity of research into the impact of scale height on peak vertical landing force (PVF) in dogs participating in working trials. The aim of this work was to determine whether an alteration in scale height impacts PVF and apparent joint angulation on landing. Twenty-one dogs who regularly competed in working trials traversed the scale at three different heights; 6ft (full height), 5.5ft and 5ft. Changes in PVF, apparent carpal and shoulder joint angulation and duration of landing were analyzed using general linear mixed models. Dogs weighing >25 kg had greater PVF at 6ft than at 5ft ($p < 0.05$). There was no effect of scale height on PVF in dogs <25kg. Duration of landing was longer at 5ft than 5.5ft ($p < 0.001$) and 6ft ($p < 0.001$). Apparent carpus angle on landing was smaller at 6ft than 5ft ($p < 0.05$) and 5.5ft ($p < 0.05$) for dogs <25 kg. Apparent carpus angle on landing did not differ at any height for dogs >25 kg ($p > 0.05$). Apparent shoulder angle was not affected by scale height for any dogs ($p > 0.05$). There was considerable variation in the study population, but this research indicates that when the scale height was lowered to 5.5ft dogs had reduced PVF and less compressed joint angles on landing. When the scale height was lowered to 5ft they altered their traversing style and greater compression and increased PVF was seen. Evidence-based approaches to canine working trials are important to ensure minimum impacts on physical health and welfare of participating dogs, in terms of risk of injury in both competition and training. Based on these findings it is recommended that the maximum height of the scale is reviewed for training and competitive purposes, to ensure minimal impacts on the health of competing dogs, while maintaining the level of competitive challenge.

Keywords: peak vertical landing force, working trials, canine, biomechanics, joint angulation

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INTRODUCTION

Working trials is a canine discipline originating in the 1920's from police and military dog work and has seen little modification in format since the 1960's. The discipline is split into three components, scent work, agility [clearing a 6ft scale (wall), 9ft long jump and a 3ft hurdle under control], and obedience tasks (1). The scale obstacle in the agility component of working trials is considered particularly physically demanding for the dogs, with a requirement for the dog to jump from a static start on the ground to 'scale' the obstacle, landing in a controlled manner, before returning over the scale. Whilst the scale obstacle originated from police dog training, the chosen maximum height for specific competitive levels (dogs exceeding 15 inches at the shoulder) is currently an arbitrary measurement of 6ft (2).

Concern has been raised about potential injury risk to dogs participating in other canine disciplines such as agility, where dogs traverse a series of jumps and other obstacles as a test of speed and athletic ability. Landing forces experienced while participating in agility have been postulated to potentially result in soft tissue injuries, notably to the back and shoulder (3–6). Studies have explored the effect of jump height (7), and distance between jump obstacles (8, 9) on the kinematics, landing forces and apparent joint angles of participating dogs. As obstacle height is increased, peak landing forces in dogs also increases (10). Both horses (11) and dogs (7) alter their apparent joint angulation as hurdle height is altered. In addition, horses have been shown to alter joint angles at take-off, suspension and landing based on both jump height and jump type (11–13). Furthermore, Birch et al. (7) also demonstrated that when dogs were asked to jump an upright hurdle that was >76% of height to their wither height, their kinematics demonstrated alterations. It thus appears that dogs and horses significantly alter their kinematics based on obstacle height.

Wider canine kinematic research suggests that peak landing force is higher when landing over an upright hurdle than running or landing over a long jump for dogs (14). On landing following a simulated jump from a car boot, peak ground force increased as the height of the platform increased (15). Whilst the working trials scale is an "up and over" obstacle, the height results in the dogs reaching the top before coming down on the other side, with a momentary pause on the top of the scale as they maneuver over the top, rather than clearing the obstacle as they would a hurdle. In cats, peak vertical force increased as the height to a landing surface was increased (16). Higher peak vertical landing forces (PVF) may increase forelimb and shoulder injury risk in dogs (3–6). Yanoff et al. (10) highlighted body mass as a significant factor in relation to peak vertical ground force. Whilst the assessment of standard gait of dogs did not vary according to body weight, the loading of dog limbs on landing may be impacted by the body weight of the dogs.

The height of the scale obstacle in working trial competitions is based on arbitrary measurements, with the maximum height for dogs > 15 inches at the shoulder, being 6ft high. There is a paucity of research on the impact of scale height on PVF and apparent joint angulation of dogs on landing, which may have ramifications for the physical health of dogs participating in this discipline. The aim of this study was thus to determine whether an alteration in scale height impacts peak vertical landing force and apparent joint angles on landing in experienced dogs routinely training and competing in working trials.

MATERIALS AND METHODS

Ethics Statement

All research protocols were approved by Nottingham Trent University, School of Animal, Rural and Environmental Sciences School Ethics Group (reference number ARE192042).

Study Population

Dogs were recruited opportunistically from the population of handlers and dogs regularly competing in working trials in the UK. All dogs had trained or competed in working trials for at least 12 months to minimize the effect of naive or inexperienced dogs. Dogs were therefore experienced in clearing the scale obstacle at the maximum competitive height.

Twenty-one dogs (15 male, 6 female) were recruited to the study from five breeds/types (identified by handlers): border collie/working sheep dog ($n = 10$), golden retriever ($n = 1$), German shepherd/malinois ($n = 4$), Labrador retriever ($n = 5$), spaniel cross Labrador ($n = 1$). Median age of dogs was 4.5 years (range 2–8 years). Dogs <25 kg ($n = 12$) had a mean ± SD bodyweight of 21.5 ± 2.4 kg, dogs >25 kg ($n = 9$) had a bodyweight of 29.2 ± 4.3 kg. Demographic details of the study population are provided in **Table 1**. All dogs were declared as physically fit enough to undertake this study by their handlers, this included being free from any current injuries. Signed consent was given for their participation in the study.

Experimental Setup

The study was carried out in a fenced outdoor equestrian arena with a fiber sand surface. The handlers prepared their dogs, as they would prior to the scale element of the working trials competition. This also allowed the dogs to acclimatize to the research environment and equipment. The study examined dogs traversing the scale at three different heights. 6ft (1.83 m) (the current maximum KC height in competition for dogs exceeding 15 inches (38.1 cm) at the shoulder), 5.5ft (1.71 m) and 5ft (1.52 m). This was the equivalent to removing one plank from the scale each time. Dogs were directed by their handler throughout the study. Dogs traversed the scale as they would do in normal training or competition and were asked to complete the scale exercise three times per height. Where dogs did not land fully on the pressure sensing equipment, they were requested to repeat the height to achieve three successful landings on the mat. The number of times each dog traversed the scale is included in **Table 1**. The order of the three heights was randomized. No time limit was put on completion of the obstacle; therefore, the owner could take breaks between attempts. If a dog failed to complete a scale, they were given one further attempt at that height, following a second failed attempt, the dog was withdrawn from the study. Dogs were withdrawn from the study at the owner's discretion. Dogs were filmed during

TABLE 1 | Demographics of participating dogs.

Dog	Sex	Breed/type	Age (yr)	Height to withers (cm)	Weight (kg)	Number of scale completions*		
						5ft	5.5ft	6ft
1	M	Working sheep dog	8	59.0	23.7	3	3	3
2	M	Border collie	4	49.5	21.7	3	4	3
3	M	Labrador retriever	5	57.0	27.7	4	3	3
4	F	Labrador retriever	3	51.0	21.0	3	3	4
5	M	Working sheep dog	3	56.5	24.1	7	3	3
6	M	Border collie	7	56.5	23.3	5	3	3
7	M	Working sheep dog	8	53.0	17.8	3	3	3
8	M	German shepherd	6	65.0	40.0	1	0	0
9	F	Labrador retriever	5	55.0	24.6	4	4	4
10	F	Border collie	2	48.3	17.2	3	3	3
11	M	Labrador retriever	5	57.0	31.3	3	3	3
12	M	Labrador retriever	4	57.0	25.8	4	3	3
13	M	Spaniel/Labrador retriever cross	6	47.0	23.2	3	3	3
14	M	Border collie	3	56.0	25.2	4	3	3
15	F	German shepherd	5	No data**	30.2	3	3	3
16	F	Working sheep dog	3	52.0	18.6	3	3	3
17	M	Border collie	2	55.0	21.3	3	6	6
18	F	German shepherd	3	56.5	26.3	3	6	4
19	M	Malinois	No data**	54.0	26.6	3	3	3
20	M	Working sheep dog	7	52.0	21.7	3	3	3
21	M	Working golden retriever	4	57.0	29.8	4	3	3

**Dogs traversed the scale height until they were considered to have landed successfully on the pressure mat three times (visual assessment from the project team). Continued traversing of the scale to achieve three successful landings on the pressure mat was at the discretion of the handler.*
***Where no data was collected, this was due to omission or due to difficulty in measuring height.*

FIGURE 1 | Scale study setup showing positioning of pressure sensing mat on landing side. The participating dog was traversing the scale at 5ft.

the landing phase of their traversing of the scale using high-definition video cameras (JVC-GC PX10 HD, 300 fps) with lateral placement to the scale with a 1 m ground marker for reference (**Figure 1**).

Peak Vertical Landing Force

A Tekscan walkway gait analysis system 3,150 pressure (sensing area of 0.87 × 0.37 m, maximum 100 Hz) (Tekscan) was placed at the landing point (**Figure 1**), covered by a thin rubber mat to standardize the landing surface. This was used to measure peak vertical force (pounds) on landing. Peak vertical force on landing across both front feet was measured using Matscan XL (**Figure 2**). If only one foot landed on the mat this replicate was discarded.

Apparent Joint Angles and Duration of Landing

Apparent carpus and shoulder angles on landing and duration of landing were measured using Kinovea Version 0.9.3. Apparent angles of the carpus and the shoulder of dogs on landing (**Figure 3**) were measured on each video frame (30 fps) during the landing from the time the first front foot touched the floor to the time the first rear foot hit the floor. Measurements were taken using a markerless system [as per (17)]. The frame at which the dog had the minimum carpus angle was taken to be the lowest phase of the landing. Minimum carpus angle, shoulder at the

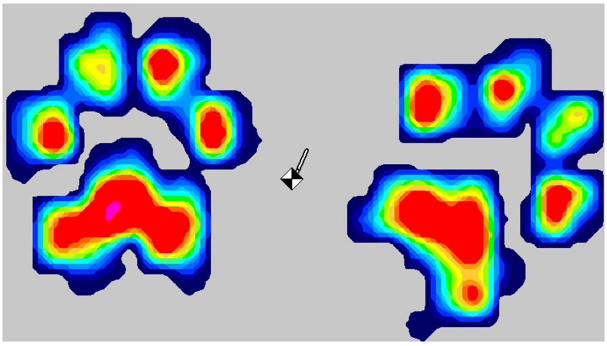

FIGURE 2 | Tekscan "heatmat" visualization of landing force. Colors provide a visual representation of measured forces from low (blue) to high (red). The black and white symbol indicates center of gravity at the point of measurement.

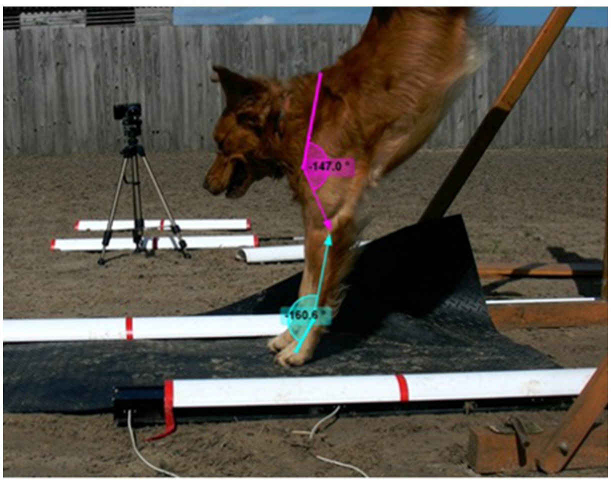

FIGURE 3 | Apparent angles of the carpus and shoulder of dogs on landing, measured using Kinovea Version 0.9.3.

lowest phase of the landing and minimum shoulder angles were used for analysis. Duration of landing was measured in seconds (using video frames).

Data Analysis

General linear mixed models, with Tukey corrected *post-hoc* tests where appropriate, were used to investigate the impact of scale height (5ft, 5.5ft, 6ft) and dog weight (<25 kg, >25 kg), on PVF, minimum carpus and shoulder angles on landing and duration of landing (seconds). Five models were created: PVF (measured in pounds) as a function of body weight (PVF/kg), duration of landing (seconds), carpus angle at lowest phase of the landing (minimum carpus angle), shoulder angle at lowest phase of the landing and minimum shoulder angle. To prevent erroneous identification of PVF, individual jumps were only included in analysis if values were present for both front feet, to enable identification of the maximum PVF across both feet. Peak vertical landing force, landing duration and angles of interest were fitted as response variables. Scale height and dog weight were fitted as fixed effects. To control for replicates, dog was included as a random effect in each model. Data analysis was undertaken in R Studio (Version 4.0.3) (18) using packages "lme4" (19) and "emmeans" (20). Variance in PVF/kg, apparent angles on landing and landing duration between dogs <25 kg and >25 kg at the three scale heights (5ft, 5.5ft, 6ft) was assessed using a Levene's test using package "car" (21). Graphs were produced using package "ggplot2" (22). Model results are reported as model estimate (β_1) ± SE. Significance values were set at $p < 0.05$ for all analysis.

RESULTS

Peak Vertical Landing Force

When the whole study population was considered there was no relationship between PVF (measured in pounds) as a proportion of dogs' bodyweight (PVF/kg) at the three scale heights ($p > 0.05$). When this was investigated in terms of weight categories, there was no significant difference in PVF/kg for dogs <25 kg at any of the scale heights ($p > 0.05$). Dogs >25 kg had significantly lower PVF/kg at 5ft than 6ft (−6.102 ± 1.92, $t = -3.173$, $p = 0.02$) but there was no difference between 5ft and 5.5ft or 5.5ft and 6ft ($p > 0.05$). PVF/kg varied across dogs. There was a trend toward lighter dogs (<25 kg) having a greater PVF/kg than dogs >25 kg (−7.423 ± 4.14, $Z = -1.793$, $p = 0.07$). There was greater variation in PVF/kg in dogs <25 kg ($F = 10.165$, $p < 0.001$) (**Figure 4**).

Duration of Landing

Across all of the study population, duration of landing was longer for dogs at 5ft (mean ± SD, 0.33 ± 0.09 s) than 5.5ft (0.29 ± 0.07 s) (−1.30 ± 0.35, $t = -3.718$, $p < 0.001$) and 6ft (0.29 ± 0.08 s) (−1.43 ± 0.35, $p < 0.001$). There was no significant difference in duration of landing between 5.5ft and 6ft ($p > 0.05$). This was then considered within the two weight categories. Duration of landing was longer for dogs <25 kg at 5ft (0.31 ± 0.09 s) than 5.5ft (0.28 ± 0.08 s) (1.3662 ± 0.466, $t = 2.933$, $p < 0.05$) (**Figure 5**). In dogs >25 kg landing duration was significantly longer at 5ft (0.35 ± 0.09 s) than 6ft (0.30 ± 0.07 s) (−1.6814 ± 0.541, $t = -3.105$, $p < 0.05$). There was no significant difference in variation in duration of landing in dogs <25 kg and >25 kg ($p > 0.05$).

Apparent Angulation of Carpus and Shoulder

The apparent carpus angle on landing was significantly smaller at 6ft than 5ft (5.590 ± 1.80, $t = 3.104$, $p < 0.05$) and mid height (5.5ft) (5.289 ± 1.80, $t = 2.945$, $p < 0.05$) for dogs <25 kg (**Figure 6**). There was no significant difference in apparent carpus angle on landing at any height for dogs >25 kg ($p > 0.05$). Neither minimum apparent shoulder angle nor apparent shoulder angle at the lowest phase of the jump was affected by scale height in either dogs weighing <25 kg or dogs >25 kg ($p > 0.05$). There was no significant difference in variation in apparent joint angles on landing for dogs <25 kg and >25 kg ($p > 0.05$).

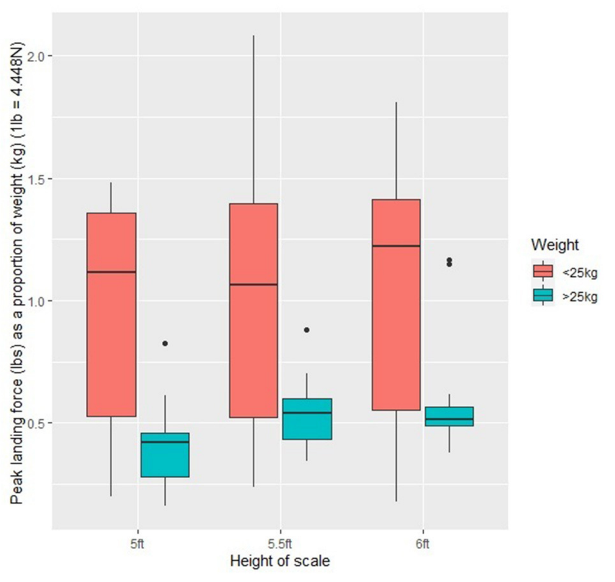

FIGURE 4 | Peak vertical landing force (PVF, measured in pounds) as a proportion of body weight across all the study dogs (n = 20) at the three scale heights (5ft, 5.5ft, and 6ft). (N.B.1lb = 4.448N).

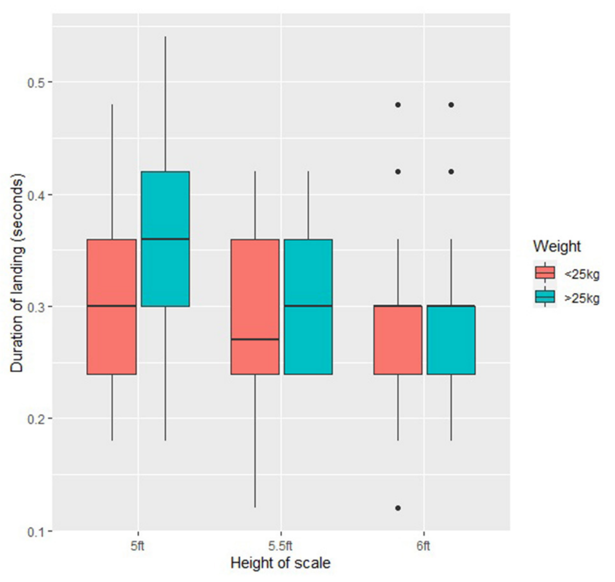

FIGURE 5 | Mean duration of landing (seconds) across all the study dogs (n = 21) at the three scale heights (5ft, 5.5ft, and 6ft).

DISCUSSION

Working trials is a canine discipline that involves participating dogs traversing an upright wooden "scale" as an integral part of the agility test of the activity. Within specific competitive levels the maximum height (6ft) of the working trials scale is based on arbitrary measurements with no scientific research to inform the suitability of the height for participating dogs.

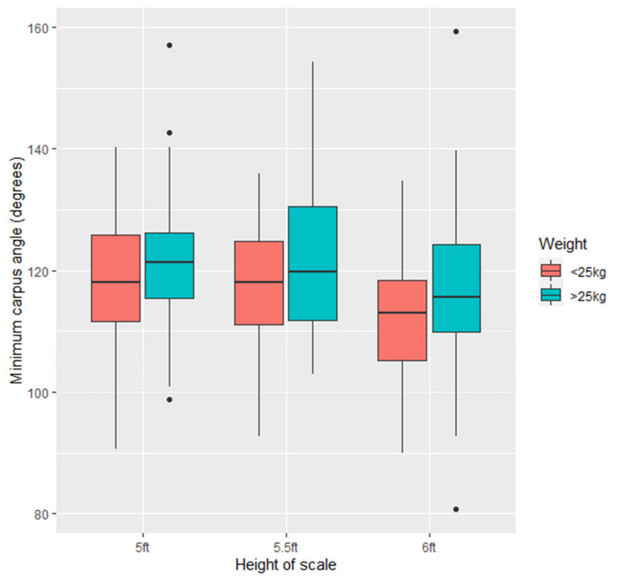

FIGURE 6 | Minimum apparent carpus angle across all the study dogs (n = 21) at the three scale heights (5ft, 5.5ft, and 6ft).

There is a paucity of research on the impact of scale height on landing forces and apparent joint angulation of dogs on landing after traversing the scale. This contrasts with the discipline of dog agility, where research has identified specific kinematic and ground reactive force alterations in participating dogs (8, 9, 14, 23). The height of scale used in working dog trials may thus have ramifications for physical health of dogs participating in this discipline.

The aim of this study was to determine whether an alteration in scale height alters PVF and apparent carpal and shoulder angles on landing. This was assessed in in dogs routinely training and competing in working trials. To determine the impact of dog weight on carpal and shoulder angles on landing, dog weight was investigated in terms of <25 and >25 kg. There was significantly different variation in dogs <25 and >25 kg and data indicates that dogs of different bodyweights were taking different approaches to landing after traversing the scale.

Peak Vertical Landing Force

Cats jumping from a flat surface (16) and dogs jumping from car boots (15) show increased PVF when landing from greater heights. This was partially replicated in this study, with dogs >25 kg showing significantly greater PVF at 6ft than 5ft. However, dogs <25 kg showed no significant changes in PVF at any of the heights. Pfau et al. (14) highlighted very high peak vertical force in the forelimbs of dogs (25 N/kg per foot) when landing from hurdle jumps at speed. This was not observed in the present study, although Pfau and colleagues examined border collie dogs of up to 19 kg, which was the weight category in which we found greatest variation despite less variability in bodyweight (dogs <25 kg 21.5 ± 2.4 kg, dogs >25 kg 29.2 ± 4.3 kg). The greatest PVF recorded was in dogs <25 kg at the highest (6ft; 8 N/kg) and middle (5.5ft; 9.3 N/kg) scale heights. However, considerable variation was observed in the study population. It is also important to highlight that dog agility involves dogs negotiating hurdles at speed and velocity affects limb dynamics in agility dogs (23). Working trials obstacles are traversed with significantly less emphasis on speed. This may permit more dynamic kinematic adaptation by participating dogs, which is supported by the altered apparent landing angles observed in this study.

Apparent Joint Angulation on Landing

In dogs of a lighter bodyweight (<25 kg) there was significantly more apparent compression on the carpal joint at 6ft than 5ft and 5.5ft. However, there was no significant difference in landing force across any of the three investigated heights, which suggests that dogs <25 kg are absorbing the landing force through their carpal joint. It is thus possible that dogs are "shock absorbing" the force of their landing though their joints. Research exploring limb dynamics in beginner vs. advanced agility dogs showed increased limb compression during the stance phase of landing in beginner dogs compared to advanced dogs (23). This suggests that experience and training may influence how dogs traverse and respond to specific equipment. Miro et al. (24) similarly demonstrated that experience affected the kinematics of how agility dogs traversed a hurdle. In the present study, median age of dogs was 4.5 years (range 2–8 years). All dogs and handers were experienced participants; dogs had been training in working trials for a minimum of 12 months. It is likely that the study dogs have developed the ability to dynamically respond to differential scale heights through training and experience. Future research to explore the impact of training and experience on kinematics of dogs in working trials is recommended, to further advance knowledge in this area and support the development of evidence-based guidelines in this discipline.

Research has indicated that both dogs (8, 9, 14) and horses (25) show variation in joint angles upon landing, and similar findings were found in this research. Dogs of >25 kg had a greater landing force at 6ft than 5ft but no significant difference was observed between 5.5 and 6ft. Although not significant, descriptive statistics indicate larger apparent carpal and shoulder angles (indicative of reduced compression on landing) at 5.5ft as compared to both 5ft and 6ft. Observations of study dogs during the trials indicated that they altered their style when traversing the 5ft scale, with some individuals trying to "jump" rather than "scale" the obstacle. It is thus possible that there are benefits to dogs in reducing the scale to 5.5ft; evidenced by reduced compression on landing, but that when the scale is reduced to 5ft these benefits are lost as the obstacle might be tackled in a different manner, thus resulting in potential impacts as highlighted in the canine agility literature. This is also significant from a competitive perspective where a level of challenge is typically required.

The observed alteration in scale traversing style was reflected in the duration of landing. Landing duration was measured from when the first front foot hit the pressure mat until the first back foot hit the mat. Dogs >25 kg showed no variation in landing duration at any of the heights, however in dogs <25 kg landing duration was longer at the 5ft (mean $\pm$ SD seconds, 0.31 $\pm$ 0.09) scale than 5.5ft (0.29 $\pm$ 0.08) or 6ft (0.28 $\pm$ 0.09). Increased duration of landing contact may be due to dogs striding off the scale through a dynamic motion, rather than the more traditional stationary landing when they have "scaled" the obstacle and released themselves from the top. They are thus potentially traversing the lower height scale like a hurdle obstacle, rather than a scale.

Limitations of the Research, Future Directions, and Recommendations for Working Trials

PVF measurements should take into account sampling frequency, which is affected by the sensing equipment used. The use of a force plate would have given a higher sampling frequency (up to 1,000 Hz) and a more accurate response (26), in addition to the capacity to measure mediolateral and craniocaudal forces. However, the field-based nature of the study limited the opportunity to use a force plate rather than a pressure mat to record PVF. This study focused on jumping down from an obstacle, therefore limiting the forward trajectory of the dogs and thus minimizing the impact of this limitation.

Dogs included in the study were representative of the breeds/types typically participating in UK working trials. However, numbers of individuals in terms of breed/type category were limited, which prevented breed/type-level analyses being undertaken. Due to this it was also not possible to differentiate beyond arbitrary weight categories. As significant differences were seen between dogs <25 and >25 kg and considerable variation was seen in dogs <25 kg, we strongly advocate undertaking such work in a wider study population, to determine the impact of greater variation of weight categories, and breed/type-level differences (27). There may be a requirement to consider breed/type and/or weight effect in dogs traversing the scale, to further understand individual participant effects. Indeed, there may already exist a level of "self-selection" in participating dogs, where those with a bodyweight significantly above or below an arbitrary threshold are less successful in competition. Further examination of the physical characteristics of participating dogs could further our understanding of key biological characteristics linked to success, in the same way as has been postulated for horses (25).

Evidence of shoulder injury has been reported in beginner agility dogs (3, 5, 6), however it is known that experience impacts kinematics in these dogs (23, 24). It is thus likely that injury reported in these studies is related to experience of the participants. It was beyond the scope of this study to investigate injuries in the study population, and no dogs involved in this research had any current injuries. However, establishing whether there are consistent joints in which injuries are occurring in the wider working dogs trial population would enable a greater understanding of whether there is any long-term impact on joint health, and how that may relate to participation in working trials. This is thus an area of research which we advocate being undertaken.

We recommend a review of the maximum scale height in working trials based on study findings and monitoring impacts on the wider working trials population, both in competition and in training. Reducing the scale height to 5.5ft is likely to reduce the PVF experienced by dogs with a bodyweight of >25 kg. In dogs with a bodyweight of <25 kg it may reduce the apparent compression of the carpal joint, whilst not leading to alterations in the way that dogs approach and traverse the obstacle. This could be of relevance in training and competitive situations. Competition may wish to retain the "challenge" of a higher scale, while training at a lower height of 5.5ft permits handlers and dogs to gain experience, with dogs experiencing reduced kinematic impact. Further reduction in scale height to 5ft has the potential to alter dog kinematics and thus lose any benefit in terms of reduced landing impact.

We also advocate for investigation of the impact of landing surface. Research has indicated that landing surface can alter landing and braking kinematics in horses (28). Working trial participants experience a range of surfaces both in training and in competition and so dogs may be landing on harder or softer landing surfaces. This could impact on PVF and apparent joint angulation, and thus is something that should be further investigated.

CONCLUSION

Evidence-based approaches to canine working trials are important to ensure minimum impacts on physical health and welfare of participating dogs, in terms of risk of injury in both competition and training. This research indicated that a reduction in the height of the scale in working trials from 6ft to 5.5ft may have positive implications for longitudinal physical health of dogs. Reducing the height of the scale to 5.5ft led to reduced PVF in dogs >25 kg and reduced apparent compression of the carpal joint in dogs <25 kg, without altering the way that dogs tackled the obstacle. We thus recommend reviewing the frequency at which working trials dogs experience the maximum height of the scale in both training and competition, while also maintaining a level of competitive challenge. Further research is needed in this field to determine whether other factors impact on PVF and joint angulation on landing, including age/experience and breed/type of dogs and landing surface.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The animal study was reviewed and approved by Nottingham Trent University, School of Animal, Rural and Environmental Sciences School Ethics Group (reference number ARE192042). Written informed consent was obtained from the owners for the participation of their animals in this study.

AUTHOR CONTRIBUTIONS

AC secured funding to support the research, conceptualized, designed, and managed the project. EW performed statistical analysis. All authors collected data, drafted, revised, read, and approved the submitted version of the manuscript.

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The Case for Animal Privacy in the Design of Technologically Supported Environments

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Privacy is an essential consideration when designing interactive systems for humans. However, at a time when interactive technologies are increasingly targeted at non-human animals and deployed within multispecies contexts, the question arises as to whether we should extend privacy considerations to other animals. To address this question, we revisited early scholarly work on privacy, which examines privacy dynamics in non-human animals (henceforth "animals"). Then, we analysed animal behaviour literature describing privacy-related behaviours in different species. We found that animals use a variety of separation and information management mechanisms, whose function is to secure their own and their assets' safety, as well as negotiate social interactions. In light of our findings, we question tacit assumptions and ordinary practises that involve human technology and that affect animal privacy. Finally, we draw implications for the design of interactive systems informed by animals' privacy requirements and, more broadly, for the development of privacy-aware multispecies interaction design.

Keywords: animal-computer interaction, animal privacy, privacy requirements, privacy aware design, multispecies interaction design

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INTRODUCTION

Within interaction design literature, privacy has been an increasing concern, concomitantly with the increasing capabilities and pervasiveness of computing systems. The discourse on privacy has, so far, almost exclusively focussed on humans, disregarding the implications that interactive technology might have for other animals who might come into direct or indirect contact with it. Some of the authors who have most influenced the discourse on privacy within computing and interaction design had recognised early-on that privacy is not an exclusively human phenomenon and that animals show a need for privacy in various circumstances. In particular, starting from the analysis of territoriality, Westin (1) and other privacy scholars, described basic privacy-claiming and distance-setting mechanisms manifested in both human and non-human animals. Unfortunately, subsequent to this early work, the scholarly discourse on privacy has neglected to examine this fundamental phenomenon beyond the human species, which is reflected in a lack of consideration for the privacy of animals in the design of interactive systems.

With the increasing development and use of technology to manage animals in households, farms, zoos, research facilities and even wild environments, privacy considerations when designing such systems have become ever more important. For example, farmers who monitor their animals electronically face exposure to cyberbreaches and recognise the importance of data protection mechanisms (2). Typically, the motivation for developing cyber security and privacy protection mechanisms in animal contexts is still a need to protect data "owned" by humans, rather than a concern for the privacy of the animals themselves. However, cyberbreaches may indeed have a serious impact on animals' lives. For example, it has recently been brought to the public's attention that data captured from GPS collars fitted on protected wildlife can be intercepted, exposing tagged animals to the attack of cyberpoachers; in response, some have called for the development of security systems that cannot be easily hacked by poachers, so that the life of the animals, rather than the data "owned" by researchers, can be protected (3).

But, in a world where animals are constantly exposed to human technologies, are privacy concerns only limited to data security and bodily safety in the context of illegal practises or do animals have other privacy needs too? What privacy dynamics, if any, do animals manifest that might need to be taken into account when designing interactive systems which may affect them, or which are specifically designed for them? How might animal privacy be considered when designing technologically supported environments? To address these questions, we searched a wide range of literature for sources that might discuss privacy-related behaviour in animals to understand the existing discourse on the topic. We found that related scholarly works are sparse across domains and that the notion of animal privacy is under-defined and under-researched. Hence, Animal-Computer Interaction researchers navigate uncharted waters when undertaking the challenge of designing technologically supported environments that might require consideration for animals' privacy needs.

To better understand animal privacy, we analysed animal behaviour literature that could illuminate what privacy-related processes are manifest among animals. We based our analysis on the definition of privacy mechanisms provided by early literature on privacy and found that animals use a variety of privacy-related mechanisms, whose function is to secure their own and their assets' safety, as well as negotiate complex social interactions. In light of our findings, we questioned tacit assumptions and ordinary practises that involve human technology and that affect animal privacy. We did so by extending the notion of privacy to animals and discuss how animal-centred interactive systems could consider animals' privacy requirements.

BACKGROUND

Animals' Privacy in Interactive Systems: An Emerging Design Requirement

In recent times, the Animal-Computer Interaction (ACI) (4) community has started investigating the privacy concerns of pet guardians when they use wearable devices to monitor their pet activities. In particular, van der Linden et al. (5) investigated the extent to which dog tracker users are aware of, and guard themselves from, potential risks to their own privacy that may come from a data breach in the tracking system. The authors concluded that dog carers are primarily concerned about physical safety consequences (e.g., dogs being stolen, and houses being burgled) since these devices can reveal data about the carer's habits and caregiving practises. In another study, the same authors describe potential personal threats to humans derived from the use of animal GPS collars. For example, these risks might occur if dog walkers were to share their habitual routes online through tracker device applications, or if malicious individuals were to breach pet location data logged into the device in order to commit pet theft (6). The authors refer to the theory of the extended self (7) to explain pet-owner relationship in relation to privacy and claim that strong animal-human bonds result in greater risks of privacy and security breaches enabled by data from animal wearables. The findings of these studies indeed show implications for the design of "privacy-respectful" pet wearables and highlight the need to introduce privacy and security safeguards to prevent data breaches. In this work, animal privacy is investigated as an extension of human privacy, whereby what is at stake is the safety and security of pet guardians' property and relationship with their pets. But is privacy just a human concern or is it important also from animals' perspective?

For example, like other animals, dogs tend to avoid both actual and perceived threats. Given the probability that being separated from their guardian is perceived by many dogs as a threat, would they not want to protect themselves from such potential harm if they were aware that the wearable system attached to their body could be breached with ill intent? Unbeknown to them, technological interventions can expose animals to serious threats which they would arguably want to escape if they were able to perceive the danger they were in.

In response to the proliferation of humans' technologically mediated intrusions upon other animals, Mills (8) questioned the ethical legitimacy of practises such as physically entering animals' territories or placing cameras into their hiding places in order to film them. Mills' argument was grounded in the observation that animals demonstrate a want for physical separation and withdrawal. At the time, Mills' argument found opposition from various quarters, including animal welfare and conservation organisations, who defended the value of using filming technology to increase people's awareness of and empathy for animals. Notwithstanding the educational value of these interventions, one might question the assumption that humans are best placed to make this kind of risk-benefit assessments, instead of (somehow) allowing the main stakeholders to do so. In this regard, Haratym (9) pointed out how Mills' argument was no different from that famously made by Warren and Brandeis (10) with regards to the use of technological devices to record and store detailed information on individuals which can be later disseminated to the public. While she recognised that avoiding any interference with their private sphere may be very difficult, Haratym argued that animals manifest the need for separation from others (i.e., privacy) and calls for the recognition of their "right to be let alone" (9, 10).

Animals' Privacy in the Early Privacy Literature: A More-Than-Human Phenomenon

While the notion of human privacy has significantly developed over time to include many dimensions such as personal, intimate, and social privacy, the phenomenon of animal privacy has received very little attention. The only existing conceptualisations are those of early privacy scholars, who theorise the phenomenon at a more fundamental level, mainly to explain the origin of privacy in humans. In his seminal work on Privacy and Freedom, Westin (1) made direct reference to Ardrey (11)'s writings on territoriality to argue that humans' need for privacy is likely rooted in our animal origins, and that humans and animals share a number of basic privacy-claiming mechanisms. Territoriality would be one such mechanism, whereby an organism "lays private claim to an area of land, water or air and defends it against intrusion by members of its own species," "to ensure propagation of the species by regulating density to available resources" and "to promote individual well-being and small-group intimacy" (1, p. 26). Humans and other mammals would also share distance-setting mechanisms that exploit sensory (olfactory, acoustic, visual, tactile) information to maintain personal, intimate and social boundaries in interpersonal relationships (1, p. 26). Citing Calhoun (12)'s work on rats' behaviour, Westin highlighted how overpopulation without the possibility of maintaining privacy boundaries impairs animals' ability to preserve social organisation, leading to serious disfunctions, such as chronic stress, constant fighting or sexual sadism. On the other hand, when afforded the opportunity to maintain privacy boundaries, social animals still seek the stimulation of encounters among their own species. Thus, privacy boundaries enable animals to maintain functional social interactions while protecting individuals from others' interference when they need to access resources that are necessary for their survival.

Later, Klopfer and Rubenstein (13) articulated the biological basis of privacy in economic terms. The authors distinguished two types of privacy that animals would manifest to varying degrees and at different times depending on their level of sociality: physical separation and information management. While territoriality would afford animals physical separation on a stable basis, various forms of concealment would afford them temporary withdrawal (e.g., when giving birth or hiding from predators). Social animals would also achieve privacy by preventing others from acquiring complete and accurate information about them or their intentions, which could be used to access resources. In this regard, the evolutionary transformation (ritualization) of behaviour patterns into communicative signals whose form is not associated with the animal's motivational states would enable an individual to withhold information, thus attaining a measure of privacy that might give them a competitive advantage (e.g., in order to deter a competitor, an animal might signal that they are about to attack, when in fact they have no intention of doing so). Since maintaining privacy has costs (e.g., having to keep guard, losing social input) as well as benefits, and social interaction has benefits as well as costs, animal populations would seek a cost/benefit equilibrium that is optimal for their fitness. Like Westin, Klopfer and Rubenstein noted how the ability to maintain privacy is essential to animals' fitness, and how privacy violations (e.g., territorial intrusions) or living conditions that prevent animals from maintaining privacy (e.g., in captivity) lead to behavioural and physiological dysfunctions. Additionally, Klopfer and Rubenstein's analysis of privacy as a cross-species phenomenon manifested through species-specific mechanisms parallels Altman's (14) influential work on human privacy, in which he describes the phenomenon as a cultural universal manifesting through culture-specific mechanisms.

Like Altman, Hirshleifer (15) talked about privacy as the means to dynamically achieve autonomy within society but, unlike Altman, Hirshleifer's model accounts for the biological as well as the cultural evolution of privacy. His analysis of the origin and function of privacy classifies the main structures of sociality in all animals based on three principles: dominance, communal sharing and private rights. The dominance principle would prevail where resources are dispersed and threats ubiquitous, and where there are advantages to being dominant (e.g., having privileged access to resources) but also to being subordinate (e.g., receiving protection). The communal sharing principle would prevail where acquiring resources (e.g., food) or safeguarding common goods (e.g., genes) requires cooperation and mutual support. The private rights principle would manifest through territoriality (over e.g., land, food sources, sexual mates), and would prevail where resources are fixed in place and stable, and where social organisation and role diversification can increase fitness and prosperity. For Hirshleifer, each structure has evolved in a particular ecological context where it provided a survival advantage, but all structures would manifest themselves in different circumstances. Critically, Hirshleifer points out how each social structure could only persist if associated with what he terms an ingrained supporting ethics, that is an evolved ethics that most members of society accept and live by out of reciprocity, thus ensuring individuals' compliance (15). With regards to territoriality, the ethics supporting privacy behaviours would manifest in the outsider's reluctance to intrude (other than surreptitiously) and in the defensive belligerence of the proprietor aimed at protecting their assets. In other words, the insistence on one's own rights and the willingness to concede the same right to others would be the two sides of the same "ethic coin" enabling territoriality to function as a social organisation principle.

To summarise, according to these early scholars, the need for privacy is a biological universal, whose purposes include preserving *personal safety*, ensuring *access to resources* and managing *social relations*. The distance-setting mechanisms through which these purposes are achieved include different forms of *physical separation* (e.g., territoriality, physical concealment) and *information management* (e.g., witholding, deception). Furthermore, animals living within a social ecosystem abide by the ethics that legitimise these mechanisms. The aim of our study was to find evidence of privacy behaviour in animals, the purpose that the behaviour might have, the mechanisms by which that purpose might be pursued, and the underpinning ingrained ethics.

THE STUDY: EXPLORING RESEARCH ON ANIMAL PRIVACY

We reviewed a wide range of literature reporting on ethological and behavioural experimental studies that had investigated the behaviour of different animal species. As mentioned above, we sought to identify some of animals' *physical separation* and *information management* mechanisms (13), and understand their function in context in relation to *personal safety*, *access to resources* and *social relations* (1). We were also interested in any expressions of the evolved supporting ethics that might compel individuals to respect others' privacy boundaries, in turn enabling them to enjoy the same benefits (15). Our aim was to search for compelling examples of animals' manifest privacy-related behaviours that could help us frame the issue of animal privacy with a view to informing the design of interactive systems involving more-than-human stakeholders.

Generation and Analysis of the Dataset

We performed our search for literary sources using data drawn from three major scientific knowledge databases containing publication records: Microsoft Academic Graph (MAG), Google Scholar (GS), and Web of Science (WoS). We extracted the data from the datasets using an Elasticsearch (ES) index (16), which firstly organised the metadata of each paper in terms of title, abstract, relevant topics, and other features, and then provided an engine for querying such data. To obtain our first set of potentially relevant papers, we queried the produced ES index looking for papers whose titles, abstracts, and whole texts contained the keywords "animal" and "privacy." We used general searching criteria because we wanted to explore whether in ethology and experimental behavioural literature privacy had ever been investigated as a distinctive animal mechanism. Through this process we obtained 928, 189, and 97 results, respectively from MAG, GS, and WoS. However, after reading titles and abstracts of each obtained result, we found that in most of the sources including the words "privacy" and "animal," these were entirely unrelated to each other (e.g., medical experiments using laboratory animals and discussing the privacy of human patients). Any abstract referring to some kind of animal behaviour led to reading the whole paper in search of connexions with the notion of privacy (which being one of our keywords had to be present somewhere in the paper). Finally, a paper was selected for our dataset if it described an animal behaviour that expressed a *physical separation* or *information management* mechanism of some kind. More specifically, our selection was informed by the following criteria:

MAIN CRITERION - is an individual performing some kind of *distance-setting behaviour*?

SUB-CRITERIA (SC) SC1 - is the behaviour establishing *some form of physical separation/proximity*? i. *what kind* of physical separation/proximity is the behaviour achieving? ii. *via what means* is the separation/proximity achieved? iii. *what function* is the separation/proximity performing?

SC2 - is the behaviour *concealing/disclosing some kind of information*? i. *what kind* of information is the behaviour concealing/disclosing? ii. *via what means* is the concealment/disclosure achieved? iii. *what function* is the concealment/disclosure performing?

These inclusion criteria were based on the definition of privacy mechanisms found in the early literature on privacy, to control against bias in our selection process. This approach was informed by Stern and MacArthur (17)'s guidelines for screening sources against inclusion and exclusion criteria and allowed us to select a first set of papers (n = 5). Then, we searched the citation lists of each paper to find further sources following a snowballing procedure, as described by Wohlin (18).

In total we analysed 22 scientific papers published, between 1966 and 2010, in the following venues: Animal Behaviour (n = 7), Journal of Perinatal Education (n = 1), Behaviour (n = 1), Zoo Biology (n = 1), Journal of Experimental Animal Science (n = 1), Obstetrics and Gynaecology (n = 1), African Journal of Ecology (n = 1), Bioacoustics (n = 1), Ethology, Behavioural Ecology (n = 1), Animal Cognition (n = 1), Journal of Comparative Psychology (n = 1), The American Naturalist (n = 1), Communicative and Integrative Biology (n = 1), Journal of Fish Biology (n = 1), Frontiers in Zoology (n = 1), and Cambridge University Press's Animal Communication Networks article collection (n = 1). We analysed animal behaviours reported by these sources to understand (1) what *physical separation* or *information management* mechanisms they might express in different contexts and (2) for what function (*safety*, *resources*, *relations*).

Although we used general keywords to explore the extent to which privacy is explicitly linked to animals, this approach might have limited species and taxa's representation in the article sample. For example, we did not find papers concerning amphibia and reptiles, or many other social species where we might have expected privacy to play a role. This does not mean that no such papers exist and the fact that we did not find any may well reflect the limitation of our approach. Nevertheless, we thought it important to maintain the systematicity of our surveying approach. Furthermore, the fact that no papers focussing on other taxa and species emerged from our general search is in itself a result, suggesting that the topic of privacy in animals is still unexplored both within animal behaviour research and animal-computer interaction research. Shedding light on this blind spot was a key aim of our paper.

Data Analysis

We analysed the text of the selected papers as follows: on first reading, pertinent excerpts of text reporting relevant animals' abilities and behaviours were extrapolated. Then, each excerpt was re-read for confirmation according to the inclusion criteria expressing *physical separation* mechanismsor *information management* mechanisms. We identified a wide range of privacy-related behaviours across various species and taxa, and then we searched for common themes to analyse their functions. In the next section, we discuss the functions and modalities of the privacy-related behaviours that we identified.

FINDINGS

We found that animals express a wide range of privacy-related behaviours, which constitute different forms of physical separation and information management, to ensure their and their offsprings' safety, protect their assets, gain access to mates, and manage social interactions and relations in different contexts.

Privacy and Physical Distantiation

Animals' need for privacy is evidenced by a range of behaviours that provide safety for vulnerable individuals, protection of resources, access to mates, and that enable individuals to manage their social interactions by including, excluding or deceiving others.

Personal Safety, Social Space and Intimacy

One of the most obvious functions of privacy is to protect oneself from potential predators, which many animals achieve by physically concealing themselves on particular occasions. For example, Lothian (19) argues that various mammal species seek quiet and secluded spots to hide during labour in order to protect themselves when they are most vulnerable and to deliver their offspring away from danger. The author reports on Newton et al.'s (20) conducted on pregnant laboratory mice who were subjected to distressing environmental conditions. Lothian concludes that a "lack of privacy" induced the pregnant females to interrupt early labour to move away from the disturbance (19). In nature, this "self-retreating" behaviour might happen for protection against predators and competitors; the latter might include males who do not belong to a female's social group and who might kill her offspring, so that she will go into oestrous again and they will be able to fecundate her to the advantage of their own genes. For example, in African lions (*Panthera leo*), among whom infanticide occurs, lionesses separate from their group to give birth and nurse their young, and only reunite with the group when the cubs are 4–8 weeks old (21).

In some species, even when the presence of others does not pose an obvious danger to one's safety, individuals who live in close proximity to conspecific occasionally seek periods of seclusion, where interaction with other cohabitants is avoided. In a study involving rhesus monkeys (*Macaca mulatta*) caged in pairs in laboratory settings, individuals spent some time out of their cage-mate's sight, when their enclosure was provided with a separating panel; being able to temporarily seclude themselves in a dyadic social context seemed to help the monkeys get along better with each other (22).

Voluntary separation from one's cohabitants may also be sought to provide the opportunity for exclusive interaction with specific individuals at particular times, as observed in bottlenose dolphins (*Tursiops truncatus*). Mello et al. (23) studied the behaviour of three dams (female dolphins) living in artificial pools, who avoided contact with members of the group before and for some time after giving birth to their calves. In particular, they proactively sought solitude to nurse, suggesting that privacy facilitates the bonding with the calf and the synchronisation of the swimming pattern of mother and calf during nursing (23). As mentioned earlier, in various mammals, giving birth and nursing is done privately in burrows or caves; since dolphins live in open aquatic environments that do not offer dens and do not afford physical seclusion, dams' avoiding contact with others might be a privacy behaviour that has evolved to replace self-concealment strategies during mother-offspring caregiving.

Protecting Assets

Protecting acquired resources is vital for many animals, to which end physical concealment is often used to protect assets that are essential for one's survival. Various mammal and bird species store food in order to have access to a stable supply throughout scarcity seasons. Caching (storing covertly) is a strategy used to protect food from foraging competitors. For example, naturally foraging grey squirrels (*Sciurus carolinensis*) adopt food caching strategies that reduce the risk of giving away their stockpiles' locations to pilferers (sneak thieves). In the presence of potential conspecific pilferers, individuals implement "secretive" tactics, such as orienting themselves away from observers when they dig and spacing caches more widely (24). Another tactic is decreasing caching behaviour when individuals perceive the presence of observers. This happens both with conspecifics (in this case, other squirrels) and with heterospecifics (e.g., blue jays) (25).

Some birds use deceptive tactics to conceal food from competitors. For example, rooks (*Corvus frugilegus*) cache food cautiously hiding the activity when conspecifics are around, such as caching in long grass where their activity is less likely to be observed [personal observation of Emery and Clayton, in: (26)]. However, they do not adopt the same prudence in the presence of other rooks who are also engaged in caching [(27), cited in: (26)], as though they were "confident" that other rooks focused on the same activity would not be interested in pilfering.

There is some evidence that storing tactics develop in specific circumstances following specific events. For example, in a two-experiment laboratory setting, Preston and Jacobs (28) observed wild-caught Merriam's kangaroo rats (*Dipodomys merriami*) overtly storing seeds for later use, in the presence of both conspecifics and heterospecifics (in this case, chisel-toothed kangaroo rats). However, after they experienced pilferage, they changed caching sites choosing more out-of-sight areas, even though these new areas had not been the spots initially preferred (28).

Similarly, western scrub-jays (*Aphelocoma californica*) who suffered pilfering of their caches in the past, unlike naïve individuals, tended to cache in new sites, out-of-view sites or shaded sites when observed by competitors [from Emery and Clayton (29), cited in (26)] or maximise the distance from an observer when this could not be left out of sight [(30), cited in: (26)]. The birds also repeatedly moved specific caches that were hidden while observers were watching, possibly to confuse them, and recached items as soon as they were given a private moment from others (26). However, when scrub-jays do not see competitors around, they show no preference between shady and well-lit sites [(30), cited in: (26)], suggesting that experience might play a role in their performance of privacy behaviours.

Interestingly, scrub-jay mates defend each other's caches from conspecific pilferers, demonstrating a sharing of knowledge about caches between the pair [(31), cited in: (26)]. Similarly, in ravens (*Corvus corax*), who are used to feeding in non-kin groups (congregations) but move away from the food source to cache food when other ravens are feeding on the same source, mating pairs cache together and therefore share the location of caches with their mate (28). Thus, while concealing caches from other ravens is probably a strategy to avoid pilferage, disclosing food location to partners may have various functions such as mate bonding and pair breeding success.

Securing Access to Mates

One important relation many animals have is that which they have with mates; mates also constitute fundamental genetic resources. To gain privileged access to mates and secure reproductive success, some species employ tacticts such as concealment and deception. In laboratory settings, male guppies (*Poecilia reticulata*) and three-spined sticklebacks (*Gasterosteus aculeatus*)-(two species of fish)-move to concealed areas of the tank to court a female, if rivals are around. This is hypothesised to avoid interference from other males and to increase the chances of copulation with the targeted female (32, 33). Experiments specifically showed that when male sticklebacks do not have the possibility of using concealed areas, they tend to court less (i.e., they perform fewer of the zigzag tail movements typical of courtship) and instead direct part of their attention to attacking rivals. It could also be that they avoid engaging in an activity that would reduce their alertness where they might be exposed to predators and fall easy prey (33). On the other hand, when they are given the opportunity of using a concealed area, they spend more time there, if a female is available.

These findings are consistent with those from another study that investigated physical concealment in sticklebacks when they want to intrude one another's mating nest. Intrusion into someone else's territory is potentially hazardous, but it is motivated by the potential advantage of acquiring a mate. In this species, external fertilisation occurs, whereby males prepare a nest where females lay their unfertilized eggs for males to fertilise, following a successful courtship. One reproductive strategy of three-spined sticklebacks males is to breach into the nest of a resident male who is courting a visiting female. To this end, sneakers disguise themselves assuming a drab coloration, which renders them harder to detect in silty water and allows them to move close to the eggs to eventually fertilise them before the nest owner has a chance to do so (34). This deceptive behaviour, used by the perpetrator to mask his intention, might stimulate resident males to want to hide their courtship from other sneakers in order to avoid nest intrusion.

Male guppies use deception to improve their mating chances, by decreasing their courtship of females they had previously targeted, if mating competitors are around and there is no possibility to hide (35). It is hypothesised that in this way they disguise their interest in order to trigger a copy effect, thus causing other males to also lose interest in the targeted female. It is the same for male Atlantic mollies (*Poecilia mexicana*), who overtly direct their mating interest toward a non-preferred female when other males are on sight. This seems to have the function of misleading other males about which female one prefers for mating before proper courting is initiated (36). These behaviours can be interpreted as concealment of real interest and intention (rather than concealment of the courting and mating activity itself), in order to gain privileged access to desired social relations and resources.

Privacy and Vocal Communication

Aside from being expressed through physical distantiation, animals' need for privacy is also evident in and achieved through different vocal communication modalities aimed at safely maintaining relevant social relations remotely or in intimate situations.

Safety and Connectedness in Remote Social Interactions

Lions use vocalisations to negotiate between the need for self-preservation and the need for group living (37); they conceal or disclose their presence and identity depending on their momentary need for safety or for contacting pride members. For example, when they are in their territory, the females and males within a group roar to advertise territorial boundaries, to contact pride-mates who are away from it, and to attract sexual mates. However, when they are outside of their territory and away from their own pride, they remain silent (37); while mothers modulate their roaring depending on whether they are alone or in group to avoid the risk of attracting extra-pride males who might commit infanticide (38). Lone lions who do not have a pride usually make contact calls with other lone individuals, disclosing their presence and identity for the purpose of creating and maintaining (some sort of) association for hunting purposes. However, if they are in the territory of rival individuals who can threaten them, they stay silent keeping secret their presence. Low signalling rates or suppression of calls avoid giving away one's position, identity, and group membership to unwelcome listeners. Individuals may even prefer to remain isolated rather than communicate with potential mates, if there is a risk that they might give away their presence to threatening competitors.

Safety and Connectedness in Intimate Social Interactions

Observations in the wild revealed that female chimpanzees (*Pan troglodytes*) mate overtly or covertly depending on their and their partners' rank. They also disclose or conceal copulating events by modulating pitch and loudness of copulation calls when mating with dominant or low-rank males. This seems to be related to retention of "social status rules," in order to avoid aggressive behaviours from high-ranking individuals (39). Specifically, when low-ranking copulating females are near high-ranking females, they produce fewer copulating calls, especially if copulation is with high-ranking males. This is probably to diminish the risk of aggression from high-ranking females, which has both social and safety purposes. Disguising communication during mating activities have been observed in fish, mammals, and bird taxa as well. For example, during the breeding season, male blackbirds (*Turdus merula*) sing quiet twitters directed at specific females, while female blackbirds emit quiet copulation trills to prevent detection from neighbouring conspecifics. These so called "quiet songs" have high frequency features that restrict the distance of transmission and can be directed toward particular individuals, so they are emitted by birds during close range and direct interactions. The phenomenon of quiet songs in songbirds is poorly explored (40) but these are good candidates for private signals. They are performed during sensitive activities in the breeding season and individuals use them to control who has access to the "arousal" information that foreruns copulation. Hence, they reveal an individual's intention to breed with the targeted mate, but conceal it from neighbours who might disrupt a pair's mating activities.

Selective Communication

Studies show that odontocetes (i.e., marine mammals like dolphins and whales) may be able to privately address information to specific individuals, potentially strengthening group bonding. In particular, dolphins' clicks (a type of call) and killer whales' high frequency calls are highly directional signals that can be potentially addressed at individuals ahead of the caller. These restricted range transmissions allow the signallers to share information such as their identity, location and direction of movement with specific receivers (41) while withholding it from a generic audience (42).

African elephants (*Loxodonta africana*) provide another example of private communication within a group to maintain social relations. These animals are able to discriminate familiar and unfamiliar calls, the former being used for maintaining contact and coordinating with members of a same group across long distances. For example, there is evidence that calls from family members are significantly responded to and followed by approaches to the area from which the call had originated (43). The author demonstrated that vocalisation brings information about presence and identity of callers and that this is shared for bonding and reunification purposes. However, although familiar calls are addressed at one's group members, the loud nature of long-distance vocalisations and the propagation medium makes this type of communication prone to interception by listeners and does not allow the caller to stop unwanted listeners from eavesdropping (43). Although from our analysis we did not find studies on "secretive" communication in elephants, this cannot be excluded if we consider what happens in other species. For example, various seal species (i.e., *Leptonychotes weddelli*) use colony-specific calls and dialects to recognise their members and possibly deliver private messages to specific groups or individuals among colony members (42). However, as with elephants, these loud calls are audible from a great distance and every individual who knows "the code" could be a receiver able to interpret the message.

DISCUSSION

Animal Privacy as Social Organistion Principle

As theorised by early privacy scholars, our peruse of literary sources shows that, far from being a uniquely human phenomenon, privacy is indeed a concern of other animals too. Whether privacy-related behaviours are conscious or unconscious, learnt by individuals or genetically inherited, they evidence the value that privacy boundaries have for animals. Indeed, at least with regards to the species discussed in the literature, animals go to significant lengths to implement a range of distance-setting mechanisms to modulate the boundaries of their interaction with others, to include or exclude different individuals at different times (as proposed by Westin), either through physical separation or through information management (as specified by Klopfer and Rubenstein).

Physical separation mechanisms, such as self-retreating behaviour, may have the function of protecting one's own safety and the safety of close relations (e.g., possibly, those who carry one's own genes) at moments of particular vulnerability, as in the case of mice or lionesses who sought separation from their social group to give birth and nurse their newborn; or in the case of sticklebacks who prefer to court in secluded areas to avoid exposing themselves to potential predators when their attention is focussed on courting procedures. But, separation *from* others does not simply exclude intruders when their presence might be dangerous or not relevant, it also creates the opportunity to develop intimate relations by allowing exclusive interaction with those one separates *with*, as in the case of the dams who separated from their group to bond with their calf and of courting stickleback pairs. Furthermore, separation may provide temporary relief from the social pressure of having to live in close proximity with someone, as was the case with the rhesus monkey pair living in a lab.

Physical separation may concern the protection of resources as well as the protection of individuals' safety, as was the case with grey squirrels, kangoroo rats, rooks and scrub-jays, who used various distancing tactics to prevent pilfering of their food caches. This included orienting themselves away from observers when caching (squirrels) or caching out of sight (kangaroo rats); it also included the use of deception, such as hiding the very activity of caching (rooks) and re-caching when not seen (scrub-jays), often as a result of having experienced pilfering (kangaroo rats, scrub-jays).

Of course, physically hiding food or the activity of caching food is also an *information management mechanism*; not only is hiding a caching activity a way of preventing others from acquiring information about it, but re-caching food is also a way of providing false information to derail a potential competitor. This kind of information management is particularly evident in the deception tactics used by some animals to attain reproductive success, as in the case of sticklebacks who camouflage to render themselves invisible to rivals and sneak into their nests to surrepotitiusly fertilise females' eggs; or as in the case of guppies who seemingly hide their intention to pursue a female in order not to stimulate rivals' own interest in the same female. Where information management mechanisms are particularly evident is in the case of vocal communication. Related literature provides examples of animals using overt vocalisations to signal their presence to others when it is safe to do so, as with lions when they are in their territory, while refraining from vocalising when it is not safe, as lions do when they traverse others' territories or when stronger rivals might be in the vicinity. Information management also takes place during mating, as with female chimpanzees who modulate their mating calls depending on the rank of the males they are mating with and the rank of females in the vicinity to avoid repercussions for their social transgressions; and as with blackbirds who exchange quiet songs to establish an exclusive and intimate communication channel with their mate. Additionally, the use of directional calls by orcas and of colony-specific dialects by seals is a way of selectively managing the information these animals share with others.

Furthermore, literature provides examples of what Hirshleifer calls ingrained supporting ethics related to different social regimes and corresponding privacy behaviour. For example, the case of subordinated female chimpanzees who subdue their copulation calls when they mate with higher ranking males in the vicinity of higher ranking females shows awareness of a *dominant-subordination ethics* whereby an individual acknowledges that dominant members of the group have priority over certain privileges and that any insubordination must be discreet if they are not to lose their standing in (and protection from) the group. Similarly, the ravens' caching behaviour exemplifies a *resource acquisition-sharing ethics* whereby animals aim to acquire and protect resources for themselves but are willing to share them where the sharing supports a common good, such as reproduction. This also might suggest that ingrained supporting ethics underpin at least some altruistic behaviours, ensuring reciprocal privacy and related benefits. Finally, the behaviour of dolphins and lions exemplifies compliance with or awareness of a *territorial ethics*; in particular, the dolphins who live within the close confines of a tank respect the spatial boundary that dams set by distancing themselves from the rest of the group to bond with their newborn; and lions refrain from vocalising when they know that they are crossing other lions' territories to avoid advertising their presence. In all these cases, animals show awareness of the ethics that underpin the social regimes of which they are part and either comply (raven pairs, dolphins) or, if they transgress, they do so surreptitiously (chimpanzees, lions).

Table 1 summarises the distance-setting mechanisms, as well as their manifestations and purposes, that we found in the literature.

In short, it seems evident that privacy, in the forms and via the mechanisms discussed above, underpin animals' social organisation and fundamental biological functions. We propose that this has important implications for human-animal co-habitation generally and for the design of technologically supported environments more specifically.

Animal Privacy as a Design Principle

Loss or reduction of natural habitats and territories is a recurring issue in human-made environments, which links the problems of privacy boundaries and human-animal co-habitation together. Since hunter-gatherers abandoned their nomadic lifestyle to cultivate the land around 10,000 BC, humans have increasingly converted natural environments into anthropogenic habitats (45), settling and expanding to accommodate the needs of an increasing human population. However, settlements take over land already inhabited by wildlife who shelter, forage, and reproduce in dens, vegetation, and waterways. When roads and edifices are built, animals are either killed or displaced (a practise commonly described as "expropriation" or "occupation" when inflicted upon humans). With the exception of endangered and law-protected wildlife, there is little attention to the destiny of displaced individuals, who end up living in smaller and fragmented intra-urban natural habitats or attempt to repopulate their former spaces now occupied by humans (46). However, many urban environments do not provide the spaces and resources many animals need to live in an ecologically equilibrate way, including the ability to implement and observe appropriate distance-setting mechanisms, particularly to regulate interspecies interactions. To survive, they end up crossing human boundaries (e.g., foraging refuses, nesting in buildings, trespassing properties), being consequently labelled as pests and disease vectors, messy scavengers, aggressive intruders, or a nuisance, and almost invariably removed (46, 47).

While displacing and marginalising wild animals, humans have also confined domesticated animals in segregated man-made environments, such as zoos, research laboratories or factory farms, where individuals are often severely constrained and have little control over their surroundings, and where they are unable to exercise agency to access resources and regulate social interactions (48), including implementing appropriate distance-setting mechanisms. As Calhoun's abovementioned experiments with rats demonstrated (12), when animals cannot maintain privacy boundaries as they want, their social organisation may become dysfunctional and their behaviours may become aberrant. More generally, it has been shown that, even when their physical needs are met, when animals are placed *in situations* that do not allow them to attain what they want (49, 50), their welfare can be severely compromised; this can lead to a deterioration of physical health, frequently resulting in the emergence of pathogens, and the spread of zoonotic bacterial and viral infections among animals and, indeed, humans.

In response to the segregation of animals, whether through displacement or confinement, some have called for multispecies integration. For example, instead of fighting back urban fauna, biologists Beatley and Bekoff (47) propose adjusting city planning policies and practises to integrate animal biodiversity into urban development and facilitate multispecies coexistence. This would include interventions such as planting and protecting autochthon vegetation, and creating animal-friendly passageways that allow animals to move around without encountering humans. At the same time, the authors propose increasing the visibility of and celebrating animals' presence in urban environments to increase the fascination and enjoyment that can derive from human-animal encounters (47). Consistent with this view, the work of urban architects, such as Metcalfe (51), has shown how it is possible to design environments that meet the needs of animal and human dwellers, thus facilitating multispecies coexistence. Designers of agricultural production systems, such as van Weeghel et al. (48), have also been advocating and experimenting with architectural and technological solutions that enable animals to take control over aspects of their living environment and production practises. Such measures allow animals to exercise agency and, at least a measure of, autonomy as active participants in production processes, aiming to improve their welfare.

These important initiatives aim to create more hospitable environments for animals, in which multiple species can coexist,

TABLE 1 | Species showing privacy-related behaviours.

	Species	Paper
Physical separation mechanisms		
Hiding during labour to protect themselves and offspring from potential danger	Various mammals, E.g.: Mice African lions	Lothian (19) Newton et al. (20) Rudnai (21)
Avoiding contacts with group members to nurse	Bottlenose dolphins	Mello et al. (23)
Spending time away from mates' sight	Rhesus monkeys	Reinhardt and Reinhardt (22)
Orienting themselves away from observers to cache food	Squirrels	Leaver et al. (24)
Caching in out-of-sight sites from observers or after experiencing pilferage	Kangaroo rats Western scrub-jays	Preston and Jacobs (28) Dally et al. (26)
Hiding caching activities from observers	Rooks Ravens	Dally et al. (26) Heinrich and Pepper (32)
Courting females in concealed areas	Guppies Sticklebacks	Hibler and Houde (44) Dzieweczynski and Rowland (44)
Information management mechanisms		
Comouflage to sneak into others' nest surrepotitiusly	Three-spined sticklebacks	Vlieger and Candolin (34)
Disguise interest to deceive competitors in mating	Guppies Atlantic mollies	Makowicz et al. (35) Ziege et al. (36)
Suppressing calls to hide presence, position and identity	African lions	Grinnell and McComb (37)
Mating overtly or covertly depending on partners' rank	Chimpanzees	Townsend and Zuberbuhler (39)
Directing 'quiet' calls and trills to potential mates	Blackbirds	Dabelsteen et al. (40)
Advertising territorial boundaries	African lions	Grinnell and McComb (37)
Sharing caching locations with mating partners	Ravens	Heinrich and Pepper (44)
Selective transmission of vocal information	Dolphins, killer whales	Janik and Slater (41) Janik (42)
Group-specific calls and dialects for private communications	African elephants Weddell seals	McComb et al. (43) Janik (42)

and to support animals' agency, including their ability to manage their interactions with others. We suggest that animal privacy considerations should be part of these proposals, because privacy is essential for harmonious cohabitation and good individual and collective welfare. Furthermore, because animals' behaviour shows that their privacy matters to them, humans have an ethical responsibility to consider animals' privacy requirements when developing technological interventions that can impact on animals' ability to manage their privacy boundaries, thus jeopardising the effectiveness of their distance-setting mechanisms and preventing said mechanisms from fulfilling their biological function. While some of this responsibility might be fulfilled by enforcing existing animal protection laws or developing new such laws, laws are an expression of societal ethical values; thus, before the importance of animal privacy can be properly reflected into the law, it needs to be acknowledged as a societal ethical value. Consistent with this, we call for a fundamental consideration of animal privacy in the design of technological interventions and the ethical values they reflect. We suggest that an investigation of animals' species-specific distance-setting (including physical separation and information management) mechanisms should inform the requirements specification for the design and development of any technologically supported or enhanced environment in which animals are expected to dwel.

The Potential of Interactive Technology

Interactive technologies have a role to play in the realisation of interventions that could foster harmonious multispecies cohabitation, as well as individual and collective welfare. Thanks to their ability to respond to the actions of individuals and groups, to dynamically modify spaces, and to influence behaviour, interactive technology-integrating sensing and actuating mechanisms-arguably makes it at least plausible to create smart systems and environments that could account for animals' privacy requirements, balancing the needs of different stakeholders.

Interactive maps and augmented reality applications could be designed to educate the public about the privacy needs of animals living in cities or in particular areas of the countryside, and about the importance of respecting their privacy for welfare and conservation purposes. Human users could be encouraged to refrain from engaging in potentially intrusive or disruptive behaviours when resident animals are engaging in activities that require privacy. This might include, during mating or nursing periods, staying away from certain areas to allow animals physical space or keeping noise to a minimum to allow for the transmission of intimate communication signals. Such systems could also provide information to help users learn about the role of the species within the ecosystem, hopefully inspiring empathy and respect for non-human cohabitants.

Interactive technology could also be designed to enable animals to set privacy boundaries when they live within the constraints of captive environments. For example, in farms, kennels, zoos, and laboratory facilities, ambient sensors and intelligence might be used to recognise stress related to lack of privacy, similarly to the way in which ambient systems can now detect indicators of disease well ahead of an outbreak, based on collective behavioural patterns (52, 53). One could envisage a system of telescopic retractable partitions or roosts that was automatically activated when privacy-related stress was detected. These barriers and perches could dynamically change the configuration of a space to give resident animals temporary access to more private sections and levels, to provide secluded areas for individuals or small groups at particular times (e.g., during sleeping hours) while allowing free-flow circulation at other times.

Naturally, all such systems would need to be designed to protect the security of the data that they generate to help prevent ill-intentioned behaviours. For example, whenever individual animals were tracked and their activities recorded using wearable or ambient devices, data security would be essential to stop, for example, as poachers from accessing information that might facilitate their illegal practises. At the same time, mobile apps designed for legal practises that aim to raise awareness about animals' activities and their privacy needs could employ mechanisms, such as information "blurring," to ensure that the animals' location or other sensitive information was not disclosed and, thus, prevent misuses of such systems, which might range from intentionally disturbing animals for curiosity to illegally culling them for personal interest. However, even perfectly legal and well-intentioned uses of such systems could have unexpected impacts that might actually exacerbate the already imbalanced relationship between humans and animals. For example, based on a system's suggestion, well-intentioned citizens might avoid frequenting a certain recreational area so as not to encroach on the resident animals during the breeding period, migrating to an alternative area instead; however, the increased influx to this other area might encroach on the resident humans, who might become hostile to the animals they see as the source cause of the inconvenience.

In this regard, van der Linden (54) argues for the importance of taking a holistic and systemic approach to the design of Interspecies Information Systems, analysing the possible interplay among humans, animals and technology in their sociotechnical context and how this may influence human behaviour toward animals. The author identifies key challenges for designers to consider-including how to understand the potential of animal data, how to effectively transform data into interspecies interventions, and how to assess the short and long term impacts of such interventions-stressing the importance of interdisciplinary collaboration to properly understand the requirements that interspecies information systems might need to meet, before they are deployed.

The Paradox of Using Technology to Protect Animals' Privacy

We have seen how many species value their privacy, go to great lengths to manage their own privacy boundaries, and operate within ethics that recognise the privacy boundaries of others. On such grounds, we have argued that animal privacy should be an essential consideration when designing technological interventions and, further, that technologies could be developed specifically to protect animals' privacy or enable them to manage their privacy boundaries. However, it seems almost inevitable that such interventions would themselves intrude animals' privacy in order to provide the envisaged benefit of protecting it; this seems paradoxical, particularly if we assume that animals are unable to provide informed consent. Would it not be better to just leave animals alone instead of monitoring their activities, modifying their environment and gathering what could be regarded as their personal data? On the other hand, given humans' expansion proclivities, if we refrained from intruding animals' space with technological interventions and left them alone, would we not just continue to breach their privacy boundaries, whether intentionally or unintentionally? These are difficult but important questions, the answer to which is likely to depend on the particular context in which humans and animals live and operate. For instance, a fair use of monitoring technologies might help us to understand, recognise, and thus protect animals' privacy needs. But what constitutes "fair" use of such technologies is likely to depend, for example: on the kind of monitoring intervention envisaged in a particular setting; the potential impact or risk the monitoring activity might have for the animals involved; the vulnerability or endangered status of the species, group or individuals concerned; the availability of essential resources relative to human and animal population density, and the likelihood of interspecies frictions due to resource shortages. Arguably, animal stakeholders' perspective on what is "fair technology use" ought to be part of the equation.

In this regard, Mancini highlights the importance of garnering animals' consent when conducting research with them, on both ethical and scientific grounds (55). The author distinguishes between two forms of consent, highlighting the parallel with the forms of consent required when conducting research with children. *Mediated consent* would need to be provided by the humans who are legally responsible for the animals, know them well and have their best interest at heart, on the grounds that they are in a position to assess the wider welfare implications of the animals' involvement. However, animal participants themselves would need to provide *contingent consent*, as expressed by their willingness to engage with research set-ups and procedures, on the grounds that the animals are best placed to assess the immediate contingencies that make their involvement desirable for them. For the author, both forms of consent are necessary, because they reflect complementary capacities and equally important perspectives. Similarly, when determining what constitutes fair use of technology, the perspective mediated by humans on behalf of animals and the perspective of the animals themselves are equally important. In other words, humans might be able to determine that a temporary intrusion is in the long-term interest of the animals in question, but the animals themselves might be best placed to assess whether the intrusion is desirable given specific contingencies (this is especially important where technological interventions might impact, in the short or long term, animals' ability to fulfil fundamental needs-e.g., protecting their or their offsprings' safety, accessing vital resources-as opposed to expressing preferences that are not of vital importance). Particularly where the expected benefit of a technological intervention is the protection of their privacy and the enablement of their privacy management strategies, control over such interventions ought to be shared with animal stakeholders. In other words, animal stakeholders should be able to influence the behaviour of the technology and of its human users, such that systems' impact was *bi-directional*-to use a term proposed by van der Linden (54).

Thus, as far as possible, technological interventions could be designed to enable animals to asses said contingencies and to allow them to dissent, such that their dissent impacts the behaviour of the technology and of its human users. For example, mobile monitoring systems (e.g., robots, drones) might be designed to recognise the signs of animals' unease to their proximity and automatically retreat out of the way. What animals' dissent to physical intrusion might imply for the design of digitally intrusive interventions (e.g., hidden cameras and sensors collecting privacy-sensitive data) and how animals' privacy preferences might be enabled to influence such digital intrusions is to be explored, but the difficulty of imagining possible solutions should not prevent designers from asking this kind of question. Whatever the answers in specific circumstances, we suggest that it is important to ask these questions. Indeed, when Mills (8) questioned the ethics of filming animals in their private moments he was not arguing for a ban on such filming practises; rather, he was bringing to our attention the importance of not taking for granted the legitimacy of trespassing animals' boundaries. Behind the "right to be let alone," advocated by Warren and Brandeis (10) and invoked by Aratym (9), is a fundamental universal need, and we propose that this universal need to be let alone should be part of the equation when designing any technological system that has the potential to affect animals.

CONCLUSIONS

More than ever before, human activity is having a massive impact on other animals, destroying natural ecosystems and the species who inhabit them, while expanding artificial ecosystems in which billion of animals languish. Among the most fundamental animal needs that human practises are disregarding is privacy, all too often regarded as irrelevant when it comes to other-than-human species. In this paper, we have questioned this assumption. To this end, we have reviewed some of the ethological and behavioural experimental literature demonstrating that, to varying extents, animals manifest a broad range of behaviours to manage privacy boundaries, disclosing or concealing information (e.g., their presence, the presence of a resource, their intentions, their interests), through different mechanisms (e.g., physical separation or proximity, hiding from or sharing with, deception and disguise or openness) and channels (e.g., "confiding" vs "advertising)" in order to fulfil personal safety, sociality and intimacy, protecting assets, securing access to mates functions. In other words, privacy matters to animals and being able to manage their privacy boundaries is important for their survival. We therefore argue for the importance of accounting for animals' privacy requirements when designing interactive systems and technological interventions for, or that may affect, animals. In this regard, we discussed animal privacy as a design principle and explored the potential of privacy-aware systems to foster harmonious multispecies co-habitation and better animal welfare. By way of example, we have envisioned possible privacy-aware applications relevant to free-ranging and confined animals. More generally, we propose the notion of privacy-aware multispecies interaction design, and encourage interaction designers to apply their knowledge and skills to ensure that their work contributes to the development of a culture in which everyone's need to be let alone is respected for the benefit of all.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

PP and CM contributed to the ideation and discussion of the argument proposed by the article, to the review of related literature and to the writing of its presentation, including the drafting of different sections and revisions of the overall draft. BN contributed to the ideation and discussion of the argument proposed by the article and to revisions of the overall draft. All authors contributed to the article and approved the submitted version.

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An Ethics Toolkit to Support Animal-Centered Research and Design

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Designers and researchers who work with animals need to employ an array of ethical competencies to guarantee the welfare of animals taking part in animal-centered research. The emerging field of Animal-Computer Interaction (ACI), which deals with the design of animal-centered interactive systems, considers ethics a fundamental concern when working with animals, and ACI researchers have proposed ethics frameworks in response to these concerns. Ethical approaches proposed within the field tend to be normative but, on their own, norms may not be sufficient to support designers who will inevitably face unexpected and ethically charged situations as the research progresses. During a research project, focused on the design of dog-friendly controls for Mobility Assistance Dogs (MADs), these limitations came to the fore. Drawing from situated ethics approaches, developed to support researchers' ethical engagement with vulnerable populations such as children and differently abled adults, this paper presents an ethics toolkit that aims to support animal-centered research and design by enabling researchers to make ethically sound situated decisions as their work progresses. The toolkit comprises three templates, each of which asks a series of questions aiming to articulate the ethical baselines of individual team members and of their research project, and to inform the development of a series of ethical guiding statements to better prepare designers to make ethical situated decisions. The application of the toolkit during the research with MADs helped the field researcher to clearly and systematically articulate the project's ethos and understand the ethical stance that guided the research team's interactions with the dogs, their trainers, and their human partners throughout the project. It also fostered a practice of active reflection within the team, which helped them to maintain their commitment to the project's ethos in the face of unexpected ethical challenges. We propose that, beyond supporting ACI research, the toolkit could support the ethical engagement of researchers and practitioners who work for and with animals in many other settings.

Keywords: ethics toolkit, animal ethics and welfare, animal-computer interaction, animal-centered design, animal research, research practice

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INTRODUCTION

Ethics is a fundamental concern for disciplines that work with animals, particularly when the aim is to study and design animal-centered interactive systems. Extending the scope of the human-centered disciplines of Human-Computer Interaction (1) and Interaction Design (2), Animal-Computer Interaction (ACI) (3) investigates how animals interact with technology and how animal-centered interactions can be designed. This is arguably more important now than ever before, given animals' increasing exposure to technology.

Most ethical approaches proposed within the field of ACI have been normative in nature, providing researchers with principles to orient their understanding of what might constitute ethical engagement when conducting animal-centered research. However, as discussed below (see Section 5) these approaches are limited in the support they can provide for researchers who, when working with animals, will inevitably face ethically charged and unexpected situations requiring them to deal with the details of the research context and make moment-by-moment decisions influenced by their own ethical position toward the animals they work with.

These limitations came to the fore during a research project, which aimed to investigate the process of designing a technological device for Mobility Assistance Dogs (MADs). In order to assist their human partners, MADs are required to interact with a wide variety of products and interfaces in diverse environments which are human-centric in nature and which fail to meet their user needs (4). Specifically, the research focused on the design of wireless dog-friendly controls that would enable MADs to better assist their human partners while enhancing their own welfare. Designing the dog-friendly controls involved a series of empirical studies (discussed below), during which we worked directly with MADs, their trainers, and human partners, and which raised a series of ethical questions that existing ACI ethics proposals did not address.

These challenges led to the exploration of other ethical frameworks from the discipline of Interaction Design, specifically the field of Participatory Design (5) and the applied ethical approach known as Situated Ethics, which is concerned with how the individual deals with and resolves specific situations – rather than the application of general rules (6). Because animal users are subject to our interpretation of their needs, ethical approaches that stem from an individual frame are of particular relevance for understanding the ethical implications of designing for them. Informed by situated ethical approaches, we developed an ethics toolkit for animal-centered design and research. This comprises three templates that, through a series of questions, assist the researcher in clearly and systematically defining the moral commitments and attitudes that underpin the research. Template A prompts the researcher to articulate their, and the research's ethical baselines as they relate to animals; Template B prompts the researcher to investigate and reflect on how their ethical baselines influence their ethical judgments during animal-centered research; and Template C prompts the researcher to articulate a series of guiding statements to better prepare them to make ethically sound situated decisions during the research. The application of the toolkit during the abovementioned research project with MADs helped the field researcher make ethically sound situated decisions during the research and design of the dog-friendly controls, supporting her interactions with MADs, their trainers, and human partners. It also supported a practice of active reflection in the research team, which proved to be extremely valuable when dealing with unforeseen situations as the research progressed.

This paper discusses the issues that led to the design of the toolkit, the ethics approaches on which it is grounded and how these helped address ethically charged situations during the research. The paper then describes in detail the toolkit components and how to use them, providing an example. It concludes by proposing that the toolkit would provide a valuable resource to support researchers' ethical engagement in any field of research and practice that involves animals.

THE CHALLENGE OF DESIGNING INTERACTIVE SYSTEMS FOR ANIMALS

While animals have been exposed to interactive technology for decades, for example in precision farming, in conservation efforts or in research settings, a more recent interest on the interactions between animals and technology has led to the development of Animal-Computer Interaction (ACI) (7). As a field, ACI aims at: i. studying and theorizing the interaction between animals and technology in naturalistic settings; ii. developing user-centered technology to improve animal welfare, support animals in their activities and foster interspecies relationships; and iii. informing the development of user-centered approaches to the design of technology intended for animals, enabling them to participate in the design process as legitimate stakeholders and contributors.

To meet these aims, ACI takes a perspective closely aligned with the perspective taken by disciplines such as Human Computer Interaction (1) and Interaction Design (2) which focus on the study, design and evaluation of human-centered interactive systems, with insights from psychology, ergonomics, engineering, informatics, social sciences, product, and service design. This implies a recognition that, to best support people's successful interaction with a system, designers must consider the characteristics and capabilities of those the system is intended for, as well as their activities and the environments in which these activities take place. To this end, during the design process, requirements for a system's usability (i.e., the extent to which the system is easy to use for its intended user) and user experience (i.e., the kind of experience the interaction with the system provides) are elicited from prospective users and other stakeholders to inform alternative designs, which are prototyped and evaluated, in an iterative process of incremental improvement. This process is challenging enough when the stakeholders in question are humans but, when it comes to designing animal-centered interactive systems, the challenges designers face are even greater. These include the potential inability of technology developed by human designers to truly represent the animals' interests; the difficulty of designing from the animal perspective when the barriers represented by interspecies differences, specifically regarding communication, are so significant; the potential for the animal users' interests to be not aligned or even in competition with those of the designers; and the difficulty of interpreting animals' interests without bias (8). Designing for animals requires the development of methods which are *"sufficiently robust but also versatile enough to help deal with the challenges, pitfalls and tensions"* (7) inherent in multispecies interaction design and which can *"reduce the arbitrariness of or biases in choices made during the design process"* (7). In this sense, designing for animals requires a strong ethical commitment toward animal stakeholders, as designers engage *with* them to develop design solutions *for* them; such commitment requires the support of conceptual frameworks and practical tools that can guide designers activities during the process.

CURRENT WORK ON ETHICS WITHIN ANIMAL-COMPUTER INTERACTION

Ethics considerations when addressing the challenges involved in designing interactive technology *for* and *with* animals have been an integral part of ACI's concerns from early on, with Mancini (3), first proposing that the discipline's ethical foundation should be based on a non-speciesist relationship between human researchers and animal participants, on the grounds that this would yield more effective interactive systems (3). The author outlined a set of general ethical principles including: preventing any type of discrimination among participants and researchers during the research and design process; protecting all participants from psychological or physiological harm; treating both humans and animals equally during the entirety of the research and design process; considering whether the work being carried out is beneficial and relevant for all participants; affording all participants the ability to withdraw from the research; and enabling informed consent for animal participants. A more detailed set of ethical guidelines was then put forth by Väätäjä and Pesonen (9), which were grounded in the framework of the 3Rs, the most widely recognized standard for humane research. The guidelines highlighted the need to conduct a cost-benefit analysis and to carefully consider animal welfare principles in each phase of any proposed ACI research (9). For example, aspects to consider prior to beginning research, included the justification and prospective benefits of the research, the choice of animal participant, the research procedures and devices, and the training of required personnel. Things to consider during the research included the researcher's responsibility toward the animal, the professional handling and housing of the animal, the approval for the animals' participation, and the monitoring of the animals' well-being. Hirskyj-Douglas and Read (10) also contributed guidelines specifically related to interaction design research conducted with dogs. In addition to ensuring that during research procedures the welfare needs of canine participants were met, the guidelines recommended giving them complete autonomy and even " *avoiding the training of canine participants in the use of technological systems*", to maintain the research's focus of the dog's *true needs* and to avoid the risk of imposing human requirements on them (10).

Such risk was discussed by Grillaert and Camenzind (11), who highlighted the potential ethical conflicts resulting from the practical application of ACI research, considering the complexity of determining harms and benefits to animal participants vis-à-vis ACI's non-speciesist and welfare-enhancement ambitions. As a way forward, they proposed the use of critical anthropomorphism (11) inviting ACI researchers to use their experience and understanding of the potential harms inherent to humans with technology as a guide to consider ways in which technological interactions might also be harmful to animals. They suggested that an interdisciplinary approach, grounded in animal welfare science, would help ACI researchers to develop ethical frameworks to support the long-term welfare of the animal participant. In this regard, following a critical review of current legislation regulating the use of animals in research, Mancini (7) proposed a research ethics protocol grounded in animal welfare theory, reflecting on the centrality of animals' interests as research partakers and technology users for ACI's non-speciesist approach. The framework covered four fundamental aspects, requiring: that the research be relevant to partaking animals as well as their species; that the welfare, both the integrity and the autonomy, of partaking animals be prioritized over societal interests; that partaking animals, including any humans, be treated impartially regardless of species; that the animals consent be garnered, both from those responsible for their well-being (*mediated consent*) and from the animals themselves (*contingent consent*), through expert monitoring of their behaviors and unconstrained choices during research procedures (8). The importance of being especially attentive to animals needs and wants when designing interactive technology was discussed by French et al. (12) who used speculative design to explore ways in which interspecies communication could be enabled by tech-supported playful activities. The speculative designs prompted a series of reflections related to ethical issues and power dynamics arising between humans and animals during play. The researchers observed how, as the *"top predator(s) in every engagement"* (12), in their interactions with animals, humans have an overwhelming influence irrespective of their intent, such that equitable relationships with non-human animals would be hardly possible. While they argued that "*humans should start listening a bit more*" (12) as part of their duty of care toward animals, they did not clarify what designers should be listening to or how.

Overall, on the one hand, contributions to the ethical discourse on ACI have provided normative frameworks (e.g., Mancini (3); Väätäjä and Pesonen (9); Hirskyj-Douglas and Read (10), Mancini (8)) for researchers to apply when designing and conducting research involving animals. On the other hand, contributions have cautioned researchers about the challenge of undertaking ACI research with animals without allowing human interests to prevail, exhorting them to carefully consider and manage their own bias (e.g., Grillaert and Camenzind (11), French et al. (12)). However, tools are still lacking which could enable interaction design researchers, who wish to conform to an animal-centered ethics, to identify and manage their own biases during the research process, by reflecting on their own values and on issues that arise as they engage with their animal participants in practice. This paper proposes an ethics toolkit for animal-centered design, which was developed during an ACI research project to address this gap. In the following sections we introduce the project to exemplify some of the challenges that ACI researchers face as they attempt to practice animal-centered research and the issues that arise from these challenges. We then discuss the ethics theories we drew from to develop the proposed ethical toolkit.

DESIGNING FOR MOBILITY ASSISTANCE DOGS

The research which led to the development of the toolkit presented in this paper investigated the process of designing a technological device for Mobility Assistance Dogs (MADs). MADs are specially trained dogs who execute tasks on behalf of their human partners, such as those related to self-care, mobility, and other physical activities (13). In assisting their human partners, MADs are required to interact with a wide variety of products and interfaces (e.g., switches, buttons, handles) in diverse environments (e.g., home, public transportation, shops). However, most of the environments and the artifacts the dogs are required to interact with are designed from a human-centered perspective that fails to recognize MADs as legitimate users and therefore fails to meet their usability needs (4). Failing to meet MADs' usability needs does not usually prevent them from being able to assist their partners but it does result in them facing significant challenges that impact their training and working performance, and that ultimately affect their welfare (4) and their experience as technology users, i.e., their user experience (14).

In collaboration with UK Charity Dogs for Good (15), which trains and pairs MADs with people who need their assistance, the research focused on the design of wireless dog-friendly controls that would enable MADs to easily operate domestic appliances such as lamps or kettles, and wired controls that would enable them to easily open motorized doors often found in buildings frequented by the public. The aim was to deliver interfaces that would provide good usability and a good user experience for MADs, thus expediting their learning process during training, enhancing their performance once paired with their assisted human, improving the accessibility of the built environment for both dogs and humans, and supporting the dogs' welfare. Designing the dog-friendly controls involved engaging directly with numerous MADs to understand the dogs' training process and working environment, to elicit their usability requirements consistent with their sensory, cognitive, and physical characteristics, and to evaluate prototypes that we designed based on our grasp of their requirements. This engagement took the form of a series of empirical studies with MADs participants, the design and execution of which raised ethical questions that existing ACI ethics proposals did not address.

For example, the first study carried out was a comparative verification test (16) in which the usability of three existing access controls was tested: a standard issue control and two canine-friendly prototypes (4). During a series of trials MADs and their trainers were asked to open a motorized door by nudging the controls. Because a "nudge" command requires MADs to use their snout to operate the control, one aspect of the control's usability that was of interest to the researcher was how reachable the controls were: 1) at the height recommended by accessibility standards (75 cm); 2) at the height determined by each dog's forward-facing snout (55 cm–65 cm); and the height of a standard electrical socket (to assess the viability of a plug-in control) (45 cm).

Unlike with the controls at a standard height (75 cm) (which required most MADs to jump up, stand on their hind legs, hold their front legs against the wall, while pushing their snout forward to activate the control), reaching the controls at "snout" and "socket" heights did not require physical effort. So, we expected that these would be easier for the MADs to interact with. However, even when interacting with these lower controls, some MADs exhibited signs of frustration (sitting or lying down, low whining, and looking away). Usually, increasing the ease of an interaction decreases user frustration (17), but apparently not in this instance. Beyond being unexpected, these behaviors required the researcher to choose between stopping the trials, to prevent the MADs from experiencing any discomfort, and continuing to pursue the research goal by continuing the trials irrespective of the dogs' frustration.

The researcher knew that frustration is commonly part of dogs' learning process when they progress from familiarization to proficiency. Nevertheless, a determination had to be made regarding the level of discomfort the MADs would be allowed to experience. Was this a level of discomfort that could be expected as part of their learning progression? If so, was this progression in the interest of the dogs to begin with? Was the researcher's assessment of MADs' heightened level of frustration accurate, despite her knowledge of canine behavior? Furthermore, the researcher questioned whether reducing the physical effort for the MADs might increase other kinds of effort. What hidden biases might the researcher have regarding what would be easier or pleasurable for the MADs to interact with? Existing ACI ethics frameworks did not provide the guidance needed to consider this kind of emerging dilemma and inform practical choices as the research progressed.

Another example of circumstances in which the researcher faced unexpected ethical challenges occurred during the second study. This aimed to investigate whether providing MADs with two controls, one to trigger an environmental state (turning on a light) and one to reverse said state (turning off a light) would allow them to connect their actions with the different states (pushing one control makes the environment lighter, pushing another control, makes it darker). To test this hypothesis low fidelity (2) but functional prototypes were constructed. The design consisted of two round push-pads, one blue and one yellow, mounted side by side on a black board and wirelessly controlling a nearby light source. The choice of colors - blue and yellow - was made to help the dogs differentiate the controls against the contrasting background. The prototypes were placed for seven days in three homes where MADs lived with their respective assisted humans. On the first day of the study, the researcher and training staff from Dogs for Good, visited each of the participant's homes. During the visit, the researcher installed the prototypes, and provided detailed instructions of how to test the controls and record observations; and the training staff trained the MADs to use the prototypes and verified that their human partners were able to instruct the dogs to interact with the prototypes as intended.

The prototypes were quickly damaged by the dogs, suffering structural or functional problems that compromised their responsiveness during the study, prompting the human participants to try and fix the prototypes themselves. Furthermore, since the dogs were asked to interact with two separate controls, the single command "*nudge*" to which they were used was no longer usable as it did not distinguish between the two devices. As a result, during the study the human participants continued to ask the researcher for guidance on how to address these issues and, yet again, the researcher faced a complex ethical dilemma, to address which existing ACI ethics guidelines did not provide adequate support. For example, if previously it had been difficult to decide when to stop a trial during which the researcher was present, making the same decision when she was absent and completely reliant on the participants' accounts was now even harder. When should the researcher tell the participants to stop the study? Furthermore, how would she ensure that continuing with the study did not jeopardize the relationship of trust she had developed with the participants, and thus the possibility of conducting future studies with them, given the levels of frustration, disappointment and confusion humans and dogs had experienced? Additionally, could these issues, or the structural and functional fixes implemented by the human participants, have changed the design of the prototypes and resulted in an interaction that might harm the MADs? The fact that participants proactively fixed the prototypes, although appreciated, also raised ethical dilemmas related to their level of involvement in the study. Had the MADs experienced more frustration on account of their partners wanting to fulfill the study requirements?

This kind of ethical challenges occurred commonly during the research. They required the researcher to moment-by-moment weigh-up ACI ethics guidelines, the research's objectives, their knowledge of the animals, and contextual aspects of the studies (e.g., who were the dogs, what humans were present, how many trials had already been observed). Addressing these difficulties, led to the exploration of ethical approaches within interaction design that are used by designers who work with vulnerable populations, including children and differently abled adults (18). The next section discusses these approaches in more detail.

SITUATED ETHICS WITHIN INTERACTION DESIGN

Frauenberger et al. (18) argue that interaction design is a quintessentially ethical practice, because it deals with the interface between humans and the products, services, and technology they interact with, meaning that a designer's intent and what they create has a direct impact on users as individuals and as members of society (19). As a practice which entails the active involvement of various stakeholders (e.g., users, designers, other experts), interaction design addresses ethical issues based on three main frames of reference, respectively relating to the professional context, broader society, and the individual (20). Because animals are always subject to our interpretation of their needs, ethical approaches that stem from an individual frame are of particular relevance for understanding the ethical implications of designing for MAD users. Within this frame can be found, for example, approaches from the field of Participatory Design (21), including what is known as situated ethics (20), which requires the designer to cultivate ethical virtues related to the promotion of cooperation between designers, prospective users, and other stakeholders; the empowerment of all participants; and the collective curiosity and creativity of design teams and the stakeholders involved. For Frauenberger et al. (18), each stakeholder is a moral agent, whose participation in decision-making during the design process helps determine the ethical costs and benefits of the technology that is being developed (19). Hence, approaches that help practitioners consider the ethical acts of stakeholders during the design process are especially valuable and, in particular, situated ethics focuses on those aspects of the design process that require researchers to make situated decisions (22). The following sections discuss applied ethical approaches developed within the scope of situated ethics that, given their consideration of situated aspects of empirical research with certain user groups, are also relevant for conducting empirical research with animals.

Micro-Ethics

Micro-ethics focuses on the seemingly mundane, yet ethically charged exchanges that occur in every interaction between individuals (23). Initially developed for application within health care contexts, the approach has been applied to research within fields as diverse as engineering, computing, and design.

In their work on participatory design with marginalized children, Spiel et al. (23) develop an interpretation of the approach that is particularly relevant for interaction designers who work with MADs, since it focuses on user groups who share some relevant traits with dogs, such as being limited in their verbal and emotional capacity compared to human adults [also recognized by ACI researchers - (24, 25)]. The researchers describe the user-related challenges encountered during two participatory design projects conducted with disabled (allistic and autistic) and visually impaired children; including, the effect of the children's difficulty to manage their emotions during data collection, the influence of the children's caretakers on their behavior during the research, and the children's demonstrations of emotions toward their caretakers and the researchers (26). Being in a position of greater power and control compared to the children, the researchers found themselves having to make moment-by-moment decisions as to how to respond to the children's behavior, which posed serious ethical dilemmas.

For example, one child who had difficulty managing their emotions and was highly reactive to certain situations required the researchers to try to anticipate these reactions and divert the child's attention to other aspects of the design process or to reframe the research experience in a more positive way. In one instance, the researchers did not react in time, and the child violently destroyed parts of the study's technological setup. In response, one of the researchers switched *"from a playful and collegial approach to a more serious and strict tone … that identified the destruction of the prototype as a point of contention"* (26). Once the child had rejoined the group, he was given the opportunity to voice his needs and, in response, the researchers reframed the incident as an opportunity to test the robustness of the setup. Was the researcher able to strike a good balance between their role, as enablers of the children's free and creative participation in the study, and their duty of care toward all other stakeholders involved? Should the study have been discontinued? If not, should a researcher have been assigned to better anticipate the child's needs or, rather, should the child have been removed from the study?

In another instance, a conflict of intention arose between the child's carer, who wanted the child to learn to interact with one of the study's interactive devices, and the researcher, who was interested in the child's feedback on their spontaneous interactions with the device. The researcher decided to withdraw themselves from the interaction and noted that the carer, in their intent for the child to use the device uttered *"restrictive questions or comments such as 'no, you're wrong' toward the child"* (26). After a few minutes, the child stopped interacting with the device altogether and moved on to something else. The researchers report that these types of conflicts recurred during the research and that, in order to maintain their relationship with the child's carers, the researchers always opted to withdraw from these interactions altogether. Was this the right thing to do for the children, their carers, or the research? Should a series of rules of engagement with clear consequences and outcomes have been issued prior to beginning the study?

To help researchers deal with challenges such as the ones described above, Spiel et al. (26) propose a framework informed by a *micro-ethical* approach that encourages designers, during the design process, to systematically analyze how their situated ethical decisions might be influenced by their own moral perspectives and ethical frameworks of reference (26). For example, to help negotiate competing values and agendas during the research, they established alternative approaches to working with the children which meant at times ignoring the negative parts of their experience for the benefit of potentially opening up new enriching interactions. They pointed out that doing so made the new interaction *"fleeting and insecure as it can only happen through precariously balancing the values of carers and researchers alike"* (26). The researchers acknowledged that withdrawing from certain interactions to protect their relationship with the child's carers might result in negative experiences for the children and compromise some of the desired conditions for the work. However, the approach seemed more effective in maintaining the carers, and thus the children, more involved during the research.

These challenges and the resulting approaches proved valuable for our project. Indeed, during our own research with MADs, we observed various similarities with the situations described by Spiel et al. (26) during their research with children. In particular, the dogs' expressions of affect, and the way in which they managed their emotions, had an effect on data collection that needed to be dealt with; and the presence of the MADs' familiar trainers and partners during trials had an influence on MADs' behavior and, in turn, influenced the research activities. This resulted in the researcher, trainers, and their partners having to make decisions on behalf of the dogs so that research activities could progress.

For example, during one of the studies in which MADs and their trainers were asked to interact with a more advanced prototype, the researcher had to negotiate when to terminate a trial with one of the MAD's trainers. The prototypes being tested consisted of two main parts, a cylindrical casing that housed the control's electrical components and a rubberized push pad. The aim of the study was to test the usability of the control and the impact on MADs' user experience while interacting with them. The controls came in three diameters; small (9 cm), medium (12 cm), and large (14 cm), and in each size there were controls respectively featuring push pads that traveled different depths, shallow (5 cm) and deep (2 cm). One of the participating MADs had, in previous trials, successfully operated the small and large controls with the shallow-traveling and deep-traveling push-pads, and the small control with the shallow-traveling push-pad. However, when trialing the small control (9 cm) with the deep-traveling push-pad (5 cm), the MAD was visibly struggling to activate the control. The trainer, possibly to give the dog a chance to end the trial with a successful interaction (a practice common in canine training), was urging the dog to persevere. However, from the researcher's perspective, the unsuccessful interaction seemed the result of the cylindrical casing being too small for dog's snout, which prevented him from exerting the force required to activate the deeper-traveling push-pad. Here, the researcher was faced with a choice: let the trial play out and assume the trainer would at some point stop asking the dog to interact with the control; or ask the trainer to stop the trial. Considering that the issue was the ergonomic unsuitability of the control, the researcher asked the trainer to stop the trial; however, she took care of explaining to the trainer that the problem was with the control's design rather than the MAD's behavior or the trainer's handling of the dog.

This decision was ultimately determined by the researcher asking herself a series of questions typical of the micro-ethics approach, such as: "Where is this decision stemming from?" (e.g., *I am going to confidently terminate the trial because the MAD is struggling due to a design issue, which is my responsibility and, thus, the likelihood that my relationship with the trainer will be affected is very low?*); "What personal, group or professional values are guiding the decision?" (e.g., *Is my desire to protect my relationship with the trainer for the sake of future trials affecting the MAD's current experience - would I make the same decision if the issue was not due to the control's design?*); "Would the dog have made a similar decision?" (e.g., *Would the dog have even tried to interact with the control again if not commanded by their trainer?*); "Were the training settings affecting the way the dog approached the control and the force they were able to exert when attempting to operate the control?" (e.g., *Would the dog's interactions with the controls have provided better results* *if they had been recorded interacting with the controls in more naturalistic settings, rather than during a repetitive controlled trial?*); and "If this decision is guided by a specific set of values, are these values different from other relevant sets of values? If so, how do they differ and why?" (e.g., *As an ACI researcher, I am aiming to obtain rigorous and replicable results in line with the guidelines established by ACI, while the trainer is aiming to build-up the dog's performance in line with the guidelines established by her organization*).

Asking these kinds of questions helped us to consider the ethical implications involved in working with MADs, which arise from the decisions that researchers find themselves making on the dogs' behalf as the work progresses. Asking these questions also helped us to contextualize and assess our decision-making process prompting us to *"reflect on those choices and discuss them, learn from them and improve our capabilities to make ethically sound judgments in the moment"* (26). For example, during the comparative usability study described in section 4, the researcher opted to continue the study by asking herself questions such as "are the heights being tested causing some MADs to be excluded from being able to operate the controls?", "how much frustration is acceptable for a dog to experience when interacting with a novel object?", "what is the trainer's feedback regarding the behavior?", "how do the MAD's previous experiences impact their interaction with the controls?", "what implications on the research would stopping the study have?", and "would the dogs opt-out of the trials if they could, or would they be stimulated by the challenge?" As the study progressed, the decision to continue proved to be the right one, as the dogs' apparent frustration lessened when they became more familiar with the controls. However, having considered this kind of questions gave the researcher confidence that her decision-making process had been guided by active ethical reflection.

Situational and in-action Ethics

Situational and in-action ethics are similar approaches, both of which recognize designers and researchers as active stakeholders during the design process, and both of which regard ethics as a "moving target" requiring the application of design and research methods that leave room for adjustment (19, 22, 27). However, compared to situational ethics, in-action ethics *"shifts the focus from the situated subject to a deeply interwoven and participatory practice"* (19). In their critique of approaches to formal ethics requirements, Munteanu et al. (22) identify what the authors call "ethical triggers", that is elements that might indicate potential challenges during the research. For example, the researchers reported that, when testing the design of BrailleTouch (28) - a software keyboard for touchscreen mobile phones based on braille typing - their visually impaired participants were so eager to participate in the research that *"They made our goals their own"* (22). This created an ethical tension between the care the researchers had taken to implement ethical principles regarding informed consent and privacy, and the care-less attitudes toward these same principles shown by their participants, who perceived the research *"as less of an experiment and more of a trivial app testing"* (22) and whose desire to contribute to what they perceived as important for their community override any privacy considerations. In response, they recommend that researchers develop the ability to assess the unexpected ethical risks encountered during the research and adapt protocols as necessary, to protect the safety, privacy, and dignity of participants, especially those belonging to *vulnerable populations.*

Frauenberger et al. (19) advocate reflection-in-action as the researcher's practice of constantly and actively reflecting on their actions during the research, enabling them to deal with the *"uncertainty, instability and uniqueness"* (19) of the unexpected ethical dilemmas, which might arise and which anticipatory planning may not enable them to deal with. They also highlight how all stakeholders share the responsibility of ethical reflection during the design process. For example, they cite a project whose aim was to apply participatory design approaches *for* and *with* autistic children to create technological artifacts that would enable the children to share their experiences, an activity notoriously challenging for them. The complexity of the research was described as being due to the project's exploratory nature, and to whether the many stakeholders involved (e.g., children, parents, teachers, school administration, special needs pedagogues, and policymakers) shared consistent moral values and how these influenced their responses to the ethical issues that might emerge. Although the team had developed a series of rigorous ethical guidelines prior to the research, these revealed themselves to be skewed toward the perspective of the researchers and not to capture the perspectives of the other stakeholders involved. In response, the team re-engaged with a few of the stakeholders and was able to develop a more nuanced approach. Although this did not entirely reconcile conflicting interests (e.g., the children sometimes expressing their desire to just be 'normal', while the researchers promoted their neuro-diversity agenda), it nevertheless allowed *"dilemmas to emerge . . . and be continuously negotiated and checked upon"* (19).

In the case of our project, both the situational and in-action ethics approaches helped us develop a reflective practice throughout the course of the research, from which we were able to draw clear guidance as to how to approach ethically charged situations with the dogs which had not been foreseen and, thus, addressed during the planning stages. For example, a similar situation to the one described by Munteanu et al. (22) emerged during our research as described in section 4, when our human research participants also *made our goals their own* to the extent that they fixed the malfunctioning prototypes themselves. Reflecting on the work of Munteanu et al. (27) prompted us to investigate why this behavior had occurred. When we asked MADs' human partners why they had tried to fix the prototypes, all of them mentioned their interest in being part of a project that would help others like them in their community and improve the lives of MADs. One participant commented how important it was for them to have been chosen to participate in the research and how this made them keen to ensure the study's success by complying with what had been asked of them. All participants mentioned that their MADs had been very frustrated and confused but that eventually, when the device did work, they seemed to be extremely "proud of themselves". Although it was clear that the MADs' human partners were well-intentioned, their motivations nevertheless raised questions regarding the safety of both humans and dogs (e.g., possible harm caused to either of them due to a malfunctioning prototype), and even the dignity of the canine participants (e.g., having to interact with what was an unusable product). Being mindful of the value that MADs' human partners gave to being part of the research enabled us to take into account how this could impact their participation and the participation they required of their dogs; we also endeavored to distance ourselves emotionally from the design of the controls while engaging with participants, so as to signal that any issues they might encounter with the prototypes during the study would not be taken personally; and we resolved to develop a set of rules of engagement for our next in-home study.

Reflecting on Frauenberger et al.'s. (19) case study with autistic children prompted us to take note of the many stakeholders our research project included (MADs, the researcher, a research fellow, the MAD's trainers and handlers, the MAD's partners, the family members of the MAD's partners, the charity's canine and administrative staff, the project's supervisors, the university, the university's board of ethics, and the project's sponsor) and the ethical risk of producing ethical protocols which failed to capture their perspectives. This risk becomes especially significant when dealing with animal research participants, who are unable to articulate their own ethical perspectives; in turn, prompting the researcher to try and interpret what the animals' perspective might be based on their own assumptions, and their interpretations of the assumptions of the other stakeholders. To mitigate this risk, an alignment meeting attended by the research team, the project's supervisors, and the charity's administrative staff was conducted, during which each stakeholder shared their goals for the project and discussed their expectations regarding the involvement and treatment of the dogs during the research. These discussions provided an open and transparent space to negotiate the moral standpoint of the project's main stakeholders and, thus, revealed a new series of ethical considerations. For example, when the charity's administrators expressed an interest in exposing their employees to the research's progression, new questions emerged, such as "if the dog trainers' involvement in the research is exposed to other members of staff, will the trainers start to interact with MADs any differently?", "will presenting the project's progress to the organization influence the way the studies are conducted?", or "will the dogs chosen to participant in the research be regarded and treated by member of staff differently from the ones who are not chosen?"

AN ETHICAL TOOLKIT FOR ANIMAL CENTERED RESEARCH AND DESIGN

The approaches and examples discussed above highlight the relevance that situated ethics had when working with MADs and its potential relevance when undertaking interaction design research with animals. To facilitate the application of situated ethics in ACI research and support designers' ethical engagement with animal users and research participants, we developed an ethics toolkit to support animal-centered research and design. The toolkit is the result of weaving together aspects of micro, situational, and in-action ethics that prompt ACI researchers to define what Frauenberger et al. (19) describe as the *project's ethos,* the "*moral commitment or stance, a moral attitude that underlies a particular practice*" (19). Although the toolkit is intended for use by individual researchers, it provides a base for negotiating with other stakeholders the ethical standing of a research project. By prompting them to systematically reflect on their own ethos and perception of the ethos of other stakeholders, the toolkit enables the researcher to acknowledge how their ethical values and perceptions inform their actions, and how their actions influence their values and perceptions in return. The toolkit is designed to support a cyclical reflection process through each new research challenge, so that the 'ethical profile' of the researcher it is constantly being developed and reflected upon.

Thus, the toolkit aims to help ACI researchers to define their project's ethos clearly and systematically by articulating their and the research's ethical baselines as they relate to animals, to investigate how these influence their ethical judgments during animal-centric research, and to make ethically sound moment-by-moment decisions during the research. Additionally, by encouraging them to actively reflect on the ethical implications of their decisions - both during the research and once their designs are implemented and deployed, the toolkit aims to help researchers to develop their own sensitivity toward the needs of the animals they interact with and to safeguard the animals' welfare. The following section describes the toolkit in detail.

The toolkit is composed of three separate sections shown as separate templates (**Figures 1–3**), each focusing on a specific aspect of the research:

- Template A: establishing the researcher's ethical baseline
- Template B: establishing the research's ethical baselines
- Template C: expressing the project's ethos.

In the top left-hand corner, each template describes the toolkit's goal, provides an outline of the template's intent, and indicates the steps the researcher will need to take to complete that template. The left side of each template describes the toolkit's steps in more detail, proving researchers with instructions on how to best answer the questions provided. The toolkit is designed to be filled in by individual researchers and designers, to be discussed by the project's stakeholders, actively revised by the project's main researcher or designer, and to be critically reflected upon as a project team at the completion of the research. In the following sections we describe each template in detail, using the terms researcher and designer interchangeably.

Establishing Your Ethical Baselines (Template A)

Template A's (**Figure 1**) aim is to help researchers establish their personal ethical baselines by prompting them to carry out a comprehensive assessment of their own understanding of the animal as a research participant and to consider how this understanding might influence their role as an animal-centered researcher. The toolkit's first step asks the designer to consider and reflect upon the inputs that have informed

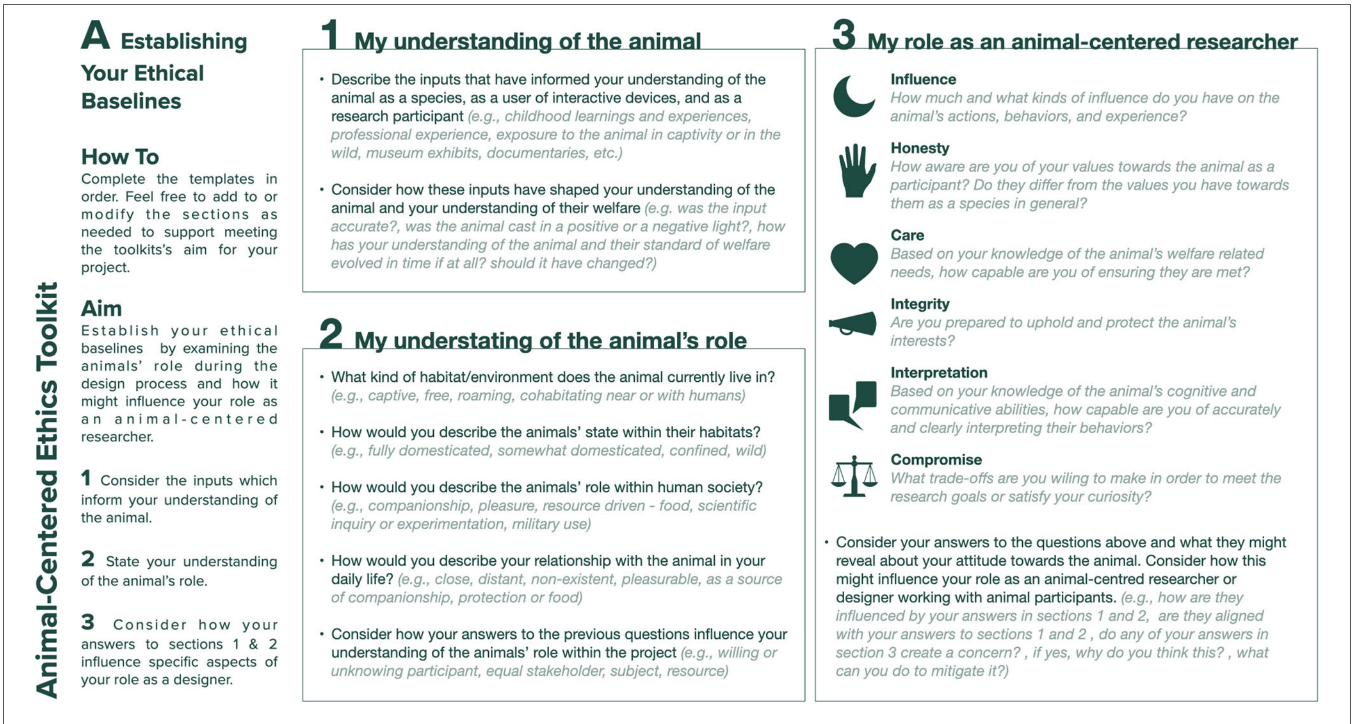


FIGURE 1 | Template A: establishing your ethical baselines.

their understanding of the animal as a species, as a user of interactive devices, and as a research participant. Step 2 prompts the designer to consider their understanding of the animal's habitat, the animal's role within human society, their relationship with the animal, and the animal's role within the research. The template then encourages the researcher to reflect on how the combination of these particular aspects might influence their overall view of the animal within the research. The intent of Steps 1 and 2 is to help researchers become aware of the elements that shape their understanding of the animal and to potentially reveal any implicit biases they might have toward the animal, prompting them to question their current beliefs regarding the animal and the animal's welfare. Uncovering such biases is especially important when working with vulnerable user groups (26), animals included, to mitigate ethical challenges inherent in the power imbalance between human researcher and animal participant. To help uncover any inconsistencies that might affect how decisions are made during the research, Step 3 prompts the designer to compare their engagement and relationship with the animal within and outside the research setting. The researcher is invited to consider the influence they have over the animal's actions, behaviors, and overall experience during the research; to honestly consider the alignment of their attitudes toward the animal as a species and as a research participant; to question their ability to care for the animal during the research and to interpret the animals' behaviors, their commitment to protect and uphold the animals' interests, and the compromises or trade-offs they are willing to make. Template A is intended to be used by individual researchers, designers, and the other project stakeholders to capture their personal views.

Establishing the Research's Ethical Baselines (Template B)

To capture the research's ethical baselines, Template B (**Figure 2**) shifts the focus of attention from the individual researcher to the research. Step 4 asks the researcher to state the main research question(s) and to consider their intent and the relevance of this for the animal user. Relevance here refers to the balance between the risk and benefit of the research for the animal, based on the principle of "*Doing research that is relevant to participants and consistent with their welfare*" (8) – Toward an animal-centered ethics for Animal Computer Interaction, International Journal of Human Computer Studies, 98p.221–233). Step 5 prompts the designer to state the research's general methodological approach and planned research settings, and to consider how these might impact the animal participant. Specifically, the researcher is invited to reflect on the research activities' inclusivity (how easily the animal will be able to participate), safety (how the researcher will be able to protect the animal from harm) and autonomy (how much self-governance the animal will be able to exercise during the research). Step 6 asks the designer to indicate the project's stakeholders and to consider their roles, responsibilities, and type of involvement (e.g., specific engagement with the animal participant) during the research. It then asks the researcher to clearly articulate stakeholders' ethical responsibilities. The intent behind these questions is to help the researcher to uncover

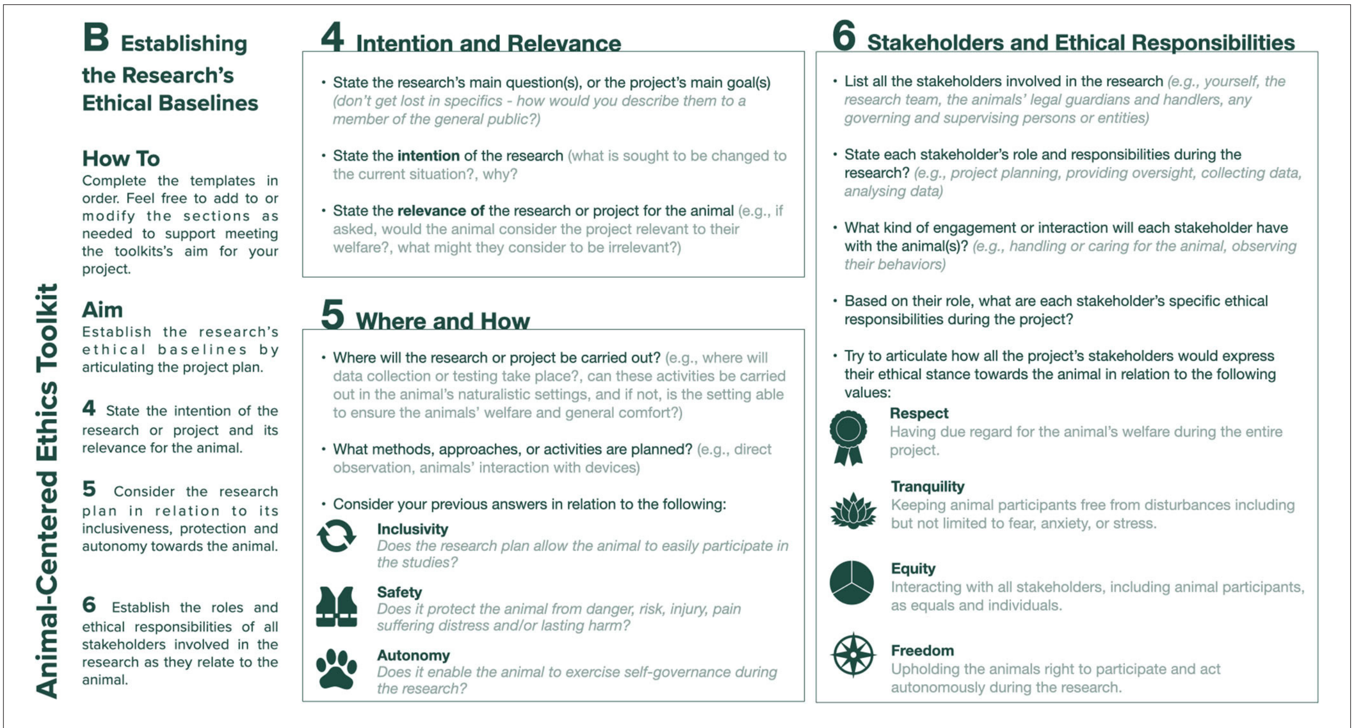


FIGURE 2 | Template B: establishing the research's ethical baselines.

any conflicts or competing goals among project stakeholders in relation to the animal participant so that, when faced whit ethical challenges during the research, conflicts can be more easily articulated and mitigated. The final question in Step 6 prompts the researcher to consider how each stakeholder, including themselves, stand in relation to the values of respect (having due regard for the animal's welfare), tranquility (keeping animal participants free from disturbances including but not limited to fear, anxiety, or stress), equity (interacting with all stakeholders as equals and individuals) and freedom (upholding the animals ability to participate autonomously during the research).

Expressing the Project's Ethos (Template C)

Template C of the toolkit (**Figure 3**) comprises Step 7, which prompts the designer to consider a series of research scenarios and their implications for the animal; and Step 8, which helps researchers to clearly articulate a set of ethical guiding statements. The aim of Step 7 is for the researcher to revisit the project's relevance for the animal participant (previously examined in Step 4 of Template B) in light of the information captured in Steps 5 and 6, and their contributions toward achieving a greater awareness of the project's ethos. It prompts the designer to consider if any of the planned research scenarios might raise ethical concerns related to the animal participant not identified during the previous steps; if so, how these might be dealt with or how any aspects of the research plan could be changed or adapted to reduce the concerns. Step 8 invites the researcher to consider their responses to Steps 1–7, and to ask themselves whether they think that the animal participant would have made a similar assessment or whether they need to re-evaluate specific aims or activities in the research plan. It then prompts researchers to consider the project's stakeholders and the values discussed in the previous steps (influence, honesty, care, integrity, interpretation, compromise, inclusivity, safety, autonomy, respect, tranquility, equity, and freedom) and produce a series of ethical statements to help articulate the project's ethos, by responding to the following prompt: *In order to uphold the (insert value) of the (insert stakeholder) in relation to the animal participant, I will (insert action).* Here, the intent is twofold: firstly, to equip researchers with a series of statements, whose production process will hopefully have helped them unpack the complex, diverse, and nuanced nature of the ethical implications arising during animal-centered research and which enable them to have a critical dialogue "*about the framing, the judgments, the context, and one's own ethical standpoint while responding to ethical dilemmas as they arise*" (19); secondly, to instill a practice of active reflection during the research by prompting a review of their previous responses to the toolkit's questions to ensure that they are aligned with the project's ethical perspectives.

To ensure that the toolkit is consistently updated to reflect the project's ethos in the face of any unexpected challenges or changes due to the practice of active reflection among stakeholders during the research: it is suggested that someone within the team take ownership of the toolkit. Doing so would arguably task said team member with the gathering and recording the team's responses: however, it would provide all stakeholders with a valuable tool to visualize, understand, and act according to the diversity of

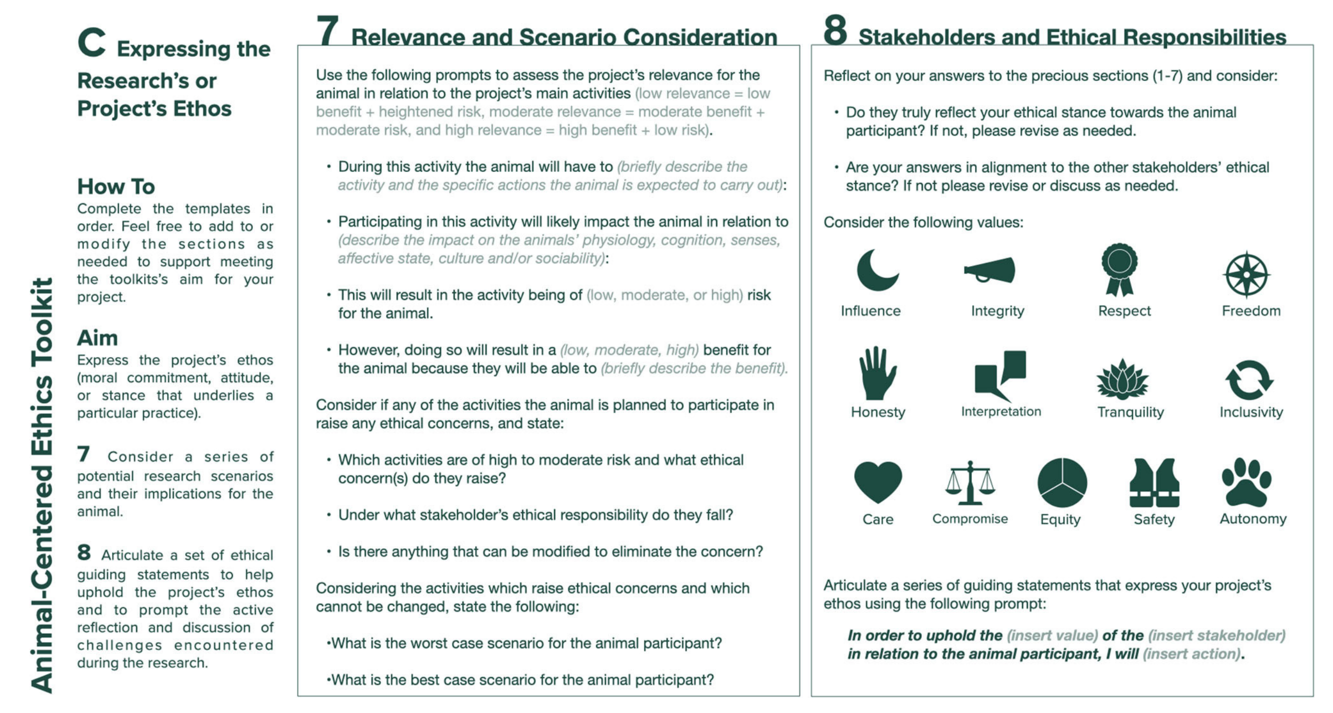


FIGURE 3 | Template C: expressing the project's ethos.

thought captured in the templates and enrich the definition of the project's ethos.

THE TOOLKIT IN USE - AN EXAMPLE FROM DESIGNING FOR MOBILITY ASSISTANCE DOGS

This section provides examples of the type of information the toolkit aims to elicit and how engaging with the toolkit's prompts can help researchers. **Figures 4–8** provide a sample of how the project's main researcher made use of the toolkit. For example, completing Template A prompted the researcher to explicitly acknowledge her bias toward typical MAD breeds (Golden Retrievers, Labrador Retrievers, or a mix between them), derived from her previous experience of training MADs (during the research, the same bias was also acknowledged by some of the trainers). Being aware of this bias then helped the researcher to ensure that her expectations on how the dogs might interact with the controls were not influenced by the dogs' breed. For another example, completing Template A also allowed the researcher to acknowledge the difficulty of treating all research participants - both non-human and human - impartially, given the challenges of knowing what the MADs were experiencing and, therefore, of knowing whether they were effectively enabled to express their concerns, just as the human participants were encouraged to do. Template B prompted the researcher to uncover a conflict between the MAD trainers' goals and the goal of the research. MADs training is impacted by a series of factors such as the timing, order, and consistency with which commands are taught. This results in the trainers being extremely focused on making the most of the small training window (no longer than 16 weeks) that they have with the dogs. Consequently, the execution of the studies that involved MADs and their trainers was likely to be influenced by the trainers' goal to make all sessions as productive as possible, while the research's goal was studying MADs' interactions with the controls without the pressure of expected productivity. This awareness then allowed the researcher to adapt the studies' protocol, including longer sessions that allowed the dogs more time to familiarize themselves with the controls at their own pace, providing reliable data for the research and a positive outcome for the trainers. For another example, completing Template C highlighted that, when working with project collaborators such as the design studio tasked with building the controls, the researcher needed to share information about MADs' training, behavior, and working life, in addition to handing over product specifications. This ensured that, during discussions regarding the controls' specific features, everyone had at least a basic understanding of MAD user needs, and their design suggestions were ethically acceptable.

Overall, the toolkit supported the exercise of incrementally building the project's ethos, by fostering an ongoing reflection on aspects of the research that might have been easily taken for granted, enabling the identification of implicit yet influential biases.

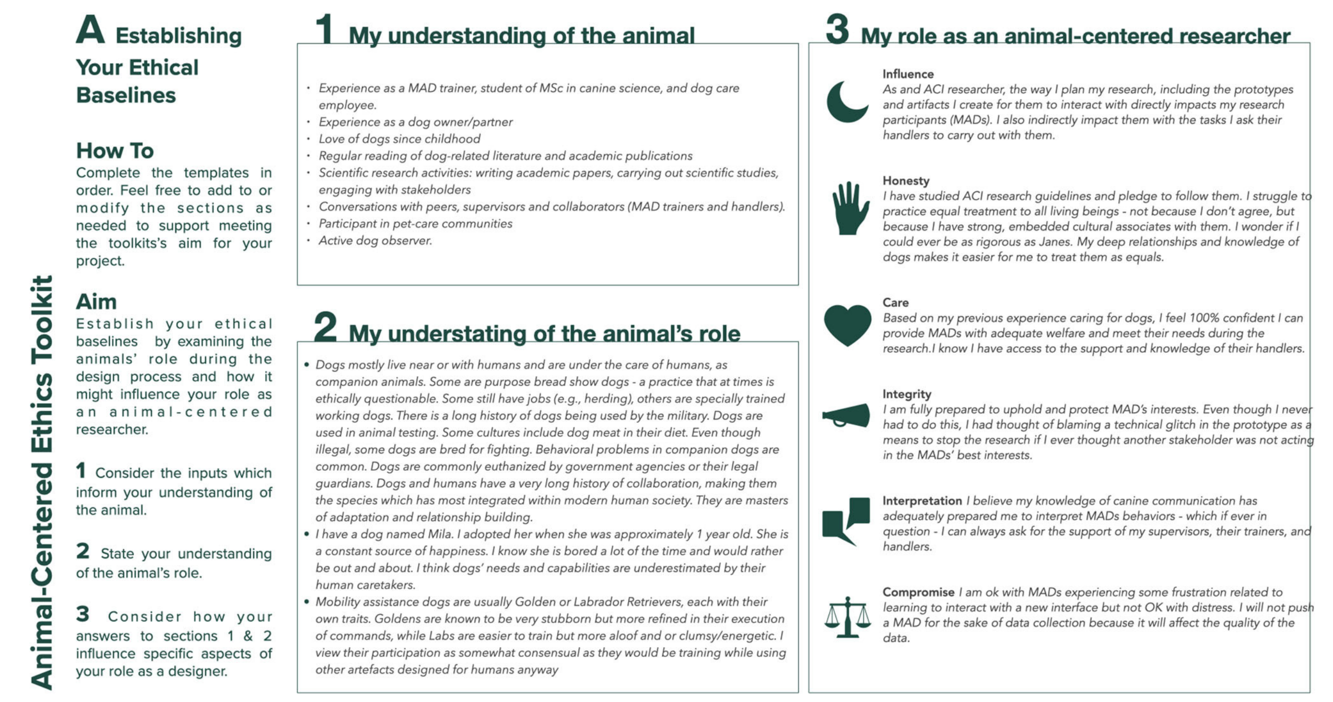


FIGURE 4 | Sample of template A: establishing your ethical baselines for the design of a set of canine-centric controls for Mobility Assistance Dogs.

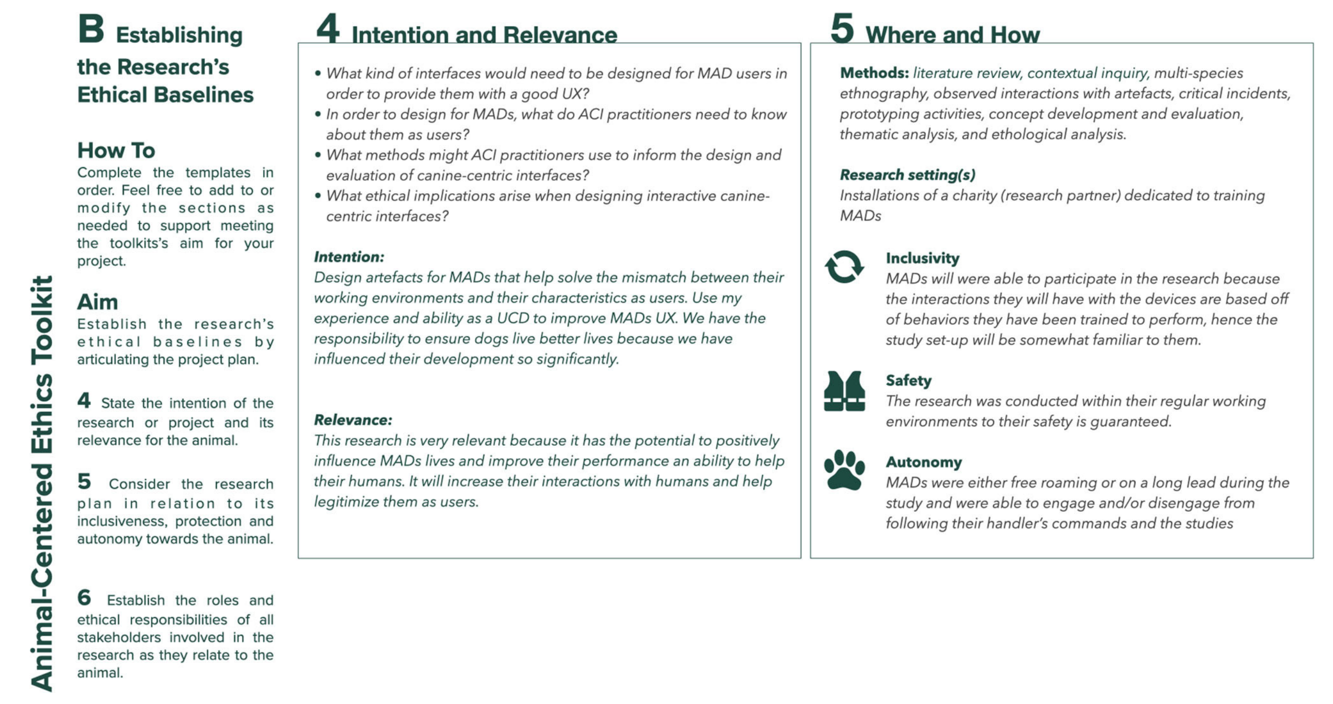
CONCLUSIONS: SUPPORTING ETHICAL ENGAGEMENT WITH ANIMALS

Compared to designing for and with humans, designing for and with animals presents an added level of complexity for the researcher, who cannot embody the intended user but nevertheless assumes the responsibility of acting as an interpreter of the animal's behavior throughout the process. In this respect, the role of the ACI researcher is especially demanding, requiring the application of all our powers of observation, empathy, and critical thinking to gain a measure of understanding of the animal as a user and of the elements that may comprise and influence their experience, if not of the experience itself. Aside from scientific competence, this requires ethical sensitivity toward the kind of user interactions and experiences that the animal participant will encounter, the elements of those interactions and experiences that might be important, the way in which these might shift over the course of the research, and the repercussions that such shifts might have.

To this end, the toolkit presented above aims to help animal-centered researchers to clearly and systematically define their projects' ethos by articulating their and their research's ethical baselines in relation to the animals involved; to identify how these baselines might influence their judgments during animal-centered research; and to make ethically sound situated decisions during the research process. Additionally, by encouraging them to actively reflect on the ethical implications of their decisions - both during the research and once their designs are implemented and deployed - the toolkit aims to help researchers to develop their own sensitivity toward the needs of the animals they interact with and to safeguard the animals' welfare.

The toolkit is designed to complement the principles and guidelines provided by animal-centered normative approaches to ethics developed within ACI. While such normative approaches provide essential scaffolding and general guidance for animal-centered research, they are not sufficient to enable researchers to deal with unexpected and ethically charged situations that may arise as the research progresses. By supporting their active and ongoing reflection, the ethics toolkit presented here enables researchers to take a situated ethics approach as they engage with their animal participants. It does so by prompting them to become aware of how their ethical position might influence their research plans, their activities throughout the research, and ultimately their findings. By prompting research teams to articulate a series of guiding statements, the toolkit also helps them develop a shared ethos among team members that is likely to increase compliance. This could provide a common foundation that accounts for multiple ethical dimensions and that can consistently inform decision-making processes, particularly when addressing unforeseen challenges.

The toolkit was developed as a result of the ethical challenges encountered during our research with MADs. Although, in their present form, its constituting templates were designed toward the end of the research process, their composition and the questions that they feature capture the reflection processes that took place as the research was unfolding, informed by a situated ethics approach. As such, we consider the toolkit a live



Animal-Centered Ethics Toolkit

B Establishing the Research's Ethical Baselines

How To
Complete the templates in order. Feel free to add to or modify the sections as needed to support meeting the toolkits's aim for your project.

Aim
Establish the research's ethical baselines by articulating the project plan.

4 State the intention of the research or project and its relevance for the animal.

5 Consider the research plan in relation to its inclusiveness, protection and autonomy towards the animal.

6 Establish the roles and ethical responsibilities of all stakeholders involved in the research as they relate to the animal.

4 Intention and Relevance

- *What kind of interfaces would need to be designed for MAD users in order to provide them with a good UX?*
- *In order to design for MADs, what do ACI practitioners need to know about them as users?*
- *What methods might ACI practitioners use to inform the design and evaluation of canine-centric interfaces?*
- *What ethical implications arise when designing interactive canine-centric interfaces?*

Intention:
Design artefacts for MADs that help solve the mismatch between their working environments and their characteristics as users. Use my experience and ability as a UCD to improve MADs UX. We have the responsibility to ensure dogs live better lives because we have influenced their development so significantly.

Relevance:
This research is very relevant because it has the potential to positively influence MADs lives and improve their performance an ability to help their humans. It will increase their interactions with humans and help legitimize them as users.

5 Where and How

Methods: *literature review, contextual inquiry, multi-species ethnography, observed interactions with artefacts, critical incidents, prototyping activities, concept development and evaluation, thematic analysis, and ethological analysis.*

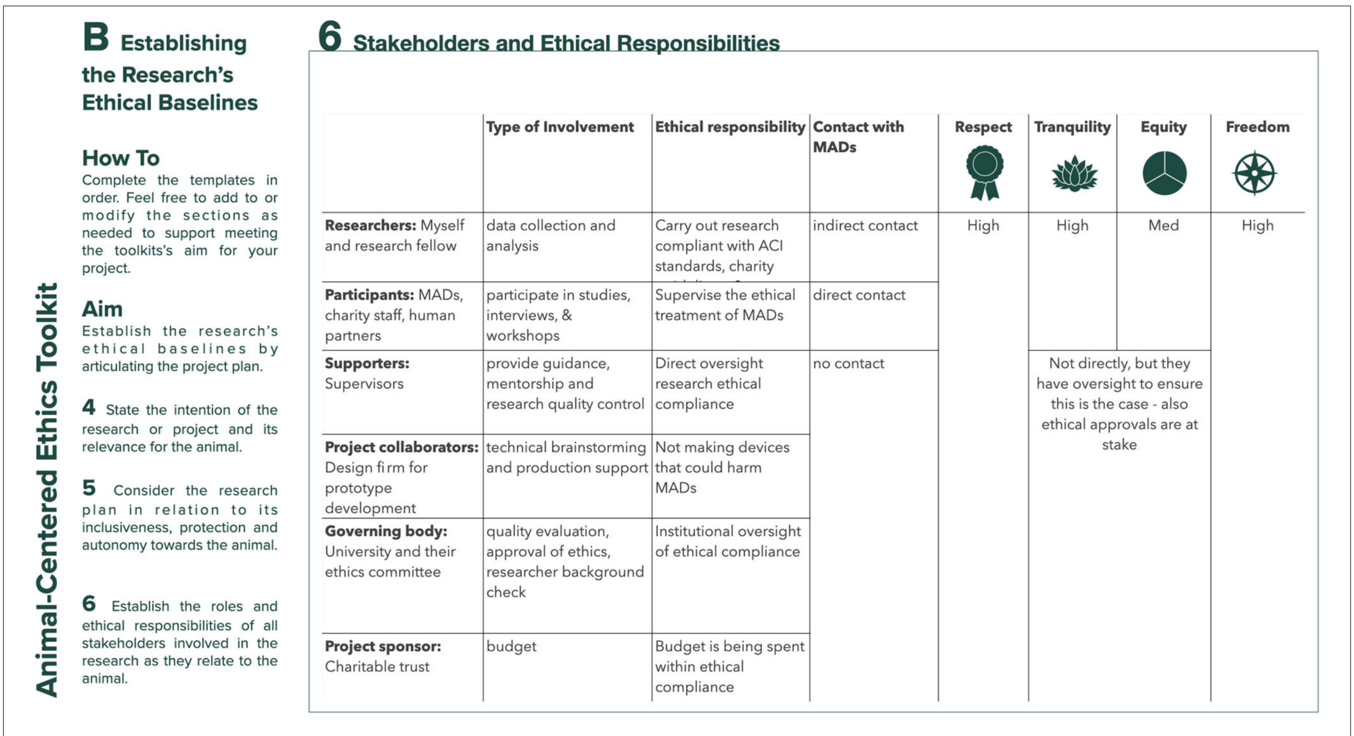
Research setting(s)
Installations of a charity (research partner) dedicated to training MADs

Inclusivity
MADs will were able to participate in the research because the interactions they will have with the devices are based off of behaviors they have been trained to perform, hence the study set-up will be somewhat familiar to them.

Safety
The research was conducted within their regular working environments to their safety is guaranteed.

Autonomy
MADs were either free roaming or on a long lead during the study and were able to engage and/or disengage from following their handler's commands and the studies

FIGURE 5 | Sample of template B: establishing the research's ethical baselines for the design of a set of canine-centric controls for Mobility Assistance Dogs, steps 4 and 5.



Animal-Centered Ethics Toolkit

B Establishing the Research's Ethical Baselines

How To
Complete the templates in order. Feel free to add to or modify the sections as needed to support meeting the toolkits's aim for your project.

Aim
Establish the research's ethical baselines by articulating the project plan.

4 State the intention of the research or project and its relevance for the animal.

5 Consider the research plan in relation to its inclusiveness, protection and autonomy towards the animal.

6 Establish the roles and ethical responsibilities of all stakeholders involved in the research as they relate to the animal.

6 Stakeholders and Ethical Responsibilities

	Type of Involvement	Ethical responsibility	Contact with MADs	Respect	Tranquility	Equity	Freedom
Researchers: Myself and research fellow	data collection and analysis	Carry out research compliant with ACI standards, charity	indirect contact	High	High	Med	High
Participants: MADs, charity staff, human partners	participate in studies, interviews, & workshops	Supervise the ethical treatment of MADs	direct contact				
Supporters: Supervisors	provide guidance, mentorship and research quality control	Direct oversight research ethical compliance	no contact		Not directly, but they have oversight to ensure this is the case - also ethical approvals are at stake		
Project collaborators: Design firm for prototype development	technical brainstorming and production support	Not making devices that could harm MADs					
Governing body: University and their ethics committee	quality evaluation, approval of ethics, researcher background check	Institutional oversight of ethical compliance					
Project sponsor: Charitable trust	budget	Budget is being spent within ethical compliance					

FIGURE 6 | Sample of template B: establishing the research's ethical baselines for the design of a set of canine-centric controls for Mobility Assistance Dogs, step 6.

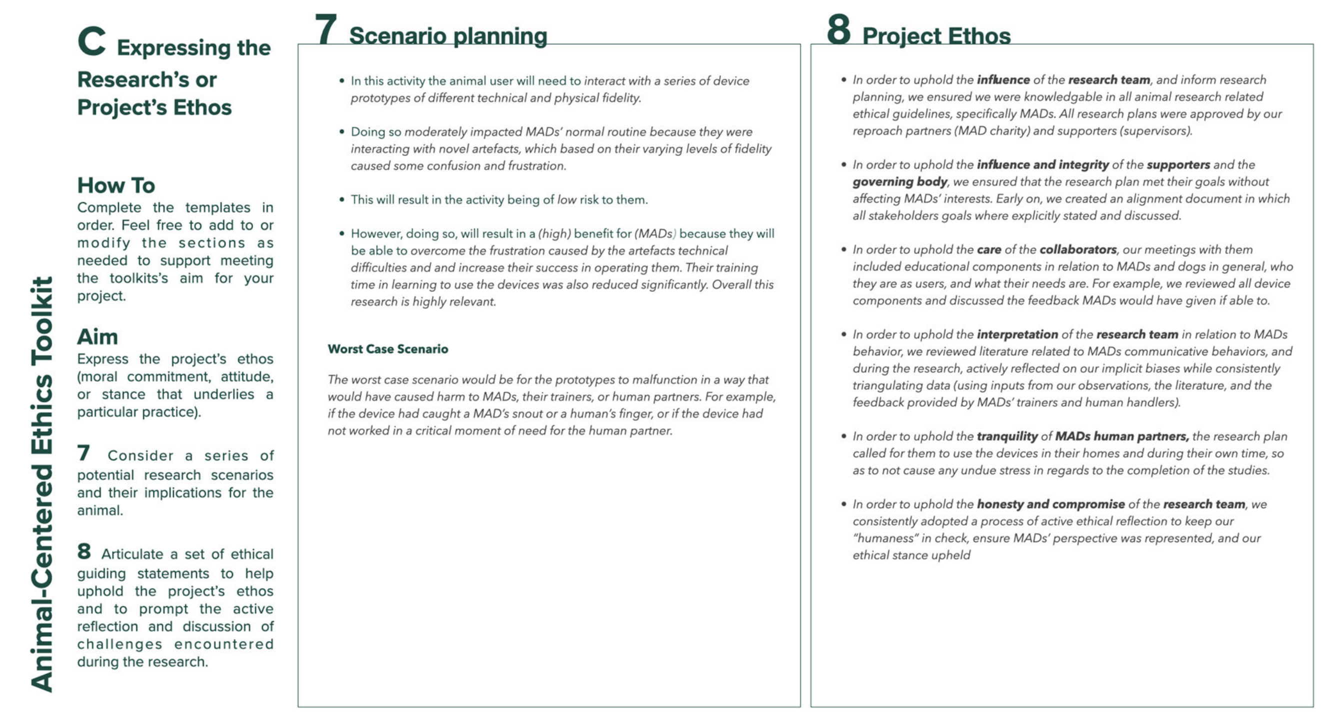


FIGURE 7 | Sample of template C: expressing the project's ethos for the design of a set of canine-centric controls for Mobility Assistance Dogs.

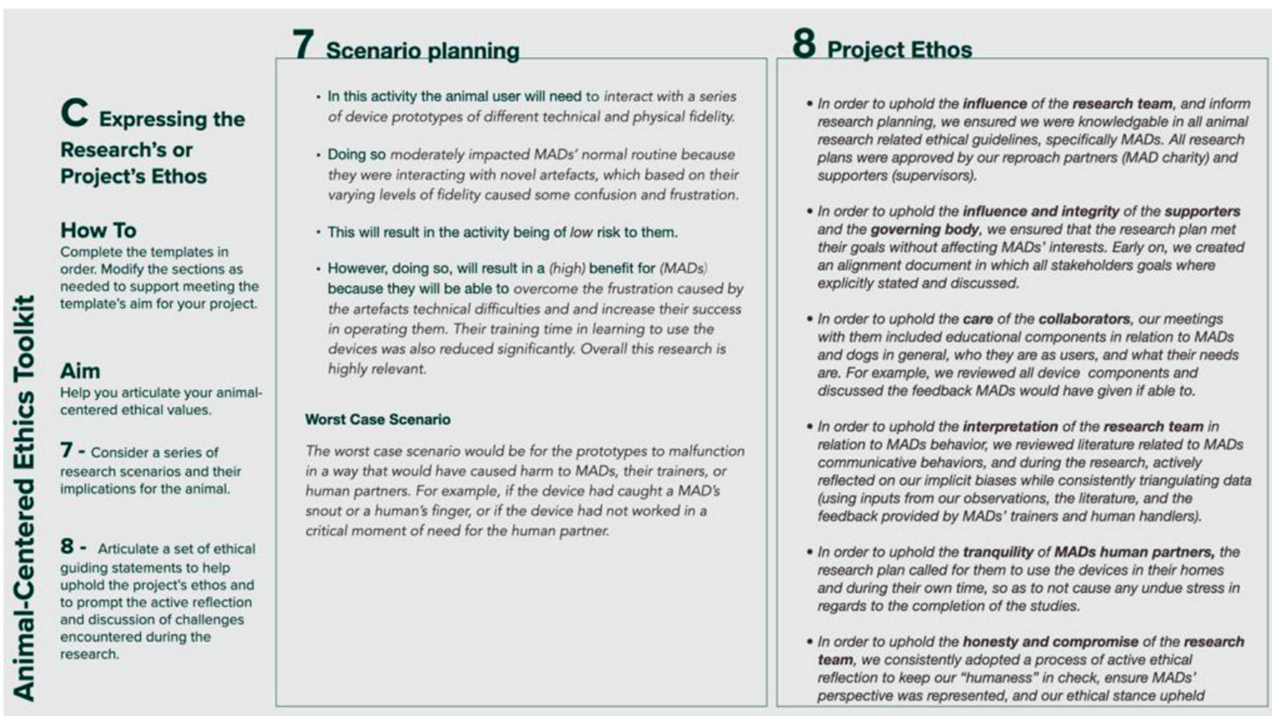


FIGURE 8 | Sample of template C: expressing the project's ethos for the design of a set of canine-centric controls for Mobility Assistance Dogs.

document to be appropriated, modified, and even extended by other researchers as appropriate for their projects, while still maintaining its purpose. In this regard, although the toolkit was developed within the context of Interaction Design and more specifically Animal-Computer Interaction research, we propose that it could support the ethical engagement of researchers who work for or with animals in any other field of research, including within veterinary, welfare and behavioral science. Additionally, we suggest that the toolkit could foster ethical human-animal interactions in any practice settings in which humans work for or with animals or have animal care responsibility, including veterinary practice, specialist training, and even farming.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by HREC The Open University. The patients/participants provided their written informed consent to participate in this study. The animal study was reviewed and approved by AWERB The Open University. During the study, written informed consent was obtained from the dog's owners for the participation of their animals, and mediated consent was obtained from the dogs themselves with the input of their owners and trainers.

AUTHOR CONTRIBUTIONS

Based on her prior work on the design of canine-centered controls for Mobility Assistance Dogs, CM contributed to the conception of the research. As the project supervisor, she provided guidance and oversight on the design of studies and compliance with animal welfare and ethics standards. LR, as the main researcher on the project, designed and carried out the studies, conceptualized and created the first draft of the toolkit, and made use of the toolkit during the research. Together, LR and CM revised the toolkit's design and contents. LR wrote the first draft of the manuscript and CM contributed manuscript revisions. LR and CM read and approved the submitted version.

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Relevance, Impartiality, Welfare and Consent: Principles of an Animal-Centered Research Ethics

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The principles of Replacement, Reduction and Refinement (3Rs) were developed to address the ethical dilemma that arises from the use of animals, without their consent, in procedures that may harm them but that are deemed necessary to achieve a greater good. While aiming to protect animals, the 3Rs are underpinned by a process-centered ethical perspective which regards them as instruments in a scientific apparatus. This paper explores the applicability of an animal-centered ethics to animal research, whereby animals would be regarded as autonomous subjects, legitimate stakeholders in and contributors to a research process, with their own interests and capable of consenting and dissenting to their involvement. This perspective derives from the ethical stance taken within the field of Animal-Computer Interaction (ACI), where researchers acknowledge that an animal-centered approach is essential to ensuring the best research outcomes. We propose the ethical principles of *relevance*, *impartiality*, *welfare* and *consent*, and a scoring system to help researchers and delegated authorities assess the extent to which a research procedure aligns with them. This could help researchers determine when being involved in research is indeed in an animal's best interests, when a procedure could be adjusted to increase its ethical standard or when the use of non-animal methods is more urgently advisable. We argue that the proposed principles should complement the 3Rs within an integrated ethical framework that recognizes animals' autonomy, interests and role, for a more nuanced ethical approach and for supporting the best possible research for the benefit animal partakers and wider society.

Keywords: animal research, animal-centered research ethics, beyond the 3Rs, ethical scoring system, research ethics principles

INTRODUCTION

The use of animals in research is a topic that raises many ethical issues and fuels endless debates. When humans are subjected to research, it is deemed crucial that they express their consent both to the procedures they will undergo and to the use of the data resulting from said procedures. Indeed, obtaining partakers' informed consent is compulsory for both clinical trials and any other studies involving humans (e.g., British General Medical Council—Consent to Research, 2000). Additionally, it is considered imperative that the interests of human research subjects take priority over the interests of science and society (e.g., British Medical Research Council—Ethics Guide, 2004). Conversely, when the research involves the use of animals, it is widely assumed that they are unable to provide consent to the studies they are involved in, which therefore makes them "objects," rather than subjects, of experimental procedures. Additionally, it is deemed acceptable that the interests of animal subjects are subordinated to the interests of science and society, including the interests of humans or those of animal populations. Worldwide legislation generally accepts these views, and delegates assessment and decision-making authority on issues of consent and interest prioritization to the local committees for the care and use of animals in research (whose responsibility is to peruse and approve or reject experimental protocols) and to veterinarians and caretakers (who are responsible for the detection of possible discomfort and pain arising from experimental procedures).

The present work addresses the ethical and procedural implications of considering animals as active participants in research, capable of consenting or dissenting to experimental procedures, and as stakeholders in the research process, based on the relevance of the research to their own interests. This possibility has been particularly considered within the field of Animal-Computer Interaction (ACI) (Mancini, 2017) but, to the best of our knowledge, such a perspective is yet to be applied to fields of biological research that involve the use of laboratory and farm animals. To this end, this paper explores the possibility of taking an animal-centered perspective on the use of animals in research. We examine the widely applied ethical framework for the use of animals in research—represented by the principles of Replacement, Reduction and Refinement (3Rs) (Russell and Burch, 1959)—and we discuss its limitations. We introduce the animal-centered perspective that underpins research in the field of ACI and propose four ethical principles—*relevance, impartiality, welfare and consent*—to define animal-centered research. We articulate the relation of our proposed principles to the 3Rs and explore their applicability, including opportunities and challenges, to animal research in other fields. We put forward a scoring system that could help researchers assess the extent to which a research procedure complies with the four principles and apply it to three examples of published studies. We conclude by arguing that our proposed principles should complement the 3Rs within an integrated ethical framework, to help researchers and delegated authorities assess the extent to which the involvement of animals in research procedures is more or less desirable, and what adjustments might need to be made in order to increase the extent to which procedures that do involve animals are animal-centered.

LEGISLATION, ETHICAL FRAMEWORK AND PRINCIPLES FOR THE USE OF ANIMALS IN RESEARCH

The ethical dilemma about using animals in research is based on a recognition that they are capable of suffering while being incapable of consenting to procedures that can harm them. To address this dilemma, Russell and Burch (1959) proposed three principles for humane animal research. The principles of Replacement, Reduction and Refinement (3Rs) can be summarized as follows:

- Replace the use of animals with alternative techniques, or avoid the use of animals altogether;
- Reduce the number of animals used to a minimum, to obtain information from fewer animals or more information from the same number of animals;
- Refine the way experiments are designed and carried out, to make sure animals suffer as little as possible; this includes better housing and improvements to procedures to minimize pain and suffering and/or improve animal welfare.

The 3Rs have been reflected in EU legislation for decades, ever since the first legislation passed on the protection of animals used for experimental and other scientific purposes, dating back to 1986 [EC (European Council), 1986]. However, the 3Rs were spelled out in EU legislation for the first time within the Directive 2010/63/EU on the protection of animals used for scientific purposes (EC, 2010). This Directive makes the 3Rs a firm legal requirement, to be considered systematically when animals are used for scientific purposes, including basic, translational or applied research, regulatory testing and production, education and training. Over the years, the 3Rs approach has offered significant benefits for animal welfare and has substantially contributed to the improvement of animal use by stimulating the adoption of new strategies, including study design, method development and project coordination (Törnqvist et al., 2014). Some specific examples of successful application of the 3Rs, as a result of the efforts carried out by the UK's National Center for the Replacement, Refinement, and Reduction of Animals in Research (NC3Rs, https://www.nc3rs.org.uk/) can be found in the study by Burden et al. (2015). They include: (1) development of *in-vitro* models of human diseases such as asthma, in order to test novel mechanisms and targets of disease and therapeutics; (2) development of a "Rodent Big Brother" software to automatically track individual rat behavior in collective cages, in order to avoid individual housing and potentially stressful conditions which affect animal welfare and impair research outcomes; (3) use of non-animal methodologies (the non-sentient amoeba *Dictyostelium*) to predict potentially emetic compounds (drugs); and (4) design of scientifically robust alternative preclinical development pathways for monoclonal antibodies to replace or reduce the use of non-human primates.

On the other hand, there are also broad fields in which the 3Rs seem to have partially failed (or are yet to succeed) in ensuring the humaneness of research (Richmond, 2000). Firstly, the balance between the 3Rs may involve difficult trade-offs. For example, if we focus on reducing animals at all costs, using fewer animals but subjecting them to more aggressive interventions (or applying less humane endpoints) could increase the total animal suffering as a result. This is also the case when choosing between the use of a lower number of individuals of "higher species" and a higher number of individuals of "lower species" (Richmond, 2000). Secondly, most experimental protocols informed by the 3Rs seem to rely on broad indicators of animal welfare status, rather than focusing on what is meaningful for the animals (for example by using positive indicators of animal welfare), which would open completely new perspectives on refinement strategies. Thirdly, in spite of its widespread application around the globe, today there is no globally standardized way of reporting on the species-specific application of any of the 3R principles (Törnqvist et al., 2014). As a result, reporting of animal use in relation to the 3Rs varies strongly between different countries, whereas a common reference framework would allow both researchers and ethical bodies to uniformly score research protocols and assess their level of humaneness in the use of animals, therefore helping to discriminate the cases in which the application of alternative methods would be highly recommendable from those in which animals would need to be used.

Although the 3Rs are now generally advocated as the gold standard to achieve the best possible compromise between animal welfare requirements and research interests and have constituted a pillar for the development of an ethics of humane animal research, in 2006 Russell himself confessed: "I hope I won't have to write any more long repetitive papers on the Three Rs," "[I] *would like to hand over to people* [...] *who are still advancing the subject and can say something new*" (Balls, 2015). In this regard, different reviews of the 3Rs have been conducted over the years. For example, Ferdowsian and Beck (2011) argued that human research ethics is aimed at protecting the interests of individuals and populations, sometimes to the detriment of the scientific question under investigation, whereas in animal research often the importance of the scientific question being researched takes precedence over the interests of individual animals, implying the presumption that animal research should proceed based on perceived benefits to humans.

Similarly, more recently, Mancini (2017) noted how the ethical framework of the 3Rs is grounded on the consideration that the use of animals in research can be legitimized to achieve a greater good for society. Thus, within this framework, the consequences are that: (i) any costs to the animals involved can be considered acceptable based on the results of a cost-benefit analysis (i.e., whenever the expected benefits to society are deemed to warrant the envisaged costs to the animals); (ii) the procedures and protocols to be adopted in order to minimize suffering and animal use are effectively subordinated to the aims of the research (i.e., they are adopted only if they do not conflict with the purpose of the research or with the data to be collected); and (iii) there is no explicit provision for enabling animals to consent (or dissent) to their involvement or to withdraw from a procedure (i.e., animals have no control over the procedures they undergo, and are recognized for their role as research objects and representative models, rather than for their individual characteristics and needs).

In other words, within the 3Rs ethical framework animals tend to be considered instruments of research rather than participants in research (Mancini, 2017), with the most important issue being the fact that the animals involved in procedures are not deemed capable of consenting and thus are not afforded the opportunity to consent. Consent has been defined in human medicine as a voluntary, uncoerced decision, made by a sufficiently competent or autonomous person, to accept rather than reject some proposed course of action that will affect him or her (Gillon, 1985). In this sense, consent requires action by an autonomous agent based on adequate information. Consenting implies the ability to understand the contingent and the long-term implications of one's involvement (Faden and Beauchamp, 1986), but obvious cognitive differences and communication barriers make it seemingly impossible to obtain informed consent from animals. For these reasons, in animal research consent is usually not directly given by animals but transferred to and mediated by other subjects (Mancini, 2017): consent for animals is given by mediators, who are capable of understanding the wider implications of animal's involvement in experimental procedures and have the legal authority to consent on their behalf. The most common agents giving consent on behalf of animals are ethical review bodies, though in some cases owners can mediate consent for their animals (e.g., when pets are involved).

When ethical review bodies are involved, their decision to authorize (or forbid) experimental procedures must be based on (i) promoting high standards of animal welfare; (ii) implementing the 3Rs, (iii) enhancing scientific achievements; and (iv) generating a culture of care (RSPCA LASA, 2015), also in response to societal concern. These functions can only be adequately carried out with the complementary contribution of animals' daily carers, animal welfare experts and independent authorities. When an animal-owner relationship is involved, various influences may intervene. For example, historically, especially in agricultural settings, the provision of informed consent had largely an economic foundation (i.e., the need to preserve the value of the animal undergoing diagnosis and treatment by the veterinarian); more recently, economic consideration have largely been replaced by emotional and moral one, and concerns about additional aspects (e.g., quality of life, empathy, anthropomorphism, speciesism) might arise (Fettman and Rollin, 2002), whereby an owner's decisions may not always coincide with what is in the animal's best interests. For these reasons, in veterinary practice, as much emphasis is placed on preventing harm and on treating animals fairly as it is placed on allowing owners to make autonomous choices (Ashall et al., 2018), which means that in certain circumstances animal patients might be better protected outside the consent process.

The same considerations made with regards to the animal-owner relationship apply to laboratory animals or animals used in research, making therefore even more relevant the contribution of ethical review bodies, animal welfare specialists, veterinarians and animals' daily carers for the adoption of good practices in animal research. Merging the 3Rs approach with the principled approach proposed by Beauchamp and Childress (2013) for biomedical research, according to which respect for a subject's autonomy is viewed as one of four guiding ethical principles (alongside beneficence, non-maleficence and justice) (Beauchamp and Childress, 2013), could open new possibilities for reframing animal use in research. In particular, it could enable a shift from a framework in which animals are seen as research instruments unable to consent to their involvement in procedures, to one in which they are seen as research participants able to give a voluntary and autonomous contribution. In this regard, Erren et al. (2017) suggested the addition of a 4th R: recognition. The authors defined Recognition as "*crediting animals for their contribution to research by giving credit where credit is due, that is the Acknowledgments section,* *unless authorship criteria are fulfilled*." Although it could be argued that recognizing human-animal co-authorship would have mainly symbolic value, animals do indeed contribute to research both as "objects" (e.g., in basic science and as models for preclinical research—Greek and Greek, 2010; Varga et al., 2010) and as "subjects" (e.g., in cognitive research-Vonk, 2016; Boeckle et al., 2020). Therefore, recognizing non-human animals' input in contributorship statements may be ethically required, even if they do not meet the normal standards for authorship (Erren et al., 2017). Recognition might therefore be the first step toward acknowledging animals as active participants and moving toward a different way of viewing animals in research.

DIFFERENT PERSPECTIVES: TOWARD ANIMAL-CENTERED RESEARCH

Within some fields of applied research, the involvement of subjects in scientific procedures is essential to the development of new knowledge and applications. This is the case for the field of Interaction Design (ID) (Sharp et al., 2019), which focuses on the study and design of interactive systems, informed by disciplines such as psychology, ergonomics, engineering, informatics, social sciences and product design. The fundamental assumption of ID is that, in order to best support those for whom it is intended, interactive technology needs to be informed by their characteristics, as well as the characteristics of their activities, and the environments in which these activities take place. To achieve this, requirements about what a technology should do, and how, are elicited from those who have a stake in its development, primarily those who will interact with it, in order to inform alternative designs, which are then prototyped and evaluated, in an iterative process of incremental improvement. In other words, stakeholders—particularly target users—are regarded as central to the design process (Gould and Lewis, 1985) and their involvement as essential (Schuler and Namioka, 1993), because the effectiveness of interactive systems depends on the extent to which they meet stakeholders' requirements. As with any other research involving human subjects, ethics frameworks regulating research procedures within ID have always required the prioritization of individual human participants' autonomy and welfare above research and societal interests. Recently, within the field of Animal-Computer Interaction (ACI) (Mancini, 2011; Mancini et al., 2017), this ethical perspective has been extended to non-human research subjects involved in the study and design of interactive systems targeted to them.

The extension of said ethical perspective to non-human research subjects is consistent with theories of justice that acknowledge animals' fundamental entitlements, particularly Nussbaum (2006)'s capabilities approach. For the author, animals are agents capable of a dignified existence, with corresponding needs for flourishing and related goals they actively pursue, to which they have a moral entitlement. Influenced by Aristotle's insistence that humans and animals are fundamentally akin and by Marx's conception that one's true functioning depends on one's opportunity to engage in life activities more than on quantifiable resources, Nussbaum's theory extends to animals Rawls (1993) prioritization of individual liberties over societal interests and Sen (2009)'s focus on one's capability to do things one values as a measure of welfare. Thus, the author's capabilities approach differs significantly from utilitarian approaches underpinning the 3Rs, because it regards the balance between pleasure and pain too crude a measure to evaluate animals' functioning. Instead, within her approach, animals' functioning is evaluated based on the opportunity they have to pursue capabilities they value (e.g., an animal may choose to engage in an activity that has value for them even if this causes them pain), and advancing societal interests does not justify violating the capabilities of individuals (i.e., reducing the pain of many does not justify inflicting pain on the few).

Nussbaum identifies basic capabilities, which would allow animals to flourish and to which they are entitled, including: staying alive; maintaining one's bodily health and integrity; experiencing sensory and cognitive stimulation; enjoying nurturing emotions and attachments; setting goals and plans; forming intra- and interspecies affiliations and managing one's social life; having control over one's environment and safeguarding one's territorial integrity. While, for the author, the relevance of capabilities is species-specific (e.g., being killed may cause greater harm to an animal who is capable of making plans that death would frustrate than to an animal who does not have such capacity), animals should be enabled to express their species-relevant capabilities at least to a minimum threshold sufficient to guarantee a dignified existence. In this regard, while admitting that in some cases research which harms animals is still necessary, Nussbaum argues that its injustice should be explicitly recognized in order to shift the perspective from which research practices are assessed, to highlight the urgency of developing alternative practices and to accelerate related innovations.

ACI recognizes the centrality of animals' capabilities for the design of interactive systems and the importance of animals' dignified participation in research to ultimately ensure the effectiveness of said systems. Indeed, we argue that ACI's ethical approach has the potential to contribute relevant innovations in animal research more broadly.

Animal-Computer Interaction: Research for and With Animals

Animals have interacted with technology for a long time. For decades, wearable biotelemetry has been fitted on wild animals to study their behavior in open fields (Samuel and Fuller, 1994), while laboratory animals have been working with interactive devices employed within behavioral (Skinner, 1959; Dudde et al., 2018) or cognitive (Reiss and McCowan, 1993) studies; farm animals have been exposed to robotic machines deployed to automate agricultural production processes (Rossing and Hogewerf, 1997) or to train them to perform specific behaviors (Dirksen et al., 2021), while dogs have been trained to operate domestic appliances such as light switches and washing machines on behalf of their assisted humans (Mancini et al., 2016). Until recently, the use of animal technology was reported mostly within research fields such as biology or engineering, with a focus on the research for which the devices were employed, but with little or no detail related to the devices' design and to the role that animals might have played in their development.

In recent years, however, researchers have begun to investigate animals' interaction with technology within ACI (Mancini, 2011), focusing on the design, development and deployment of technology intended for animals, the role that animals play in these processes and how they are affected, not merely as sources of data, but as legitimate stakeholders and contributors. ACI extends the boundaries and core values of ID (Norman, 1986; Norman and Draper, 1986; Sharp et al., 2019) to non-human animals, whether the interaction is active and intentional (Robinson et al., 2014), active and unintentional (Mancini et al., 2015), passive and intentional (Cheok et al., 2011) or passive and unintentional (Mancini et al., 2012), dyadic and direct (Pons et al., 2014; Westerlaken and Gualeni, 2016) or distributed and indirect (Aspling and Juhlin, 2017). Consistent with the tenets of ID, if it is to be used for a specific purpose, as with operant devices, interactive technology is expected to afford good usability for animal users (e.g., being easy to learn how to use, helping users to perform a task efficiently—Zeagler et al., 2014; Robinson et al., 2015); if it is to be worn, as with biotelemetry devices, interactive technology is expected to provide good wearability for animal wearers (e.g., being imperceptible and unobtrusive, or at least acceptable to the wearer—Valentin et al., 2015; Paci et al., 2019). In any case, interactive technology is expected to provide, mediate or lead to good experience for animal stakeholders (e.g., being motivating and stimulating for a user to use, and not interfering negatively with a wearer's daily experience). As a field of research and practice, ACI takes an animal-centered perspective on the study and design of interactive systems, aiming to develop frameworks and methods that enable animals to participate in the design process as legitimate stakeholders and contributors (Mancini, 2011; Robinson et al., 2014; Westerlaken and Gualeni, 2016; Hirskyj-Douglas et al., 2017; Webber et al., 2020).

Recognizing animals as participants in and contributors to the design process is consistent with the 4th R proposed by Erren et al. (2017), but within ACI's animal-centered paradigm to designing interactive systems for and with animals, such a recognition has fundamental implications on multiple levels. Firstly, it requires that the features of an interactive product be informed by the animals' characteristics, and by the characteristics of their activities and of the environments in which they operate. In ACI design, this is exemplified by systems that feature species-specific interfaces (Resner, 2001; Jackson et al., 2013; Pons et al., 2015) or that are seamlessly integrated in learning and working processes already familiar to the animals involved (Robinson et al., 2014; Mancini et al., 2015). Secondly, an animal-centered perspective has methodological implications, whereby approaches to the design process ought to enable the animals involved to express their requirements through appropriate forms of participation consistent with their characteristics. In ACI research, this is exemplified by work in which methodologies typically used in ID or other relevant disciplines have been adapted for use in ACI projects to study interaction in context (e.g., multispecies ethnography—Mancini et al., 2012; ethnomethodology—Aspling et al., 2018), to assess the animal's experience (e.g., ethological observation—Baskin and Zamansky, 2015; Paci et al., 2016; Ruge et al., 2018—preference testing—Lee et al., 2006; Hirskyj-Douglas et al., 2017) or to elicit design requirements (e.g., "quick and dirty" prototyping—Robinson et al., 2014; high fidelity prototyping (Jackson et al., 2013; Westerlaken and Gualeni, 2016). Thirdly, animal-centered design has implications for the ethical perspective adopted by researchers, informing research practices that foster the conditions for animals' autonomous involvement in the design process as legitimate stakeholders and design contributors. Arguably, adopting an animal-centered research ethics that places animals and their interests (as individuals) at the center of the design process is a methodological requirement (Ritvo and Allison, 2014) the fulfillment of which is necessary to foster the conditions for animal-centered design. In this regard, while acknowledging that animals often find themselves involved in human practices they have neither designed nor consented to in the first place, Mancini (2017) proposes that ethics frameworks supporting animal-centered research should be informed by four core principles: relevance to part-takers, impartial treatment of part-takers, part-takers' welfare prioritization and part-takers' consent.

Fundamental Principles of Animal-Centered Research

Firstly, the principle of relevance (Mancini, 2017) implies that that animals should be involved in any research procedures only if said procedures are directly relevant and beneficial to them. According to current regulations (EC, 2010), in any cost-benefit analysis related to a procedure, envisaged benefits do not have to be to the advantage of the individual animals involved and envisaged costs to the individuals are deemed acceptable if the expected benefits to society are deemed to warrant such costs. Within an animal-centered ethics, such a separation in the benefit-cost equation, where those who pay are not those who gain, is highly problematic. However, the problem is not only ethical, it is also methodological. As mentioned above, in disciplines such as ID and ACI, working directly with stakeholders to develop interactive products that can adequately support their activities is deemed essential. If those who pay the cost of being involved in the research process are also those who are set to gain from the outcomes of the process, any input that researchers receive from their participants is far more likely to be relevant and lead to the development of a product that is ultimately fit for purpose. Conversely, working with those who have no stake in the outcomes of the design process is likely to lead to a product that does not meet user requirements. For example, working with mice to develop the touch-screen interface of a system that macaques are expected to use during tests designed to better understand their cognitive abilities would be counterproductive; in order to enable the macaques to express their abilities, the interface would need to meet the specific usability and user experience requirements of the macaques, as determined by their physical, sensory, cognitive, social and otherwise experiential characteristics.

Secondly, the principle of impartial treatment (Mancini, 2017) implies that ethics frameworks supporting animal-centered research should afford protection to all partakers, not in virtue of their characteristics (e.g., species, sex, age, provenance) and any capacities attributed to those characteristics (including sentience), but in virtue of their role (i.e., the very fact that they part-take in the research process). In current legislation (EC, 2010), only species possessing certain characteristics (e.g., a spinal cord, sentience) are protected and species regarded as companions rather than food (e.g., dogs vs. pigs in Western cultures) enjoy a higher degree of protection regardless of their characteristics, simply based on societal considerations (i.e., from a human perspective). However, within an animal-centered ethics, it is essential that researchers acknowledge and respect the individual characteristics of everyone partaking in research procedures, regardless of taxonomical or other categorizations based on what is necessarily interim knowledge. Researchers should treat all research partakers as individuals equally deserving of consideration and care according to their welfare needs (as defined below). Again, this is important, not only on ethical grounds, but also on scientific grounds. At any given time, knowledge and understanding about the implications of animals' characteristics is inevitably limited, so any form of discrimination on the basis of taxonomic distinctions is likely to bias research findings. It is only by acknowledging and respecting partakers and their characteristics without discrimination that researchers can develop research set-ups and protocols that provide the best possible understanding of those they are working with. Indeed, for a long time, researchers' anthropocentric perspective when studying other species resulted in a significant underestimation of many animals' capacities and in the development of research protocols that reflected human-centric biases, in turn hindering the development of new knowledge about those species (Vonk, 2016).

Thirdly, the principle of welfare prioritization (Mancini, 2017) highlights the importance, for an ethics framework, of prioritizing partakers' welfare at all times in order to support animal-centered research. The author refers to Stamp Dawkins (1998, 2003, 2012) definition of welfare according to which animals enjoy good welfare if they are healthy and have what they want, on the grounds that, in addition to evolving physical adaptations that allow them to thrive in their environment (e.g., a streamlined body to move underground, sharp teeth to open seed shells), animals have also evolved the capacity to want things that are conducive to their health (e.g., wanting to burrow to hide from predators, wanting to gnaw to maintain sharp teeth). Of course, being able to stay safe and acquire resources is essential to maintaining good welfare, to which end animals need to be able to make predictions (to decide what they want) and to exert control so they can act upon those predictions (to obtain what they want). Thus, within an animal-centered ethics framework, researchers should endeavor to respect the animals' biological integrity (i.e., their physical and psychological health) and autonomy (i.e., their ability to express and pursue their wants). They should avoid any procedures that could physically or psychologically harm the animals, and protect individuals from any harm (including death); they should also work in contexts that are habitual for and thus familiar to the animals, and endeavor to avoid obtruding their activities or disrupting their daily life patterns and routines. In brief, researchers should give partaking animals space for expression and control over the research process, and use only forms of interaction that are respectful of and responsive to the animal's needs and wants. Critically, according to the principle of welfare prioritization, when considering the potential impact of a procedure, any cost-benefit analysis of the research should be carried out based on the animal's best interests, and the interests of individual participants should prevail over the interests of science and society.

Although the principles of relevance, impartiality and welfare are all important when considering whether animals are used as objects for a procedure or are enabled to partake as subjects in a research process, consent is the criterion that has mostly been discussed within the related literature (e.g., Beauchamp and Childress, 2013). In this regard, Mancini (2017) argues that, within an animal-centered ethics, researchers have a responsibility to always garner the animals' consent in two complementary forms: mediated and contingent. Mediated consent would be provided by those who are capable of comprehending the wider implications of the research in relation to the animals' welfare needs, who have the legal authority to consent on their behalf, who have in-depth knowledge of partaking animals as a species and as individuals, and who have a vested interest in prioritizing the welfare of the individuals concerned. These competences might be covered by different agents (e.g., the animal's legal guardian and the animal welfare expert might be the same or two different persons; the legal authority may be provided by a legal guardian and by an independent animal welfare and ethical review body as envisaged by the European Directive (EC, 2010) but they should all be represented.

However, garnering consent from mediators would not exempt researchers from garnering consent from the individual animals themselves, since consent implies voluntary engagement and it cannot be assumed that mediators know what individual animals want under specific contextual conditions. The assumption is that, while mediators representing the animals are in a position to assess the wider implications of a procedure, the animals themselves are best placed to respond to the contextual conditions of a research set-up according to the impact that these might have on their own welfare (e.g., an animal might not want to enter an experimental space if they deem it unsafe and the very fear they might experience when in that space may have a severe impact on their welfare). Thus, contingent consent would need to be provided by individual partakers and researchers should ensure that those individuals are afforded sufficient control to make relevant choices, including the choice not to engage. If a partaker could choose the pace and modality of their engagement with a research process at any time, then their response could provide a measure of their consent to engaging with a specific research set-up. To this end, procedural set-ups should enable partakers to assess the situation as much as possible (e.g., allowing the animal to freely explore their surroundings or any research equipment before and during a procedure), to make relevant choices between alternative forms of engagement (e.g., between different ways of interacting with experimental equipment or between reward mechanisms) and to effectively withdraw or withhold engagement (e.g., plenty of escape routes or comfortable rest areas as appropriate). Since any contextual variations may affect the partaker's assessment of the situation and their willingness to engage, contingent consent should be seen as a dynamic process to be expertly monitored for signs of dissent (as is the case with non-competent human research participants—British Medical Research Council—Ethics Guide., 2007).

Principles of Animal-Centered Research Ethics and the 3Rs

The principles of the animal-centered research ethics reported above are only partly aligned with the principles of the 3Rs (Russell and Burch, 1959) discussed above. From an animal-centered perspective, the 3Rs present two fundamental limitations. Firstly, these are grounded in the assumption that animals cannot provide consent to their involvement in potentially harmful research procedures and thus provide an approach to manage the ethical conflict between animals' assumed inability to consent and the fact that human society considers their use in such procedures necessary to achieve a greater good. Conversely, the principles of an animal-centered research ethics are grounded in the assumption that animals can provide mediated and contingent consent (or dissent) to their involvement in research procedures, as long as they are allowed to assess a research set-up (and thus make predictions as to the impact on their welfare) and to choose whether and how to engage (and thus exert control to express and attain what they want). In this regard, from an animal-centered perspective, the most ethical research set-ups or procedures would need to make any potential threats to the wellbeing of partaking animals materially explicit and assessable by them, and would give them control as to whether and how to engage. Alternatively, the presentation of such set-ups or procedures would enable those who represent the welfare interests of partaking animals to assess any potential harms, enabling them to prioritize the animals' welfare.

Secondly, albeit animal-welfare-minded, the perspective underpinning the 3Rs cannot be deemed animal-welfare-centered, since procedures that are harmful to the animals involved are still permissible under the 3Rs provided certain conditions. Conversely, within an animal-centered ethics, procedures which are harmful to the participant and to which the participant does not provide consent would simply not be permissible, and the potential risks of any procedures would be primarily assessed with respect to the interests of the individual animals involved. Nevertheless, Mancini (2017) notes how the principles of refinement, reduction and replacement have various degrees of relevance for the animal-centered ethics being discussed here. In particular, the 3Rs principle of refinement is highly relevant as its application can help ensure that any (foreseen or unforeseen) procedural risks to partaking animals are minimized. In this regard, refinement of course pertains both to the design and execution of research procedures, and to their documentation and publication, and its importance for ACI research has been highlighted by Väätäjä and Pesonen (2013). The principle of reduction has relevance also in animal-centered research. But, while the involvement of individual animals should always be justified (and of course their interests should always be prioritized), the criterion of statistical power commonly used for reduction is not the only important factor to be considered, since animals are involved in research not merely as representatives of a category (e.g., species) but also as individuals with their unique characteristics (Robinson et al., 2014).

The principle of replacement, Mancini (2017) argues, is only partially relevant to animal-centered research, wherein partakers are not regarded as the substitutable components of an experimental set-up, and there is an expectation that any procedure they are involved in be relevant and beneficial to them. Therefore, replacing one species with another species (even a less sentient one) would not necessarily be appropriate or beneficial to the animals of either species, unless the individuals of the species involved as a replacement had themselves a stake in the research process. For parts of the research or development process, researchers could apply heuristics, execute technical tests and involve consenting competent humans in preliminary testing before involving the target animals; but these could not be replaced altogether, as they have unique characteristics, interests and requirements that should be allowed to inform the research process at least at key stages, with the proviso that partakers' involvement is justified and their interests prioritized.

In a nutshell, within an animal-centered ethical framework, the welfare and autonomy of individual animals taking part in procedures should always be respected and their individual contribution to the research processes and outcomes should always be sought and valued in its uniqueness. But to what extent could the principles of the animal-centered ethical framework discussed above be extended to other fields of research and practice involving animals? What might be, if any, the benefits of applying such a framework to research fields outside of animal-computer interaction? Arguably animal partakers would benefit significantly, but would research processes and outcomes also benefit and, if so, in what way, to what extent and under what circumstances?

EXPLORING THE APPLICABILITY OF ANIMAL-CENTERED RESEARCH PRINCIPLES TO ANIMAL RESEARCH

As we have seen, the ethical framework discussed above substantially differs from the general perspective regulating the involvement of animals in research in fields other than ACI, where animal research might take place (e.g., farms, laboratories, slaughterhouses and zoos). As highlighted by Mancini (2017), ethical boundaries are often context-dependent and often need negotiating in specific cases. This means that, in principle, an animal-centered ethics could be applied to a range of research contexts to reduce animal suffering or improve their quality of life. In such cases, when any of the principles of animal-centered research seems incompatible with a research procedure, it is important for researchers to acknowledge that an ethical concern arises, and that this is not due to the animals' inability to express their consent or dissent to procedures that might harm them, but rather to the prevailing tendency to involve animals as instruments in research processes in which they have no stake. The future of animal-centered ethics in animal research will likely depend on the balance between animals' participatory involvement and animals' instrumental use in research. At the same time, arguably the extent to which animals are involved in research as participants rather than as mere instruments needs to be part of the equation of what counts as "humane research." This section explores the possibility of extending the four core principles of relevance, impartiality, welfare and consent to animal research conducted in different fields. We consider each principle and how different kinds of research might score against it, along a five-point scale ranging from the highest to the lowest compliance, and what different levels of compliance might imply for animal research studies and for animal research policies more generally. Research shows that the reliability of scales drops when scale points are below five or above 10 (Preston and Colman, 2000). Five-, seven- and 10-point scales are comparable for confirmatory factor analysis or structural equation models, although five-point scales tend to be easier for respondents to use (Dawes, 2008). We propose a five-point scale scoring template as a trade-off between reliability and usability for those assessing procedures' compliance with the principles. **Table 1** provides the scoring template we propose to use.

Principle 1: Relevance to Partakers

A domain in which relevance to partakers can be immediately assessed is animal welfare research. When this kind of research is conducted, for example on farm animals, typically some experimental groups are kept under regular farming conditions (respecting all the requirements set out by animal protection laws), whereas other groups are kept under "high welfare" conditions (e.g., different flooring, bedding material, environmental enrichments, access outdoors, additional space and so on). Example studies of this kind have investigated space allowance for pigs (Nannoni et al., 2019), lighting requirements for pigs (Martelli et al., 2015), flooring systems for beef cattle (Magrin et al., 2019), straw provision and tail docking in pigs (Di Martino et al., 2013), as well as reviewing attitudes toward access to pasture by dairy cows (Charlton and Rutter, 2017). As mentioned, it is clear that the welfare of part of the animals involved in these studies is expected to be improved compared to conspecifics kept under conventional farming conditions. Also, the aim of these trials is usually to propose (or identify) a rearing system that is more respectful of the peculiar needs of the studied species. Overall, although in these trials some invasive measures (e.g., blood samplings) might be deemed necessary to assess welfare levels (e.g., stress hormones), the prospective aim of the trial is to improve the welfare of all animals of the examined species which are raised for commercial purposes. In some cases, these studies are designed to collect data at commercial farms, in order to investigate under which farming systems animals benefit from the best welfare (e.g., Regula et al., 2004—housing systems for dairy cows) or from a reduced risk of lesions (e.g., Taylor et al., 2012—tail biting risk for pigs kept in commercial farms).

In these scenarios, relevance to partakers is maximized: although not all animals participating in the trials might benefit from improved welfare, at least a portion of them does. Moreover, the prospective benefit of these studies might be extended to large populations (e.g., if acknowledged within an animal protection policy, the benefit might be potentially extended to all the animals of the same species farmed under commercial conditions in Europe). Therefore, this kind of research scores very highly against the principle of relevance. Despite this, at present, animal welfare research that directly benefits the animals involved and that might lead to considerable benefits for an entire category still needs to follow exactly the same authorization procedure as any other research protocol. We suggest that, along with fostering the development of alternative methods when research does not benefit animals, policies should facilitate this kind of animal welfare research, thus favoring the improvement of many animals' living conditions (in farms, laboratories, zoos and private houses).

A more controversial example with respect to relevance is the case of pharmacological research: in this case, a drug is tested on a species (which might be either a model or the target species) in order to assess for example its toxicity and mode of action, or to predict its effects on the target species. Whether this kind of research is to be considered beneficial for the partakers will depend on trade-offs between the possible outputs (i.e., benefit for the target species and/or for the model species) vs. the process (i.e., the severity of the procedures to be carried out and their impact on the individuals taking part in the research). Therefore, in this kind of studies, relevance could be considered moderate when animals taking part in the trial belong to the target species (or are expected to receive direct benefits from the use of the drugs in their species, even if they are used as a model). Noteworthy, in this example, is that relevance is assessed in terms of overall benefit for partakers intended as a category, and not as the individuals taking part in the trial. In the absence of direct benefit for the individuals, the highest score for relevance cannot be met. In our framework, the relevance for partakers decreases as the expected benefits decrease. We propose that relevance should be assessed regardless of the number of animals involved, as the 2Rs known as "reduction" and "refinement" are considered a prerequisite to this kind of ethical evaluation.

Principle 2: Impartial Treatment of Partakers

This principle of animal-centered research is aimed at guaranteeing non-prejudicial treatment to partakers. As the animal-centered ethics we propose values contribution and participation, we believe that, regardless of their species, sex, age, etc., each partaker in the experimental process can contribute to both research and research design. To achieve this, similarly to what has been described above for prototyping in the Interaction Design field, research should be considered as an iterative process of incremental improvement, in which iteration should be preferred over repeatability. To this end,

TABLE 1 | Scoring template for assessing research procedures against animal-centered (AC) principles.

Ethics standard	Compliance with principles of animal-centered research			
	***RELEVANCE* to partakers**	***IMPARTIALITY* toward partakers**	***WELFARE* of partakers**	***CONSENT* of partakers**
5. Very high	Procedure is directly relevant and highly beneficial for partakers	Individuals receive highest consideration regardless of their capacities	Procedure enhances partakers' welfare	Partakers are enabled to choose whether and how to engage with procedure
4. High	Procedure is relevant but benefits may not be direct or immediate	Individuals receive high consideration but not as much as others with more capacities would	Procedure does not impact negatively on partakers' welfare	Partakers are mostly able to choose whether and how to engage with procedure
3. Moderate	Procedure has some relevance but benefits are only indirect and only in future	Individuals receive some consideration but notably less than more capable ones would	Procedure has minor impact on partakers' welfare	Partakers have limited ability to choose whether and how to engage with procedure
2. Low	Procedure has little relevance and benefits are only indirect and only in future	Individuals receive significantly less consideration than more capable ones would	Procedure has significant negative impact on partakers' welfare	Partakers are mostly not allowed to dissent or withdraw from procedure
1. Very low	Procedure has no relevance whatsoever and no benefits for partakers even indirectly or in future	Individuals receive very little or no consideration compared to more capable ones	Procedure has severe negative impact on partakers' welfare	Partakers are not allowed to dissent or withdraw from procedure in any way

the involvement of animals as stakeholders in the research design process is regarded as essential, as it might lead to important design decisions and inform alternative research designs. Impartial treatment is key to enabling this process and should be guaranteed by avoiding prejudicial considerations on animals' sentience or discomfort/pain perception: all animals should be regarded as active contributors, deserving of the best welfare conditions possible, and capable of indicating consent or dissent with their behavior/physiology and to inform changes in experimental design.

Of course, we need to acknowledge that all animal research takes place within a socio-cultural, and legislative, context that does not treat different animals impartially. For example, current European regulation (EC, 2010) grants a higher degree of protection to those that are considered companion species (e.g., cats, dogs) compared to similarly complex species, consistent with the public's greater sensitivity toward companion animals. In a European context, farming cows and pigs for human consumption is regarded as acceptable by most people and is indeed legal, while farming cats and dogs for the same purpose is regarded as unacceptable and is indeed illegal. In a British context, some species, such as house mice or gray squirrels, are considered vermin and the public are encouraged to kill them and are forbidden from rescuing them, while other—similar—species, such as dormice or red squirrels, are protected under the law and harming them is an offense (Countryside and Rights of Way Act 2000 for England and Wales). Admittedly, this kind of socio-cultural and legislative bias might make the impartial treatment of individual animals partaking in research more difficult to achieve, as researchers are themselves part of the socio-cultural, and legislative, context in which they operate and which might bias their perceptions and dispositions. Nevertheless, researchers should endeavor to afford all their research partakers treatment standards equivalent to those that would be warranted to the animal species most protected under the law (the human). Research procedures that take explicit measures to guarantee impartial treatment to all partakers would score very highly against the impartiality principle.

Principle 3: Partakers' Welfare Prioritization

As described in section Fundamental Principles of Animal-Centered Research, this principle is grounded in the consideration that the interests of individual participants should prevail over the interests of science and society, and any research decision should be based on the animal's best interests. However, sometimes this evaluation is not straightforward, as it may depend upon trade-offs between the importance of preserving the animals' physical integrity (see Stamp Dawkins, 2003) and the potential benefits provided by the research. For example, during an animal welfare study, assessing whether for the animal it would be preferable to live a better life during a trial but undergo a mild procedure that affects his physical integrity (e.g., blood drawing), or not to take part in the trial at all and live a "regular" life might not be straightforward. However, we suggest that this kind of assessment is relevant for the scoring of any study against the *welfare* principle, and therefore it should be attempted to score the envisaged experimental procedures against this principle.

Additionally, it has been argued that under many circumstances killing is an inevitable consequence of animal use once they have fulfilled their scientific utility. This is sometimes true (when animals are culled because they would otherwise suffer needlessly) but is also associated with a predominantly "welfarist-utilitarian" influence, which regards death as a lesser issue (provided the killing is carried out humanely) and curtailing the life of laboratory animals as of little ethical importance (Franco, 2016). Within our animal-centered framework, we argue that the welfare of partakers should be guaranteed also after their use in research, by adopting a "no-kill" approach whenever possible. This is in line with a new set of "3Rs" (Re-use, Rehabilitation and Rehoming) according to which a high animal welfare level ensured during a trial is also maintained or even improved after the end of the trial (for an extensive review on the topic see Franco, 2016; Franco and Olsson, 2016). The application of these Rs would significantly contribute toward the higher scoring of a study against the *welfare* principle.

It has been observed that providing animals with technology that enables them to better control the functions and environments in which they are already involved affords them the possibility to exert a measure of autonomy, albeit with some conceptual limitation (Mancini, 2017), thus leading to an improvement in their welfare (Weeghel et al., 2016). This is also relevant to the prioritization of animal welfare during trials. Additionally, systems for monitoring animal welfare designed and described for on-farm use (Rushen et al., 2012; Zehner et al., 2012; Matthews et al., 2016; Caria et al., 2017) would also be useful within research environments to enable the quick identification of sick or uncomfortable animals by continuously and closely monitoring specific welfare parameters (e.g., temperature, level of activity, social behavior, use of functional areas). The use of interactive and monitoring technology during trials to enhance animal welfare would contribute toward a higher score against this principle, provided that appropriate measures were taken to guarantee the welfare of partakers (e.g., temporarily or permanently withdrawing individual animals from the trial, or arresting the trial altogether when necessary).

Apart from any ethical considerations, though, evidence shows that good animal welfare is linked to the quality of research data derived from laboratory animals (e.g., validity as models of human disease, number of animals required to achieve statistical significance, reproducibility of *in vivo* studies) (Prescott and Lidster, 2017). This is due to the fact that the endocrine condition and immunology of laboratory animals, which experimenters may assume to be normal, can be compromised by social conditions, developmental history, rough handling, inadequate environment and various stressors in the animal unit or experimental laboratory. These uncontrolled variables may make animals unsuitable subjects for scientific studies, and compel scientists to do everything practicable to ensure the happiness of laboratory animals and therefore the quality of their own research (Poole, 1997).

Principle 4: Partakers' Consent

The issue of animal consent is what triggered our conceptualization of an ethical framework for animal-centered research beyond the field of ACI. As argued above, animals used in research are usually not given the possibility to assent or dissent to the procedures they undergo. This is likely due to the belief that allowing animals to express their will might limit the execution of several procedures. It should be acknowledged that in many cases animals do clearly express their will, and that it is generally considered acceptable to overlook (to some degree) signs of distress and temporary discomfort for the sake of the ongoing trial—which highlights the need to preventively set adequate humane endpoints (Humane Endpoints, 2016). For example, although farm animals may disagree to being restrained for blood sampling, the procedure in itself is minimally painful and invasive, and results in only a temporary discomfort, so it is generally carried out regardless of the animal's dissent.

Animals' consent or dissent is likely to be evident in the choices they make during experimental procedures. One of the best examples of research in which animals are free to express their choices is the field of preference and motivation testing, whereby animals are asked to indicate with their behavior their preferences for common housing options (such as temperature, illumination, types of bedding and flooring, loading ramps, pens) and to clarify how strongly they avoid various aspects of confinement and methods of restraint (Fraser and Matthews, 1997). However, researchers warn that this kind of preferences may not always be indicative, especially if the choices fall outside the animals' sensory, cognitive and affective capacities, or if animals are required to choose between short- and long-term benefits. These aspects should be carefully considered when assessing a procedure against *consent*.

The 3Rs framework aims to achieve the best possible trade-offs between animal welfare and human benefits. However, once the 3Rs are satisfied, the experimental protocol is deemed to have satisfied all ethical requirements and is allowed to be carried out. In contrast, we propose that animal consent should be regarded as a key principle of animal-centered research. Procedures which enable participants to choose when and how to partake will score highest against this principle, whereas those which do not allow partakers to dissent or withdraw will score the lowest. Although the argument for animal consent might appear purely theoretical, our aim is to table a discussion about animal consent within the real world (where, for example, procedures carried out on animals as a model of human disease might be deemed acceptable because of their expected benefits for human health, regardless of animal consent). With our animal-centered research framework, we wish to recognize and raise awareness of the issue of animal consent as an open ethical question, in the belief that acknowledging its importance, instead of overlooking it, will eventually lead to improvements in animal use in research and related outcomes.

SCORING RESEARCH PROCEDURES AGAINST ANIMAL-CENTERED ETHICAL PRINCIPLES

As discussed above, different procedures may be more or less consistent with the principles of *relevance*, *impartiality*, *welfare* and *consent*, depending on the aims of the research and on the methods through which those aims are pursued. Scoring against each of the principles could help researchers assess the extent to which a procedure can be deemed ethical and humane from the perspective of the animals involved, based on scores across all four parameters. Clearly, a procedure that scored high against all the parameters (i.e., that was highly relevant to the individuals involved, that gave equal consideration to the welfare needs of all participants, that was highly compatible with their welfare and that enabled them to give or withhold their consent at will) would be considered ethical and humane from an animal-centered perspective. However, a procedure would not necessarily need to score high against all of the parameters in order to be deemed ethical from an animal-centered perspective.

This section presents three examples of studies conducted with animals to illustrate how our scoring system might be applied to assess a research procedure against the four principles we propose. The scoring process could be undertaken at the point of designing a procedure, to ensure maximum possible adherence to the principles, or retrospectively to evaluate a procedure against the principles and identify opportunities for improvement. The examples are based on published studies.

Example 1: Investigation of a Dog's Interaction With Dog-Friendly Controls

If a procedure was not particularly relevant to the individuals involved, but was still beneficial to someone related to them or to them in future, and if all participants were treated impartially, the procedure was not detrimental to their welfare, and they were able to choose whether and how to partake, then said procedure might still be deemed relatively highly animal-centered. As a case in point, consider a study conducted to test the readiness with which a dog might learn to use different canine-friendly prototype controls designed to facilitate the work of mobility assistance dogs routinely trained to carry out tasks, such as opening doors or switching lights (Mancini and Lehtonen, 2018). In this study, researchers trained a dog, Zena, who was not a mobility assistance dog and was not on a training program to become one. However, the task they trained her for was similar to one with which she was already familiar and the training took place in an environment that she frequented regularly. During the study, Zena was free to move around and choose whether to engage or walk away, thus setting the pace of the exercise. Bedding, water and toys remained readily accessible to her at all times during the study period. For the duration of the study, she continued to live with her guardian, maintaining her usual routine, receiving her usual exercise and consuming her usual diet; the treats used as a reward during the training sessions and the stimulation provided by the training activities were all extras. The procedure utilized an apparatus, comprising door-opening and light-switching controls, which was specifically designed with canine ergonomic characteristics in mind and which was pre-tested by humans for safety. The training leveraged classical and operant conditioning rules, whereby positive reinforcement was used to teach Zena to interact with the controls, during 4 days distributed over a 2-week period. Each day included several training sessions lasting up to 5 min each, with long breaks in between, depending on Zena's willingness to engage. Sessions were ended either by Zena herself (if she walked away), or by the researchers (if she showed signs of disengagement, including light panting, looking away, sniffing the ground or becoming distracted). Zena's participation in the process directly informed a framework for multispecies participatory design and further requirements for dog-friendly controls.

While the process and outcome of the exercise was not immediately beneficial to Zena, the procedure had relevance in the longer term as the kind of controls she was trained to use could plausibly become commercial products any dog, including her, could use to control aspects of their living environment. Since the procedure did not have immediate relevance for the canine partaker, working with mobility assistance dogs who could immediately benefit from their engagement would have been better. This limitation was partially off-set by the fact that the procedure did not have a negative impact on Zena, as it was consistent with her welfare needs and posed negligible risks, with regards to both the safety of the apparatus and the appropriateness of the training process, during which her body language was continuously monitored for signs of concern. The procedure was highly compliant with the principle of impartiality, since her needs were arguably given the same consideration that would have been given to human participants in the same position and since her input was regarded as a significant research contribution. Finally, Zena was enabled to provide contingent consent, as she could choose whether and how to engage at all times during the study. Overall, she had a significant amount of control over the procedure, and the chance to express her preferences in relation to different prototypes and the interaction modalities that these afforded. The balance of scores for this trial could be summarized as shown in **Table 2**.

In cases like the one described above, although there is clearly room for improvement, the compliance with the four principles of animal-centered research is high or very high. In these cases, animals' ability to exert their agency through their engagement choices, including contingent consent or dissent, is essential to the success of this kind of research. When the research is relevant or highly relevant and beneficial in the short or long term, enabling animals to represent their interest through participation is important, and not including them might be ethically problematic. In this regard, impartiality and welfare are key to ensuring that their participation in a procedure is unincumbered by unmet needs.

Example 2: Validation of Health Monitoring System for Cows

A procedure might not afford the animals involved the opportunity to provide or withdraw consent, but might be highly relevant to them and beneficial to their welfare, while not impacting negatively on the welfare of the participants who are treated less favorably. For example, consider a study conducted to validate a health monitoring system for cows that captured data about the animals' rumination activity, food and water intake, and locomotion (Zehner et al., 2012). The wireless system included a halter headcollar incorporating a vegetable

TABLE 2 | Assessment of the compliance of the dog controls study with the four principles of animal-centered research (Mancini and Lehtonen, 2018), with more relevant descriptors displayed in bold character.

Ethics standard	Compliance with four principles of animal-centered research			
	***RELEVANCE* to partakers**	***IMPARTIALITY* toward partakers**	***WELFARE* of partakers**	***CONSENT* of partakers**
5. Very high	Procedure is directly relevant and highly beneficial for partakers	**Individuals receive highest consideration regardless of their capacities**	Procedure enhances partakers' welfare	**Partakers are enabled to choose whether and how to engage with procedure**
4. High	**Procedure is relevant but benefits may not be direct or immediate**	Individuals receive high consideration but not as much as others with more capacities would	**Procedure does not impact negatively on partakers' welfare**	Partakers are mostly able to choose whether and how to engage with procedure
3. Moderate	Procedure has some relevance but benefits are only indirect and only in future	Individuals receive some consideration but notably less than more capable ones would	Procedure has minor impact on partakers' welfare	Partakers have limited ability to choose whether and how to engage with procedure
2. Low	Procedure has little relevance and benefits are only indirect and only in future	Individuals receive significantly less consideration than more capable ones would	Procedure has significant negative impact on partakers' welfare	Partakers are mostly not allowed to dissent or withdraw from procedure
1. Very low	Procedure has no relevance whatsoever and no benefits for partakers even indirectly or in future	Individuals receive very little or no consideration compared to more capable ones	Procedure has severe negative impact on partakers' welfare	Partakers are not allowed to dissent or withdraw from procedure in any way

oil-filled silicone tube with a built-in pressure sensor to capture jaw movements, placed over the bridge of the cow's nose, and connected to a data logger unit and a battery unit placed at either end of the silicone tube over the cow's cheeks. Additionally, the system included an accelerometer to capture body motion, placed around the cow's foot. Data related to rumination and food intake was collected from 12 cows for 14 days, water intake data was collected form 5 cows for 22 days and motion data was collected from two cows for three days.

It is unclear whether the same cows were used for collecting data on all the measures or whether different cows were used for different measures, and thus whether some of the cows were fitted with more than one device. It is also not clear whether the cows involved wore the devices for longer than the data collection periods. There is no evidence to suggest that any mechanisms were put in place to allow the cows to consent to being fitted with wearable devices that might have bothered them (particularly those mounted on the headcollar) or to withdraw from the study (e.g., if they showed signs of unease). While the devices in question do not appear to be particularly obtrusive, there is a lack of information about the possible experiential impact of the study on the welfare of individual cows. Said impact might depend on how many devices each might have been fitted with and for how long, or how each might have responded, and on whether the study procedure might have been adjusted as a result. However, the procedure took place in the animals' habitual environments and, aside from the presence of the monitors, did not involve alterations to their daily routines, behaviors and conditions, and no invasive procedures were carried out. The lack of information on the cows' experience during the study suggests that this was not deemed to warrant discussion, which in turn suggests that their perspective was not given the consideration it might have been given to human participants in the same position. On the other hand, the study had direct relevance for the participating cows as it aimed to validate tools that could monitor their welfare, something from which they themselves must have benefitted during the trials and which many other dairy cows were set to benefit from. In brief, while some aspects of the study were not necessarily compliant with our proposed principles for animal-centered research, other aspects were highly consistent with them. The balance of scores for this trial could be summarized as shown in **Table 3**.

In cases such as this, the inability of partakers to choose whether and how to engage may be offset by the fact that a procedure is very relevant and highly beneficial for them directly, presumably in the short as well as in the long therm. However, in these cases, it is important for researchers to ensure that the procedure does not impact on the welfare of the animals, particularly if they are unable to opt out. Similarly, granting them consideration as impartially as possible, compared to human participants in the same position, would help compensate for the fact that the animals are not allowed to provide contingent consent.

Example 3: Acute Toxicity Test of Pesticides With Mice

A procedure that was not relevant to the individuals involved, that did not give impartial consideration to participants, that was detrimental to their welfare and that did not afford them the opportunity to effectively withhold consent could not be

TABLE 3 | Assessment of the compliance of the cow health monitor study with the four principles of animal-centered research (Zehner et al., 2012), with more relevant descriptors displayed in bold character.

Ethics standard	Compliance with four principles of animal-centered research			
	***RELEVANCE* to partakers**	***IMPARTIALITY* toward partakers**	***WELFARE* of partakers**	***CONSENT* of partakers**
5. Very high	**Procedure is directly relevant and highly beneficial for partakers**	Individuals receive highest consideration regardless of their capacities	Procedure enhances partakers' welfare	Partakers are enabled to choose whether and how to engage with procedure
4. High	Procedure is relevant but benefits may not be direct or immediate	Individuals receive high consideration but not as much as others with more capacities would	**Procedure does not impact negatively on partakers' welfare**	Partakers are mostly able to choose whether and how to engage with procedure
3. Moderate	Procedure has some relevance but benefits are only indirect and only in future	**Individuals receive some consideration but notably less than more capable ones would**	Procedure has minor impact on partakers' welfare	Partakers have limited ability to choose whether and how to engage with procedure
2. Low	Procedure has little relevance and benefits are only indirect and only in future	Individuals receive significantly less consideration than more capable ones would	Procedure has significant negative impact on partakers' welfare	Partakers are mostly not allowed to dissent or withdraw from procedure
1. Very low	Procedure has no relevance whatsoever and no benefits for partakers even indirectly or in future	Individuals receive very little or no consideration compared to more capable ones	Procedure has severe negative impact on partakers' welfare	**Partakers are not allowed to dissent or withdraw from procedure in any way**

deemed ethical and humane from the perspective of the animals involved. Numerous examples, in this regard, are provided by procedures conducted within research aiming to primarily benefit humans, as is typically the case with pharmacological toxicity tests conducted *in vivo* using laboratory animals such as mice, rats, guinea pigs and rabbits. Consider the case of an acute toxicity study conducted to determine what dose of three different commercial toxic agricultural chemicals would result in the animals' death, how long it would take for the toxicity to manifest itself and how the animals' immune response might interact with the substance's toxicity (Belay, 2019). For this experiment, 15 Balb C mice were transported to the laboratory where the procedure was to be carried out. Nine mice underwent the procedure. The mice were divided into three groups, labeled using different colors corresponding to the pesticide that was to be administered to them. They were then placed in separate cages, where they were kept for 2 weeks under standard environmental conditions and daily feeding regime. After this time, blood was drawn from each of them, by puncturing their facial and tail veins, for immuno-assay, after which they were given 3 days to recover, before being dosed with the pesticides. Each group was dosed with a different pesticide and each mouse in the group was given a different dose, using an intragastral tube. Four hours after dosing, blood was again sampled from each mouse for post-treatment comparative immunoassay. The mice where then kept in their cages, fed daily and monitored regularly for 5 days, as opposed to the 24 h typical of acute toxicity tests. Depending on the chemical they had been administered, the mice presented with symptoms ranging from breathing problems, salivation, trembling, lacrimation, miosis, hypo-activity and general weakness. Those who received the highest doses died between 1.5 and 12.5 h after administration, depending on the pesticide; one of the mice who received the second highest dose of one of the pesticides died after 26 h; the other mice appeared to have recovered after a few days but continued to present with significant body weight loss. The conclusion of the study was that the level of toxicity and its resulting symptoms was dependent both on the administered dose and on the effectiveness of the individual's immune response; at lower doses, this seemed able to somewhat neutralize the substance's toxicity, to observe which an observation period longer than the standard 24 h had been required.

This study exemplifies a case in which animals are used as instruments of a scientific apparatus, allowing researchers to observe the pharmacological properties of a substance within a living organism. Clearly, the procedure had no benefit for the individuals involved and it is very doubtful that it had any benefits for the lab-bred species. The chemicals used for the experiment were commercial pesticides, which means their toxicity had already been tested, and the study concluded that a period longer than 24 h might be needed to fully assess the toxicity of a substance at different doses. Far from yielding future benefits for animals, this could in fact result in experimental subjects suffering for a longer period of time (e.g., one of the mice took 26 h to die of their symptoms) before being ultimately euthanized. Since it is doubtful that this kind of procedure could be legally conducted on more complex species such as primates and humans, it seems clear that the procedure did not treat the mice impartially, even though all the mice involved were treated equitably. It seems also clear that the procedure was highly detrimental to the welfare of the mice. All the mice suffered from severe symptoms due to the substance's toxicity and some died as a result of the symptoms' acuity. It is unclear what happened to the surviving mice at the end of the 5 days of the experiment, but it is likely that they were euthanized. It is also unclear what kind of caging system the mice were kept in and whether any comforts, such as nesting materials or boxes or other forms of enrichment, were provided and how their separation affected them. Finally, no mechanism seems to have been in place to enable the mice to express consent or dissent to their involvement, or to choose whether and how to engage with the procedure. They were transported and kept in cages, which presumably they were not able to leave, and were dosed via intragastric tube, which suggest that they had no choice as to whether to ingest the substance. Had they known what consequences being dosed would have, it is doubtful that they would have consented to the procedure. The balance of scores for this study could be summarized as shown in **Table 4**.

While this kind of studies may be deemed necessary for the advancement of scientific knowledge and for the development of technologies, including pharmaceutical products, that are beneficial to humans, it is important to acknowledge the full extent of the impact that these procedures have on animal subjects. In particular, where a procedure such as the one described above scores low or very low against the principles of relevance, impartiality, welfare and consent, this should to be fully acknowledged and every effort should be made to develop alternative methods to study the same phenomena. In these cases, using our proposed scoring system, could help researchers and delegated authorities to sharpen the focus on such a necessity and further support the case for replacement.

CONCLUSIONS

The principles of the 3Rs originally proposed by Russell and Burch (1959) are universally regarded as the gold standard for regulating the use of animals in research. They were developed to address the ethical dilemma that derives from the fact that, on the one hand, animals cannot provide informed consent to research procedures that can harm them but, on the other hand, their use in potentially harmful procedures is deemed necessary to achieve a greater societal good. This ethical perspective assumes that animals are unable to assess the implications of a procedure and to consent or dissent to their involvement; because of this inability and of the experiential impact that a research procedure may have on them, it is assumed that their use should be limited, although it is permissible where warranted by a cost-benefit analysis. Although the aim of this ethics framework is to protect animals, such cost-benefit analysis does not prioritize the role and interests of the animals in question. In other words, the 3Rs reflect a process-centered perspective that regards animals as instruments within an experimental apparatus.

However, animals' growing exposure to and interaction with technology is increasingly highlighting the importance of taking an animal-centered perspective on doing research and design, which is informing the fast-developing field of ACI. A growing body of ACI research shows how involving animals in research as legitimate stakeholders and partakers can benefit both the animals and the processes in which they are involved by giving partakers the opportunity to inform design outcomes that are relevant to them and to other stakeholders (including humans).

TABLE 4 | Assessment of the compliance of the mouse acute toxicity study with the four principles of animal-centered research (Belay, 2019), with more relevant descriptors displayed in bold character.

Ethics standard	Compliance with principles of animal-centered research			
	***RELEVANCE* to partakers**	***IMPARTIALITY* toward partakers**	***WELFARE* of partakers**	***CONSENT* of partakers**
5. Very high	Procedure is directly and highly beneficial for partakers	Individuals receive highest consideration regardless of their capacities	Procedure enhances partakers' welfare	Partakers are enabled to choose whether and how to engage with procedure
4. High	Procedure is relevant but benefits may not be direct or immediate	Individuals receive high consideration but not as much as others with more capacities would	Procedure does not impact negatively on partakers' welfare	Partakers are mostly able to choose whether and how to engage with procedure
3. Moderate	Procedure has some relevance but benefits are only indirect and only in future	Individuals receive some consideration but notably less than more capable ones would	Procedure has minor impact on partakers' welfare	Partakers have limited ability to choose whether and how to engage with procedure
2. Low	Procedure has little relevance and benefits are only indirect and only in future	**Individuals receive significantly less consideration than more capable ones would**	Procedure has significant negative impact on partakers' welfare	Partakers are mostly not allowed to dissent or withdraw from procedure
1. Very low	**Procedure has no relevance whatsoever and no benefits for partakers even indirectly or in future**	Individuals receive very little or no consideration compared to more capable ones	**Procedure has severe negative impact on partakers' welfare**	**Partakers are not allowed to dissent or withdraw from procedure in any way**

It is evident that, when allowed the opportunity, animals are capable of providing *contingent consent* to their involvement and that animal-centered research has the potential to yield the best research outcomes. In other words, existing work in ACI highlights the need to move beyond the 3Rs to integrate these very important principles within an ethics framework that recognizes animals as active partakers and contributors, motivated by their own interests and capable of consenting or, indeed, dissenting.

This paper has explored the possibility of taking an animal-centered perspective on the use of animals in research, beyond the field of ACI. In particular, we have discussed the applicability of what we propose as the four core principles of animal-centered research—*relevance, impartiality, welfare* and *consent*—to diverse research scenarios, highlighting opportunities and challenges. We have proposed a scoring system against which the extent to which a research procedure aligns with these principles could be assessed and, as a way of illustration, we have applied this to three different examples of research studies involving animals. These examples illustrate how our proposed principles could help researchers and delegated authorities consider when the involvement of animals in research might be in their best interests and, conversely, when using alternative methods (Replacement) or the minimizing the number of animals used (Reduction) would be most desirable (as with Example 3). The application of our proposed principles could also help identify where improvements to a procedure (Refinement) should be considered (as with Example 1), or when a less than ideal condition (e.g., the inability to withdraw from a study) might be at least partially off-set by another condition (e.g., the direct benefit of partaking) making a procedure acceptable from an animal-centered perspective (although the overall purpose of the research might not be entirely animal-centered, as with Example 2). While the animal-centeredness of a research procedure would ideally require that all four principles be met, the range of our examples aims to illustrate that a procedure could still be regarded as humane depending on the balance between different principles; for example, if a procedure is not relevant to an animal but presents virtually no risk to their welfare, or if an animal is given the opportunity to withdraw from a procedure that may present welfare risks.

We acknowledge that our proposed framework is general. We believe that its generality is a strength, as it makes it applicable to any procedure and for any species. At the same time, its generality is also a weakness, as it leaves its application open to possibly widely varying interpretation when applied to specific procedures and specific species. To support the standardization of the framework's application, species-specific criteria could be developed to help researchers and delegated authorities consistently score a procedure to determine the extent to which the research aligns with animal-centered principles. Although we believe that a five-point scoring scale might be easier to use and sufficient, particularly when complemented by specific scoring criteria, a more detailed (up to 10-point) scale could also be used.

Notwithstanding these different options, we argue that our proposed principles should complement the 3Rs within an integrated ethical framework that recognizes animals as autonomous agents with their own interests, as primary stakeholders in experimental procedures and as legitimate research contributors. We argue that such recognition, and the application of the envisaged integrated ethics, could support the best possible research for the benefit of animal partakers and wider society.

AUTHOR CONTRIBUTIONS

CM and EN have contributed to the ideation and discussion of the argument proposed by the article and to the writing of its presentation within it, including the drafting of different sections and revisions of the overall draft. Both authors contributed to the article and approved the submitted version.

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Quantifying canine interactions with smart toys assesses suitability for service dog work

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There are approximately a half million active service dogs in the United States, providing life-changing assistance and independence to people with a wide range of disabilities. The tremendous value of service dogs creates significant demand, which service dog providers struggle to meet. Breeding, raising, and training service dogs is an expensive, time-consuming endeavor which is exacerbated by expending resources on dogs who ultimately will prove to be unsuitable for service dog work because of temperament issues. Quantifying behavior and temperament through sensor-instrumented dog toys can provide a way to predict which dogs will be suitable for service dog work, allowing resources to be focused on the dogs likely to succeed. In a 2-year study, we tested dogs in advanced training at Canine Companions for Independence with instrumented toys, and we discovered that a measure of average bite duration is significantly correlated with a dog's placement success as a service dog [$Adjusted\ OR = 0.12,\ Pr(>|z|) = 0.00666$]. Applying instrumented toy interactions to current behavioral assessments could yield more accurate measures for predicting successful placement of service dogs while reducing the workload of the trainers.

KEYWORDS

quantified interactions, computational behavior, Canine Companions for Independence, animal behavior, instrumented toys

Introduction

A *service dog* is a dog that is specifically trained to aid a person with a disability (1, 2). There are upwards of 500,000 active service dogs in the US at present time. To become a service dog, candidates go through ∼2 years of extensive training. Depending on their program and the career they are best suited for, raising and training costs can reach up to \$50,000 per candidate (3). Programs like Canine Companions for Independence (CCI), who breed their dogs specifically for temperament suitable for service dogs, still incur significant cost. Even with CCI's large breeding and puppy raiser program, as many as 60% will fail in training due to behavioral issues. Identifying quantifiable features and "profiles" for which dogs are likely to succeed or fail in their program as early as possible has the potential to increase availability and save millions of dollars in training and living expenses. This goal is important specifically because CCI is a nonprofit, and these dogs are either gifted to their recipients or are sold at a loss to the centers that train them.

Traditional predictors of training success for service dogs (detailed in section Existing research on behavioral testing) require subjective methods of temperament assessment. *Temperament* is the inherent nature of a dog, which affects (often unalterably) their behavior (4). For example, a dog's temperament can be generally calm, or fearful, or aggressive.

Currently, the accuracy of generalizable behavioral evaluations have been shown to range between 64 and 87% (5). And while specificity, which is the true negative rate and highlights correctly identifying dogs who should fail out, is somewhat consistent, ranging between 81.8 and 99.6%, the sensitivity, which is the true positive rate and looks at correctly identifying which dogs should be placed, varies between 3 and 85% (5). The problem we address in this research is to strengthen the consistency of the true positive rate of identifying dogs who should successfully be placed as service dogs and, hopefully, in identifying for which programs they would be best suited for.

Due to this variability in accuracy and true positive rate, veterinarians and animal behaviorists are calling for robust quantitative measures of canine behavior and interaction (6–9). In search of a quantifiable measure of temperament, researchers have identified four components to measure the validity of a temperament test: the test must be (1) conducted and (2) evaluated consistently across all participants; (3) it must be reliable and, ideally, replicable with significant correlations; and (4) it must accurately measure what the experimenter is attempting to measure—in other words, it must exhibit internal validity (10, 11).

In Byrne (12), we discussed the construction of instrumented toys for predicting suitability of service dogs. Although the prediction was effective (87.5% accurate) and would save CCI over five million dollars a year in resource costs, we had not yet delved into understanding the factors that made the predictions so accurate. In this new study, we investigate if the quantified toy interactions have any explanatory effects on the outcomes of the service dogs. As John Spicer says, "it is possible to make successful predictions without being able to explain why these predictions work. Similarly, the workings of a phenomenon may well be explained, but predicting its future states may be impossible because of the many other factors that enable or prevent the occurrence of these states" (13). In this article, our research investigates *why* our predictions work and provides an understanding of which computational play-based interactions are indicative of service dog suitability.

Existing research on behavioral testing

The rate of success for most service-dog-in-training programs hovers around 30–50% of dogs entering a program (14–16). To improve these numbers, assorted subjective behavioral tests have been leveraged over the past 80 years by service dog groups and breeders to varying degrees of success (17–21). Recently, researchers have even employed biometric means such as imaging dogs' brains with fMRI (14, 22) and eye-tracking (22) to obtain behavioral information. Due to behavioral variability in canines, the animal behaviorist community has not been able to standardize a specific vocabulary fully describing the complexity of behaviors. Even the label "temperament" has been defined differently across researchers. For example, in their survey of the literature, Diederich and Giffroy (11) compared the relationships across the definitions of temperament and stated that "it implies that these differences (in temperament) are: (1) present at an early age; (2) elicited in a set of situations; (3) (relatively) stable over time."

To assess temperament, evaluators observe canine responses to objects and other stimuli, such as audible or olfactory stimuli (23). These tests typically include behavioral ratings (reactions) to a stimulus such as a noise or a novel visual stimulus (such as a man in a hat or an umbrella opening). Because they are subjective, they also rely on the intuition and experience of the evaluator. For example, as part of the C-BARQ temperament test, the analyst rates a dog's reaction to "sudden or loud noises (e.g., thunder, vacuum cleaner, car backfire, road drills, objects being dropped, etc.)" on a 5-point Likert scale from no fear or anxiety to extreme fear (24).

In their review, Bremhorst et al. (5) discuss the current state of temperament assessment techniques, reporting that assessment tool accuracy is only 64–87% accurate according to studies (25–27). However, the ability of these tools to predict which dogs will fail is extremely variable, as low as 3% accuracy up to 85% accuracy. Overall, the tests tend to bias the results toward keeping a dog in a program; they rarely recommend releasing a dog in error. They also found that adding physiological prediction methods (such as fMRI) in combination with behavioral tests produce better accuracy (14, 28).

Within the last 5 years, researchers have been increasingly investigating prediction of a dog's suitability using these qualitative assessments. Harvey et al. show that adaptability, body sensitivity, distractibility, excitability, general anxiety, trainability, and stair anxiety can predict outcome; discusses the use of thresholds and scales to assess dogs ($n = 1{,}401$) (29). Additionally, Bray et al. (30) show that a decrease in body tension during an exam, a decreased reactivity to noise and prey, a decreased resistance to handling, and increased recall response in the presence of another dog are related to success.

Toward the quantified assessment of behavior and computational ethology

In recent years, there have been calls for more universal and measurable definitions of behaviors and behavioral categories (6, 31). Based on a survey from 174 biologists and 3 biology societies, Levitis et al. define behavior as "the internally coordinated responses (actions or inactions) of whole living organisms (individuals or groups) to internal and/or external stimuli, excluding responses more easily understood as developmental changes (32)." Extending this definition, a unit measure of behavior can be defined as a specific spatio-temporal distribution of an animal's body parts ("behavior category/unit/element") and the likelihood of those actions occurring in some order. These actions can occur sequentially or in parallel and should be related to context, aka they should exhibit "connectedness" (e.g., a tucked tail and the baring of teeth are less likely to occur in the presence of a familiar, friendly human) (33). According to Miklòsi, "the quantitative assessment of behavior [measures] the temporal distribution of these predefined behavior categories" (33). Furthermore, Miklòsi decomposes the complexity of measuring behavior as understanding behavior categories and ethograms, the temporal dynamics of behavior, splitting and lumping behaviors, arbitrary behavior measures that exist, and the importance of intra- and inter- observer agreement (33).

In the emerging field of computational ethology, the goal is to facilitate the automation of quantifying animal behaviors, particularly in ways that do not alter the animal's interactions (9, 34). Current literature focuses on using computer vision techniques for pose estimation and tracking, and the automatic behavior analysis from audio (34, 35). However, recently, Mealin et al. show extremely promising results using inertial measurement unit (IMU) data for predicting a dog's performance with 92% accuracy on the behavioral checklist (BCL), a behavior scoring system developed for and in collaboration with several US service dog organizations (23, 36, 37). Their research looks at the relationship of on-body, passive-sensing methods, specifically capturing electrocardiography and inertial data, to the activities and physiological responses exhibited during the BCL evaluation tasks (23, 36, 38). Recently, Menaker et al. (39) have started to look beyond this analysis and investigate the implications of these techniques and their ability to provide information for improving a researcher's decisions with respect to data analysis. In this paper, we approach computational ethology from the perspective of the object being interacted with, capturing actions (9) using rule-based methods (34) that are difficult to quantify using video-based techniques that rely on human coding to identify behaviors.

Advantages of quantifying canine behavior

In *Toward a Science of Computational Ethology*, Anderson and Perona state that the "reliance on human observation to score behavior imposes a number of limitations on data acquisition and analysis" (9). They list the limitations of human observation as (1) it is slow and time-consuming, (2) it is not precise and is inherently subjective, (3) it is low-dimensional, (4) it is limited by the capabilities of human vision, (5) it is limited by what humans can describe in language, and our favorite, (6) "it is mind-numbingly boring (9)." Together, these factors can influence a study's sample size, and consequently, its statistical power and the theoretical reliability of results. Without proper considerations, the potential for various observer ascertainment biases is limited by the tools of measurement (36). In contrast, quantified methods, such as sensors and biometrics, can provide more accurate measurements that do not require tedious human observation. Data can be collected and processed with computation such as machine learning to identify patterns in the behavioral data, making temperament evaluation more efficient and effective. Sensors can also detect subtle differences in behavior that cannot be reliably observed by a human, such as the bite pressure on a toy.

Limitations of quantifying canine behavior

There are a variety of different approaches to measuring canine activities, including body-worn sensors and video analysis (40); however, these approaches all have similar limitations. When we employ sensors to measure something, we receive valuable data about behavior, but we also introduce several constraints. First, we restrict ourselves to only what the sensors can measure (33). Aspects of the behavior that are not specifically measured by the sensors can be lost. Secondly, by adding on-body sensors or cameras in the environment, our measurements potentially introduce bias into our systems (41). For example, Clara Mancini showed how the placement of GPS on a collar changed the ranging behavior of both human and canine participants (42). Lastly, Miklòsi states that sensor systems can only recognize those categories of behavior that had been previously defined (33). In other words, sensors are unlikely to detect novel or previously unobserved behaviors.

Experimental methodology

This section summarizes our background study described in Byrne et al. (12). Our goal was to create devices that do not require training. Fetch toys are among the most common objects used in play between humans and dogs (43). Although different breeds tend to vary in their desire to play with a ball, the retrievers that CCI raises and trains tend to enjoy toy play. Consequently, we designed new sensors in the form of common toys with which many dogs naturally engage. We built a self-contained, ball-shaped sensor approximately the size of a tennis ball consisting of food-safe silicone. We designed the

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instrumented ball-shaped sensors so that they could be used with or without a human so we could test for changes in interaction with the instrumented toys when humans were not directly involved in the play. Prior research indicates that companion dogs prefer play activities and interactions that involve humans over asocial interactions (44). Therefore, we wanted to be able to test whether the toys with human interaction, vs. the toys alone, could tell us anything about a dog's eventual success.

Ethics

The methods and materials were reviewed and approved by the Institutional Animal Care and Use Committee (IACUC), the animal subject ethics board, at the authors' institution. The experimental protocol (A14109) was informed by conversations with DogStar Technologies and Canine Companions for Independence (CCI).

Participants

We collected data from 48 dogs undergoing advanced training at the CCI facilities in parallel with Berns et al. (14), as they performed their fMRI experiments on the same cohort. All the dogs were either Labrador retrievers, golden retrievers, or lab/golden crosses. All of these dogs were purpose-bred for the CCI program. Eight of these dogs were selected for other programs outside our scope (breeding or diabetic alert) or released due to medical reasons and were removed from our cohort, leaving us with 40 dogs. Some of the dogs were still in advanced training and some were already released; however, we were blind to the outcomes of the dogs during the study to prevent bias. All dogs had basic obedience training and socialization and were between 17 and 21 months old, which is the age that the puppies transition from their puppy-raiser homes to advanced training at the CCI training centers. More detailed information on the demographics can be found in (12). At the end of our study, we learned that of the 40 dogs, 10 were released due to behavioral reasons, which varied from excessive barking to fearfulness of riding an elevator. The remaining 30 dogs successfully finished advanced training and were placed in one of five categories. They could be placed as a skilled companion, a service dog, a hearing dog, a post-traumatic stress disorder (PTSD) dog, or a facility dog, each of which has varying levels of service dog skills involved. Table 1 shows the dog outcomes for the study.

A skilled companion typically has a calm temperament (as assessed by the CCI trainers), no health issues (as assessed by CCI veterinarians), and basic obedience training. They are placed with individuals who cannot manage a dog by themselves, such as children or non-independent adults with disabilities. A service dog assists with both physical tasks and provides emotional support for independent individuals with a disability. A hearing dog is trained to recognize different sounds for the hearing impaired. A PTSD dog is trained to help veterans who suffer from flashbacks or other PTSD-related conditions. A facility dog is trained to work with a professional therapist or teacher to help multiple individuals, such as at a school or therapy facility.

TABLE 1 Demographics and outcomes of the service dogs.

Outcomes	#
Service dog	17
Skilled companion dog	6
Facility dog	4
Hearing dog	1
PTSD dog	2
Behavioral release	10
Medical release (removed)	3
Breeders (removed)	4
Diabetic alert dog (removed)	1
Total dogs	**48**

Data collection process

We tested the dogs with a silicone instrumented ball (described in detail below). We traveled to CCI's National Headquarters in Santa Rosa, CA four times, testing a total of 48 dogs. We were blind to any history on the dogs other than names and ages, to reduce bias in the study. CCI trainers brought the dogs to us and took them back to the kennels after the study; we did not observe them outside of the study. We tested each dog with ten trials of each of the two ball conditions in a randomized order, with at least 30 mins of rest between:

1. Ball sensor, rolled by human (researcher)
2. Ball sensor, rolled down a ramp (machine)

We performed ten trials of each condition for each dog, for a total of twenty trials per dog. Each run of ten trials was video recorded, and after each run, the device's battery was changed, and the data and video were uploaded to determine if any loss occurred. If there was a loss, we re-ran the missing trials. Each trial was video recorded from two perspectives. One camera was near the researcher, allowing us to review the trials from the perspective of the researcher, and another camera was at the other end of the room focused on the researcher, to capture early interactions.

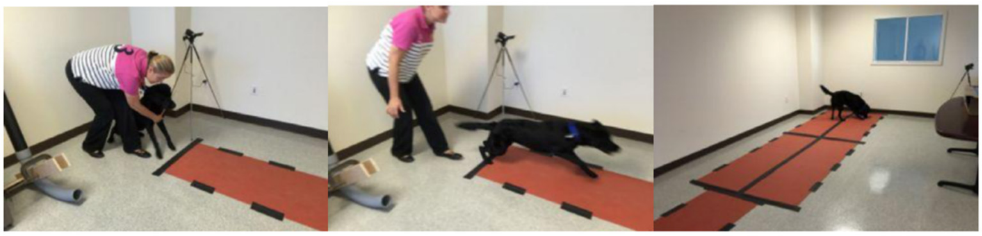

FIGURE 1
Ball-Human Sensor experiment setup. The experimenter rolls the ball, and then (left) the dog is mildly restrained for one second, and (middle) released to pursue the ball. The dog then retrieves and interacts with the ball (right).

Silicone ball sensor experiment

The silicone ball sensor experiment was conducted in a closed room, with the shades drawn, to prevent distraction from trainers and other dogs. Figure 1 shows the experimental setup for the ball-human condition. Both conditions had a $15' \times 4'$ wide section of the floor covered in 5 mm non-slip PVC mats so that, as the dogs ran after the ball, they wouldn't slide and hit the wall. Before and after each dog's session, we ran a magnet along the length of the ball so that we knew the exact start and finish times. After each session, the sensing board was removed from the silicone enclosure and the data was uploaded and removed.

Condition 1—Ball rolled by a stranger. For the first condition, a researcher unfamiliar to the dogs stood at the end of the "runway" and rolled the ball toward the other end, holding the dog back for one second before releasing the dog.

Condition 2—Ball released by machine/ramp. For the second condition, the dog started each trial next to a ramp, which was a tube with a curved end constructed of PVC pipe (shown in Figure 2). Researchers put the ball into the ramp and released it, simultaneously releasing the dog.

Instrumented ball data collection system

The instrumented ball sensor is composed of an inner ball and an outer ball, both molded from silicone. As shown in Figure 3, the inner ball (bottom) has an opening to accommodate inserting the electronics and has a locking mechanism to prevent the outer ball from rotating on the inner ball. The outer ball (top) has an opening to allow insertion of the inner ball. The outer ball protects the electronics and provides air space for the barometric pressure sensor to operate. When a dog bites the sensor, the air pressure inside the ball increases, and the electronics record the pressure on an SD card.

Bite force estimations

Tools for measuring bite force continue to be developed, however, we can provide an approximation of expected bite forces per breed and by weight. Hyytiäinen et al. constructed a bite sleeve embedded with compression force sensors and found that on average German Shepherd Dogs (GSD) ($n = 7$) and Belgian Shepherd Dogs, Malinois (BSDMs) ($n = 13$) police dogs produced a median bite force of 360.4 Newton (N) and 247.0 N, respectively (45). Lindner et al. (46) use a rawhide-covered force transducer to measure bite force across 22 pet dogs that range in weight and size. On average, literature shows that dogs ranging between 11 and 23 kgs exhibited 168 N of bite force, with a range of 66–340 N. Dogs ranging between 23 and 34 kgs had a mean bite force of 180 N (range 40–367 N) and dogs heavier than 34 kgs had a mean bite force of 442 N (range 184–937 N). Ultimately, we can expect service dogs to exhibit a bite force of anywhere between 44 N and 937 N.

However, there are several important differences between measuring bite force and the work presented here. First, it is important to note that tools for capturing bite force measure at the point where the teeth meet the sensors. Our work, however, is not measuring bite force but is measuring the variability of pressure within the ball. We use this as a proxy for capturing bite strength, assuming that there is a linear relationship. Secondly, the measurements are dependent upon the type of sensors used. For example, a series of compression force sensors, such as those in the Hyytiäinen et al. paper, will provide high granularity force measurements across a sleeve, providing a range of localized measurements where presumably the force closer to the temporomandibular joint (fulcrum) is higher than the forces exhibited by the canine teeth; whereas a single-dimension transducer, such as the Lindner paper, will provide an average bite force across the rawhide "plate." We did not perform a full calibration of our instrumented ball to capture the mapping of pressure to force, however, the lack of calibration doesn't affect the model's ability to discriminate dogs' performance. This calibration will be included in future work.

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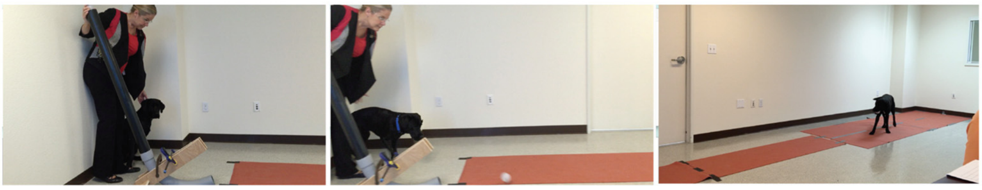

FIGURE 2
Ball-Ramp experiment setup. The experimenter drops the ball down the enclosed ramp and then (left) the dog is mildly restrained for one second, and (middle) released to pursue the ball. The dog then retrieves and interacts with the ball (right).

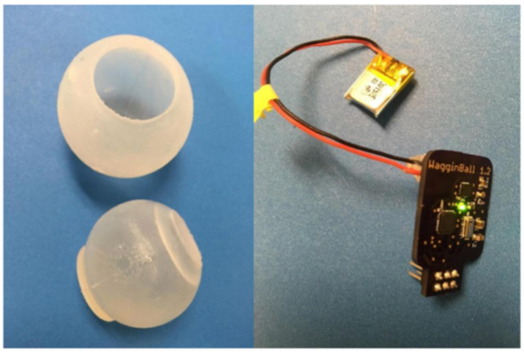

FIGURE 3
Ball sensor. left: outer ball and inner ball; right: electronics and battery that are placed inside the inner ball.

Instrumented ball implementation

The electronics consist of a custom printed circuit board that we designed. A barometer and a 9-axis inertial measurement unit (IMU) were integrated into the board. The barometer is a sensor that measures the changes and variations in internal pressure based on the ambient internal air pressure. We chose this barometer specifically for its calibration specifications—the value provided for barometric and atmospheric pressure accounted for pressure sensor linearity and the variability in ambient temperature, such as a city's altitude[1]. Data was collected in kiloPascals (kPa).

Additionally, our electronics incorporated an IMU device to capture the force and angular movement exhibited on the ball. Specifically, the IMU collected changes in X, Y, and Z values of the accelerometer, gyroscope, and magnetometer. The accelerometer in the IMU measured the rate of change in velocity, which allowed us to capture some "kill behaviors" (shaking toy) as well as characterize the intensity and duration of the dog's play behaviors. The IMU's gyroscope measured orientation and angular velocity, and let us quantify movement "gestures," as well as detect a rolling ball. The magnetometer in the IMU measured the strength and direction of magnetic fields and gave us the opportunity to perform a sync trigger with a small magnet useful for synchronizing our data collection with the video recording.

Lastly, the translucence of the ball allows researchers to observe the green light inside, indicating that the board has power. We built two new boards for the ball sensors and six new silicone balls to prepare for our first test at CCI.

1 Miniature I2C Digital Barometer.16.

Analysis methodology

Our previous analysis focused on predicting whether a service dog would be placed in advanced training; however, for this study, we were interested in constructing hypotheses about the differences and relationships of toy interactions between successfully being placed as a service dog or not. Using the data from our final cohort of 40 dogs, we start by engineering features and generating a set of summary statistics of the trials. Next, we used a general linear model (GLM) with a binomial probability distribution over a dog's individual trial summary features to explore which interactions were more likely to be exhibited by service dogs who are placed in homes. Additionally, to gain more insight into how these relationships change with respect to each feature, we estimate service dog success given specific instrumented ball interactions. This analysis was conducted in RStudio (47).

Feature engineering of the instrumented ball

One primary method for automatic behavior classification is to use rule-based methods for feature engineering. The disadvantages of this method according to Egnor and Branson (34) are that rule-based detection is difficult to tune; it may depend only on a minimal number of features; it fails for more complicated behaviors; and it rarely generalizes well. Here, we are more interested in looking at the base features, constructing summaries of these interactions as opposed to building out trajectories over time. The primary advantage of feature engineering is that it allowed us to simplify our model, making it faster to run and easier to understand and maintain over time. Feature engineering allowed us to also understand the underlying behaviors of the different dog classes and therefore provide further insight into how these tools can benefit working and service dog programs.

We constructed 22 features from the raw data of each of the ball conditions. We constructed these features from observations during previous generic canine interactions. To generate the trial summary statistics, we calculate a core set of features and then determine the average, maximum, and total measurements of these features during each trial. These features are visualized in Figure 4.

For the instrumented ball, our features were:

- Interaction Time: the amount of time required for a single trial, from the time the ball rolled out of the ramp or hand until the dog retrieved the ball to the handler.
- Number of Bites: the number of times the pressure crosses a threshold during each trial in a dog's session.
- Average bite strength: the peak pressure throughout the duration of a bite.
- Average bite duration: the amount of time between the beginning and end of a bite.
- Average bite frequency: number of bites in a trial, divided by the length in seconds of that trial.
- Average bite RMS: the root mean square of all pressure samples throughout the duration of a bite.

General linear model

The trial summary statistics data is an unbalanced dataset, where the number of trials was between 8 and 10. The general equation for GLM is:

$$y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \ldots + \beta_k X_{ki} + \varepsilon_i,$$

where the binary response variable, y_i, $i = 1$, is modeled by a linear function of a set of k explanatory variables, $X = (X_1, X_2, \ldots X_k)$, plus an error term. β represents the coefficients, or weights, for their associated variable X.

Before conducting our analysis, we used a heatmap correlation matrix (shown in Figure 5) to identify the highly correlated features and determine which features lack multicollinearity. We then remove the variables with high inter-correlations and perform the analysis with the five following independent, explainable variables:

1. Average bite duration: Average bite duration within a trial.
2. Average bite strength: Average peak pressure throughout the duration of a bite.
3. Interaction time: the amount of time required for a single trial, from the time the ball rolled out of the ramp or hand until the dog retrieved the ball to the handler.
4. Peak bite frequency: The maximum number of bites in a trial, divided by the length in seconds of that trial.
5. Condition: This feature can either be "human" or "ramp".

We then calculate the odd ratios for each feature, which provide us with an estimate and the confidence intervals of a relationship between our binary outcomes (48).

Estimated marginal means

We use the output of the GLM to calculate the estimated marginal means, and their confidence intervals. The estimated marginal means provides us with the mean response for each class, adjusted for each of the covariates (49), and visualizes the deltas between classes.

To calculate the estimated conditional expectation of Y we use:

$$E[Y = y \,|X_i = x, X_{condition}],$$

where Y is the outcome and X is the expectations of the outcomes given the independent variable on the x-axis and the condition. We provide a corresponding plot to show the expectation of predicted outcome over the range of each feature.

Results

In total, we ran 960 trials (10 trials * 2 conditions * 48 dogs). We discard the 160 trials collected from the dogs removed from our cohort. Out of the remaining trials, the dogs didn't interact with the instrumented ball for 41 of the trials in the "Machine/Ramp" condition and 36 of the trials in the "Human" condition. We report those as zeros in the data. For example, in Figure 6, you will see an average bite strength of zero in the plots and this refers to zero interaction.

Adjusted odds ratios

Adjusted odds ratios provide an interpretable measure to the general linear model output. These adjusted odds ratios provide insight into the strength of correlation of a feature to an outcome while also controlling for other predictor variables. Thus, we use this adjusted odds ratio to discuss feature importance. The "Intercept" gives us the "base" log odds, which is the log odds when all the variables are 0, and the coefficients that are associated with a variable give us how much that log odds increase every time the corresponding variable goes up by 1 unit. Per the results shown in Table 2, both Average Bite

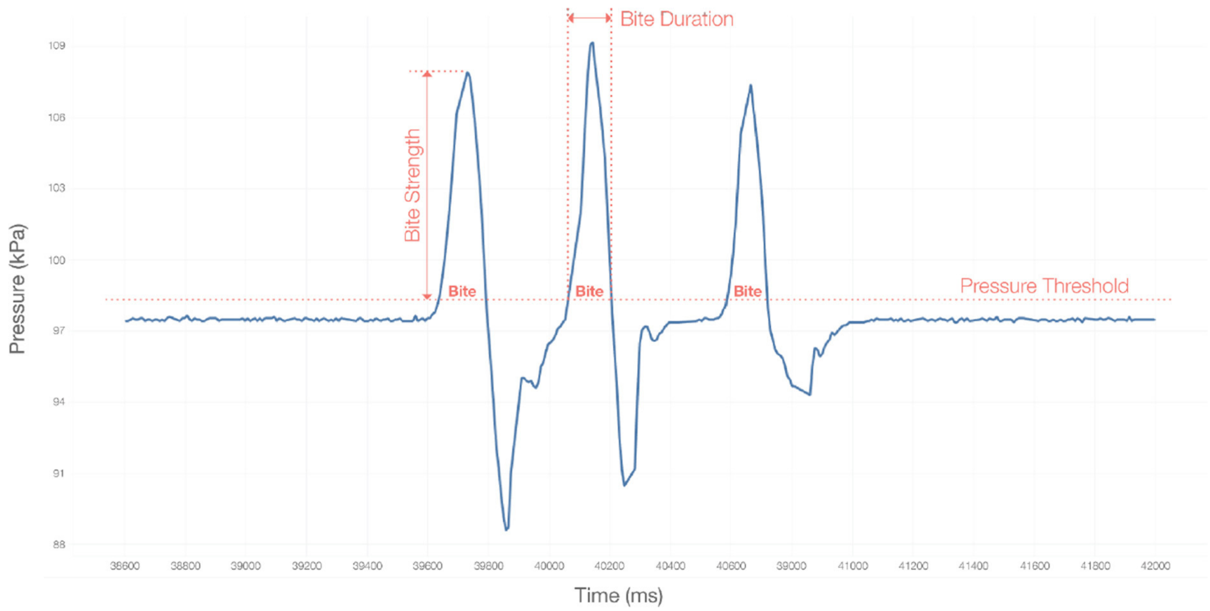

FIGURE 4
A visual description of the engineered bite.

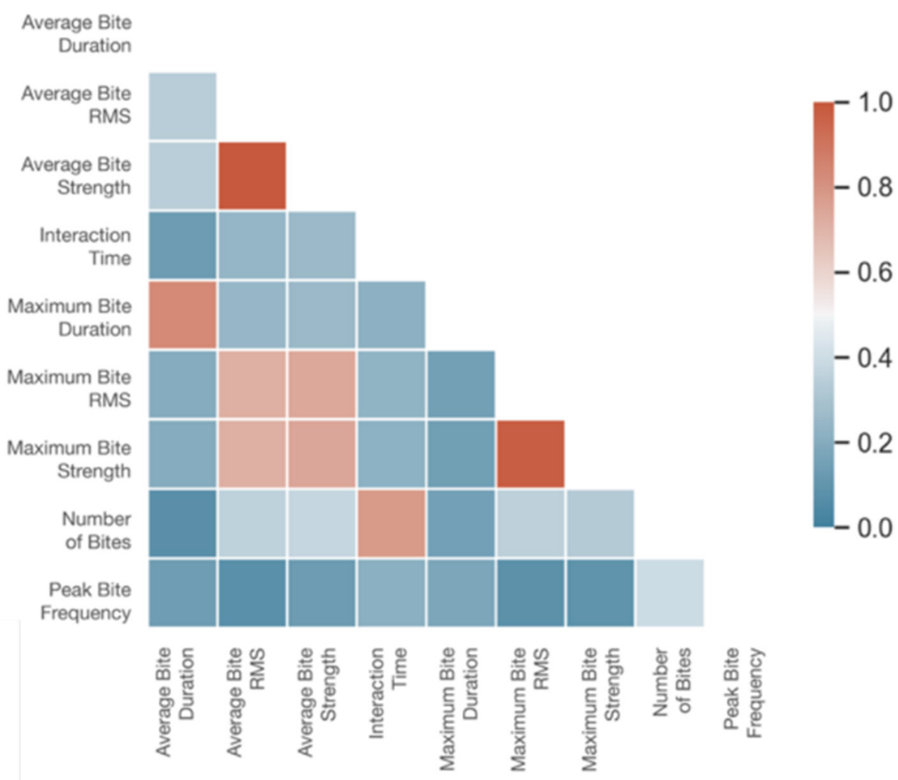

FIGURE 5
Correlation matrix of CCI features collected by the instrumented ball (modeling feature importance with respect to class).

10.3389/fvets.2022.886941

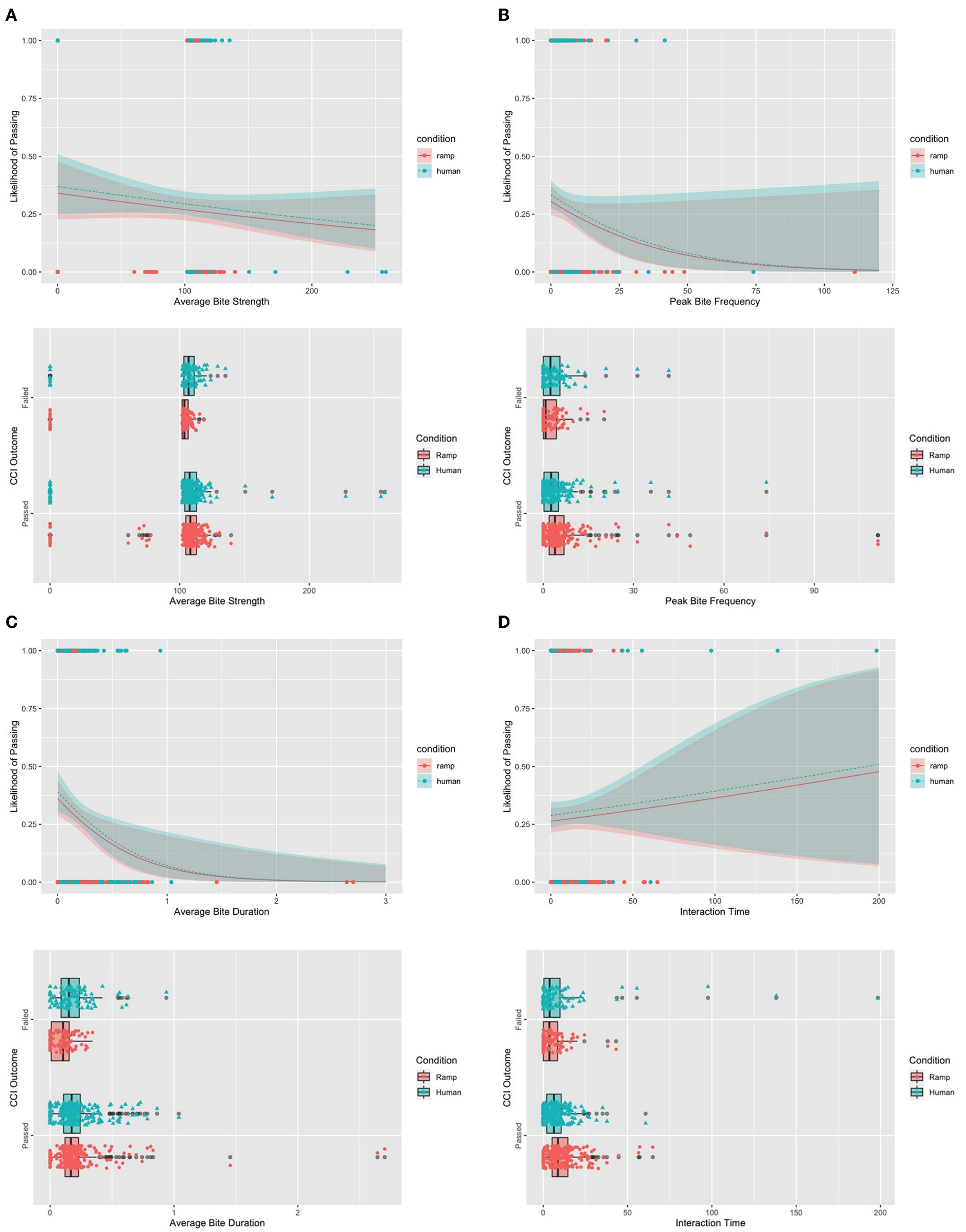

FIGURE 6
Likelihood and distribution plots for each feature. **(A)** Top: The likelihood of passing the CCI criteria using average bite strength plotted by condition. Bottom: Distribution of average bite strength for each condition plotted against CCI outcome. **(B)** Top: The likelihood of passing the CCI criteria using peak bite frequency plotted by condition. Bottom: Distribution of peak bite frequency for each condition plotted against CCI outcome. **(C)** Top: The likelihood of passing the CCI criteria using average bite duration plotted by condition. Bottom: Distribution of average bite duration for each condition plotted against CCI outcome. **(D)** Top: The likelihood of passing the CCI criteria using interaction time plotted by condition. Bottom: Distribution of interaction time for each condition plotted against CCI outcome.

Duration *[Adjusted OR = 0.12, Pr(>|z|) = 0.00666]* and Peak Bite Frequency *[Adjusted OR = 0.97, Pr(>|z|) = 0.07264]* show decreased odds with the likelihood of becoming a service dog. Across all four features we see that the human condition is more likely to provide us with higher and potentially more precise estimates of passing the criteria for being a service dog at CCI.

TABLE 2 Adjusted odds ratios of the general linear model for CCI outcomes.

	Adjusted OR	2.5%	97.5%
(Intercept)	0.88	0.56	1.40
Average bite strength	1.00	0.99	1.00
Peak bite frequency	0.97	0.93	1.00
Average bite duration	0.12	0.02	0.49
Interaction time	1.00	0.99	1.00
Condition (Human)	1.13	0.80	1.60

Distributions and their estimated marginal means

To understand the influence of these features further, we display the estimated conditional expectation, or likelihood, of being placed as a service dog for each feature: Average Bite Strength (in Figure 6A, Top), Peak bite frequency (in Figure 6B, Top), average bite duration (in Figure 6C, Top), and interaction time strength (in Figure 6D, Top). The line in these plots shows the estimation of a dog passing against a feature, while the ribbon displays the 95% confidence intervals associated with those estimations, and the points display the data points of each class. Per the legend, blue features refer to the Ball-Human condition, while the red features refer to the Ball-Ramp condition. Below each likelihood plot, we also provide a boxplot displaying the distributions of each feature across conditions and CCI outcomes (see in Figures 6A–D, Bottom).

We also provide the mean, minimum, and maximum values of the independent features for each condition. Average values across the entire cohort of dogs are reported, as well as the mean, min, and max values for the dogs who succeeded in being placed (pass) and the dogs who did not succeed (fail). Values for the Ball-Ramp condition can be found in Table 3 and values for the Ball-Human condition can be found in Table 4. The primary goal of these tables is to give insight into what the range of values looked like when the dogs *were* interacting with the ball. Therefore, we did not include trials where the dog did not interact with the ball in this analysis. These "zero-interaction" trials, however, were included in the estimated marginal means analysis.

Average bite strength

Average bite strengths for interactions with the Ball-Ramp condition range between 60 and 139 kPa, reporting a mean strength of 108 kPa. For trials interacting with the Ball-Human condition, on average the dogs exhibited a minimum of 102 kPa bite strength and a maximum of 258, where the mean bite strength hovered around 111 kPa.

Looking across the outcomes of each dog, we see that dogs who do not get placed, who fail, demonstrate a range of average bite strength, within the Ball-Ramp condition, from 102 to 119 kPa, with a mean value of 106 kPa when they interact with the toy. For the Ball-Human condition, however, their average bite strengths range from 101 to 135 kPa, with a mean value of 109 kPa, and demonstrate a wider range of values than in the Ball-Ramp condition when they interact.

Dogs who are placed in a role have a wider range of average bite strength when they interact in the Ball-Ramp condition, from 60 to 140 kPa, with a mean bite strength of 109 kPa. In the Ball-Human condition, we find that the minimum values of bite strength stay around 102 kPa, similar to the dogs who fail, however, their maximum average bite strength values within a trial can go up to 258 kPa when the dog interacts with the instrumented ball. Their mean bite strengths are also slightly higher than the dogs who fail, at 112 kPa.

The distributions at the bottom of Figure 6A visualize some of the trends. The plot shows higher ranges of bite strength when the dogs are interacting with a human and that the bite strength shows higher variability for dogs who are placed. The top of Figure 6A shows a downward slope in the likelihood of passing for dogs who have a higher bite strength, suggesting that dogs who have higher bite strength will not become active service dogs.

Peak bite frequency

When the dogs interact with the toys during the trial, the average peak bite frequencies in the Ball-Ramp condition range between 0 and 111 max bites/trial time (s), with a mean frequency of 7 max bites/trial (s). Contrastingly, the dogs exhibit average peak bite frequencies for the Ball-Human condition between 0 and 74 max bites/trial (s), however their mean values are similar to the Ball-Ramp condition, around 6 max bites/trial (s). The range in general for peak bite frequency in the Ball-Human condition appears to have less variability. Interestingly, the zeros as minimum values here demonstrate that there is a quick but minimal interaction with the toy, as showcased by the low values in average bite duration and interaction time.

For dogs who do not get placed, their peak bite frequencies in both the Ball-Ramp and Ball-Human conditions show ranges of 0–20.20 and 0–41.67 max bites/trial (s), respectively. The Ball-Human condition shows more variability in dog interaction, as their mean values are slightly higher at 4 max bites/trial (s).

TABLE 3 Mean, min, and max values for each independent feature for the ball-ramp condition (feature average and by outcome; does not include trials with zero interactions).

	Avg bite strength (kPa)			Peak bite freq [max #/trial time (s)]			Avg bite duration (s)			Interaction time (s)		
	Avg	Pass	Fail	Avg	Pass	Fail	Avg	Pass	Fail	Avg	Pass	z
Mean	108.07	108.96	105.97	6.82	7.16	3.44	0.21	0.24	0.14	10.95	12.11	8.19
Min	60.33	60.33	101.83	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.02
Max	139.61	139.61	118.65	111.11	111.11	20.20	2.70	2.70	0.34	64.95	64.95	43.18

TABLE 4 Mean, min, and max values for each independent feature for the ball-human condition (feature average and by outcome; does not include trials with zero interactions).

	Avg bite strength (kPa)			Peak bite freq [max #/trial time (s)]			Avg bite duration (s)			Interaction time (s)		
	Avg	Pass	Fail	Avg	Pass	Fail	Avg	Pass	Fail	Avg	Pass	Fail
Mean	111.04	111.87	109.13	5.56	4.58	4.44	0.23	0.23	0.21	9.77	8.64	12.37
Min	101.86	101.93	101.86	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01
Max	258.19	258.19	135.27	74.07	74.07	41.67	1.04	1.04	0.94	198.50	60.72	198.50

The dogs who do get placed show peak bite frequencies of 0 to 111 max bites/trial (s) in the Ball-Ramp condition, with a mean peak bite frequency of 5 max bites/trial (s). For the Ball-Human condition, we find lower values, ranging from 0 to 74 max bites/trial (s), with a mean value of 5 max bites/trial (s). While the means of the two conditions are the same, the variability differs.

Overall, the variability between dogs who are placed and dogs who do not get placed is very different. Interestingly, in the distribution plot of Figure 6B we see that when the dog does not get placed, the distribution is wider in the Ball-Human condition, while the distribution is wider in the Ball-Ramp condition when the dog is placed. In Figure 6B's estimated marginal means plot, we see that the likelihood of passing the CCI criteria decreases as peak bite frequency increases.

Average bite duration

On average, the average bite duration when a dog interacts with the instrumented toy in the Ball-Ramp condition, we see a range between 0.01 and 2.7 s, with a mean time of 0.21 s. The average bite duration ranges in the Ball-Human condition go from 0.01 to 1.04 s with a mean score of 0.23s—slightly higher than the Ball-Ramp condition.

Looking at the dogs who do not get placed, we see that when the dogs are interacting with the toys in the Ball-Ramp condition, their bite durations last on average between 0.01 and 0.34 s with a mean time of 0.14 s. In the Ball-Human condition, the bite durations that the dogs exhibit on average range from 0 to 1.04 s, with a mean value of 0.23 s.

The average bite durations for dogs who do get placed demonstrate do not appear much different. The dogs who interact with the ball in the Ball-Ramp condition showcase ranges from 0 to 2.7s with a mean bite duration of 0.24 s; meanwhile, the average bite durations in the Ball-Human condition are lower, ranging from 0.01 to 1.04 s with a mean value of 0.23 s.

In the distribution plot at the bottom of Figure 6C we see that the distributions across conditions for dogs who pass are similar. However, we see differences in average bite duration within the set of dogs who do not get placed and between the dogs who get placed and the dogs who do not. Additionally, as we can see in Figure 6C, as the average bite duration increases over time, the estimated likelihood of that dog passing reduces.

Interaction time

Lastly, we look at the differences in interaction time. On average, we find that active trials in the Ball-Ramp condition had mean interaction times of 10.95 s, with a range of 0.01–64.95 s. The Ball-Human condition shows a slightly lower mean interaction time, 9.77 s, but wider spread from 0 to 198.5 s.

Diving into the dogs who did not get placed, we see that the average interaction time during the Ball-Ramp condition extends from 0.02 to 43.18 s with a mean of 9.18 s. Contrastingly, we see that the interaction times range from 0.01 to 198.5 s in the Ball-Human condition and have a mean value of 12.37 s.

The differences in interaction times for dogs who were placed lie in the mean values of the distribution. In the Ball-Ramp condition, the interaction times ranged from 0.01 to 64.95 s with a mean interaction time of about 12 s. The interaction times for the Ball-Human condition range from 0.01 to 60.72 s and have a mean value of 8.64 s.

As shown in Figure 6D, the mean values and ranges within conditions are inverted between dogs who are placed and dogs who are not. Furthermore, in the estimated marginal means plot of Figure 6D, we see an upward trend in interaction time for dogs who are more likely to become a service dog. However, the high variance exhibited by the confidence intervals suggests a lack of confidence in that estimation.

Discussion

The primary goal of this research was to assess whether instrumented toys, and computation in general, could provide more insight into what a successful service dog means. The instrumented ball showed promise as a method for helping characterize temperament by using rule-based methods for engineering features that are difficult to quantify using other techniques. Previously, we showed that these toys can predict whether a service dog is placed, but not why our predictions are successful.

In this study, we analyze the engineered features within each trial using a GLM with a binomial probability distribution to determine which features and interactions were more likely to be exhibited by successfully placed service dogs. Furthermore, we estimate the likelihood of service dog success and plot how those change as the interactions change. We identify that average bite duration and peak bite frequency contribute the most to our understanding of service dog suitability using these toys, as their odds ratios show some level of significance. One hypothesis as to why average bite duration and peak bite frequency is important is that service dogs are taught to bite precisely, such as biting to pull a sock off a foot, and we could potentially be capturing the differences in dogs who treat the ball as a play object as opposed to a "thing to precisely interact with." These findings, however, support previous studies which have shown chewing as an important feature for predicting service dog placement (30).

Additionally, it is important to highlight that within our characterization of a dog's average bite duration and peak bite frequency, the distribution of the data has more variability in the "ramp" condition for dogs who "passed" or were deemed suitable for service dog work. Furthermore, the distribution of data across all four features shows the mean scores are slightly lower when interacting with a human. This finding suggests that dogs who show less interest in playing with a human are more likely to successfully be placed.

Except for interaction time, the dogs who do not get placed as service dogs exhibit a narrower range of distributions for each independent feature. Reflecting on the study, interaction time is interesting because two of the 13 dogs who failed played "keep away" or became aggressive when the humans rolled the ball, extending the interaction time. This behavior again suggests that the relationship with any human is nuanced.

In the past, hesitation has been expressed at the inclusion of both conditions as it can be tedious to run multiple studies; however, the distribution plots show the importance of having a human involved in the study implementation as well as not having a human participating. Again, this appears to be supported by literature.

The relationship of correlation and prediction

Tying this analysis back to our original work, we discuss the individual feature performance of the instrumented ball interactions (12). In the prior prediction analysis, we summarize the individual trial data used in this analysis to generate statistics across a dog's entire session. Using a subset of these features, we were able to predict a dog's suitability with 87.5% accuracy.

While investigating the validity of our prior research, we showed that variations of the number of bites and average bite duration independently provided between 72.5 and 82.5% accuracy of predicting whether a dog would be suitable for placement within a home, as shown in Table 5.

The analysis presented in this paper supports the prior prediction analysis. As a result, we can provide insight into why our computational play-based interactions are indicative of service dog suitability. In particular, we can say that as a dog takes longer to bite on their instrumented balls, the likelihood of that dog being placed in a home reduces significantly.

Limitations

We used f2, a power analysis method for general linear models, within RStudio's pwr package to calculate how many dogs we would need to run to achieve statistical significance. With the 5 coefficients we use in the GLM, 0.5 statistical significance, a small expected effect size, and a goal to achieve a 0.80 power level, we would need to collect ~641 data points. Since we use both ramp and human conditions, we collect 20 data points per dog, which equates to 33 (to be inclusive) dogs worth of data for each research question. Our research achieved these significance numbers for the Service Dog analysis.

The majority of our limitations lie with our hardware and our software. Our initial experiments highlighted situations in which the sensors could fail and allowed us to make them more robust. Initial problems included:

Silicone failure

Initially, dogs could bite hard enough to puncture the silicone and consequently damage the electronics inside. We experimented with different densities and thicknesses of silicone and discovered that a harder silicone prevented the ball from

TABLE 5 Individual feature performance metrics in predicting service dog placement (adapted for relevance).

	% Accuracy	Precision	Recall	*F*	MCC	AUC
Max # bites—ball ramp	82.5%	0.821	0.825	0.803	0.480	0.798
Avg # bites—ball ramp	80%	0.792	0.800	0.766	0.385	0.780
Max # bites—ball human	75%	0.563	0.75	0.643	0.000	0.500
Avg bite duration—ball ramp	72.5%	0.679	0.725	0.690	0.131	0.510

being punctured. We used the same silicone density and hardness for all of the testing in the CCI study.

Hardware failure

In general, the hardware did not fail unless the ball was punctured. However, we did have a few instances of the battery being unplugged, or the SD card being ejected by bites that perfectly aligned with those junctures. We solved this by wrapping the inner electronics in soft fabric to cushion them and to keep them from moving around inside the inner ball.

Inner ball rotation

Some of the harder-biting dogs were able to compress the outer ball enough that the inner ball could rotate inside of it, allowing the opening to be exposed. This problem was exacerbated by the fact that the dog's saliva could lubricate the two pieces of the ball to allow them to slip more easily, so dogs that interacted longer were more likely to rotate the inner ball. We describe a fully-contained ball in our future work.

Future directions

Self-enclosed

We completed all testing with the original nested-ball sensor design for continuity. However, we have been designing and experimenting with a fully-enclosed silicone ball that would be superior for "real world" use. This improvement would minimize damage to the internal components and speed testing, because the ball would not need to be disassembled to upload the data and change the battery. It would also allow for us to capture data wirelessly, transmitting all of the data reliably.

Additional testing to boost accuracy and increase generalizability

To further refine and verify Smart Toys, we intend to continue testing what we have discovered on new cohorts of dogs. As mentioned earlier, the cohort we tested required training to enter an fMRI and to participate in being scanned. Given that the normal graduation rate is 40% and that the graduation rate of this set was 75%, we wonder if the ball could help reject dogs in the average cohort of CCI candidates even more accurately than suggested in the testing above. Investigating dogs in other service programs would allow us to extend the generalizability of this framework to a wider class of working dogs.

Leveraging activity recognition to understand the quality of each interaction and how it changes over time

Our goal for this study was to initially examine what it would take to predict the success and failure of service dogs. Opportunities exist to dive deeper and investigate how a canine's interactions vary across different temperaments. For example, do dogs with varying levels of reactivity or attachment have different bite patterns? We are also intrigued by the possibility of using changes in our features to determine the ongoing health of an individual dog or their ability to perform their duty on a given day.

Exploring the relationship of familiar humans and strangers

We know that there are differences in which portions of the dog's brain activate when seeing humans of varying familiarity. The results above show evidence that play interactions are altered when a human is involved and their importance to successful placement as a service dog. Given the socialization strategies used by most service dog organizations and the fact that these dogs are placed in new homes, it would be interesting to study how varying levels of familiarity influence quantified play behavior.

Conclusion

In this study, we have shown that play-based interactions measured using an instrumented ball can quantify a canine's object-play behavior. We also constructed a novel methodology for building and evaluating predictive models that forecast the suitability of puppies successfully completing advanced training. Exploring outputs from the sensors allowed us to identify various features that are more valuable for the prediction of a service dog and we used these features to validate our original predictive model demonstrating 87.5% accuracy. Furthermore, we discuss why these models are effective models that could be significant for helping service dog organizations reduce the cost of training dogs, increase the efficiency of their programs, and enable trainers to spend more time developing dogs with temperaments more suitable for service dog careers.

Data availability statement

The datasets presented in this article are not readily available because we do not have approval to share this dataset with others. Requests to access the datasets should be directed to cearabyrne@mit.edu.

Ethics statement

The animal study was reviewed and approved by IACUC, Georgia Institute of Technology. Written informed consent was obtained from the owners for the participation of their animals in this study.

Author contributions

MJ, TS, and CB developed the experimental protocol and designed the toys. MJ and CB ran experiments. CB conducted the data analysis under the advisement of MJ and TS. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Clustering for Automated Exploratory Pattern Discovery in Animal Behavioral Data

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Traditional methods of data analysis in animal behavior research are usually based on measuring behavior by manually coding a set of chosen behavioral parameters, which is naturally prone to human bias and error, and is also a tedious labor-intensive task. Machine learning techniques are increasingly applied to support researchers in this field, mostly in a supervised manner: for tracking animals, detecting land marks or recognizing actions. Unsupervised methods are increasingly used, but are under-explored in the context of behavior studies and applied contexts such as behavioral testing of dogs. This study explores the potential of unsupervised approaches such as clustering for the automated discovery of patterns in data which have potential behavioral meaning. We aim to demonstrate that such patterns can be useful at exploratory stages of data analysis before forming specific hypotheses. To this end, we propose a concrete method for grouping video trials of behavioral testing of animal individuals into clusters using a set of potentially relevant features. Using an example of protocol for testing in a "Stranger Test", we compare the discovered clusters against the C-BARQ owner-based questionnaire, which is commonly used for dog behavioral trait assessment, showing that our method separated well between dogs with higher C-BARQ scores for stranger fear, and those with lower scores. This demonstrates potential use of such clustering approach for exploration prior to hypothesis forming and testing in behavioral research.

Keywords: machine learning, clustering, animal behavior, behavioral testing, Data Science

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1. INTRODUCTION

Measuring behavior is key to behavioral testing, as well as many other behavior-related research methods in ecology, neuroscience, veterinary science, psychology, and many more. Traditionally, it is done through direct observation, and involves carefully designed steps: choosing the behavioral categories to observe, defining them in precise terms (usually they can have types of either event or state), deciding on the type of measurement, sampling method, etc. The seminal book "Measuring Behavior: an Introductory Guide" by Martin and Bateson (1) provides an excellent introduction to this topic.

However, it has long been acknowledged that relying on human observation imposes severe limitations on behavioral data acquisition and analysis. As highlighted by Anderson and Perona (2), it is first of all a laborious and tedious task, limiting the volumes of processed data, as well as the number of analyzed behaviors or behavioral variables. But even more importantly, human analysis of behavior is prone to *subjectivity*.

It strongly depends on human perceptual abilities, leaving lots of room for human error and making efficient tacit knowledge transfer in training. Moreover, human understanding and interpretation of behavior is in itself subjective and sometimes inconsistent.

The need for promoting objective and quantifiable assessment and measurement of behavior [cf. (3–5)] pushes forward the emerging field of computational animal behavior analysis (2, 6), in which a variety of machine learning (ML) techniques are employed for animal behavior analysis. The release of the deep learning framework DeepLabCut (7) has unleashed the potential of video-based motion tracking and pose recognition in many animal species. Additional tools such as EZtrack (8), LEAP (9), DeepPoseKit (10), idtracker.ai (11) provide more light-weight options, large group tracking and more features.

Yet even our AI-supported abilities to analyze animal behavior remain inherently human-biased in a number of aspects. First of all, most of the tools mentioned above are based on supervised learning approaches, meaning that they learn from data annotated by human experts. But humans also choose the behavioral parameters for AI to recognize, usually based on some a-priori hypotheses. As highlighted by Forkosh (12), "We can now track the position of every fly's leg or immerse a tiny fish inside a virtual world by monitoring its gaze in real time. Yet capturing animals' posture or gaze is not like understanding their behavior. Instead, behaviors are still often interpreted by human observers in an anthropomorphic manner. Even newer tools that automatically classify behaviors rely on human observers for the choice of behaviors". Forkosh suggests focusing on animal personality as a roadmap to human-free interpretation of behavior, as personality is linked to behavior and can be quantified objectively.

Hsu and Yttri (13) refer to methods in which pre-established (by humans) criteria are applied to behavioral data as "top-down", reiterating the problematic aspects of supervised machine learning classifiers are trained to replicate their user's annotations. They suggest *unsupervised learning algorithms* as an alternative route to overcoming this gap. Such methods allow for searching hidden patterns in data without making a-priori hypotheses or deciding on specific parameters to measure. One of the most important unsupervised learning problems is *clustering* (14, 15), which aims to find structure in a collection of unlabeled data by extracting useful features. Clustering means in a sense organizing objects into groups, the members of which share some similarity, and discovering the characteristics of this similarity. A cluster is therefore a collection of objects which are "similar" between them, and are "dissimilar" to the objects in other clusters.

A paradigm shift toward less supervised and more "human-free" automated analysis methods can recently be observed in many animal-related fields. In neuroscience, for instance a new generation of tools such as MotionMapper (16) and MoSeq (17) allow for "human-free" discovery of behaviors through clustering sophisticated motion representations and have been applied in neuroscience for the study of behaviors of mice (17), zebrafish (18), fruit flies (16), and more. A similar shift can be observed in ecology, where unsupervised approaches are applied to analyze animal movement trajectories (19–21).

While more attention is turned toward unsupervised approaches in neuroscience and ecology, this topic remains under-explored in the context of dog behavior, and specifically—behavioral testing. As a consequence of their living close to humans as pets, working or sheltered animals, dogs exhibit immense behavioral variability, stemming from their innate capacities as well as from environmental influence (22). Therefore, methods of *canine behavioral testing* are popular in research and practice. They are extensively used in cognitive science, veterinary science, working dog organizations, shelters for various purposes such as selection for breeding (23), learning abilities (24), prediction of suitability for work (25), adoptability in shelters (26), animal models for human diseases (27), welfare (28), and many more.

Machine learning approaches are only beginning to be applied in the context of canine behavioral testing. As such testing usually involves dogs freely moving in a room or outside, in naturalistic settings. Automating those approaches present additional challenge as they have mainly been applied in a "top-down" manner, i.e., for supporting manual coding and checking specific hypotheses. For instance in (29), automated analysis was used to support behavioral testing analysis in a multi-method study on canine attachment to care-giver. In (30), supervised machine learning methods were used to classify hyperactive behavior of dogs visiting a veterinary clinic.

To the best of our knowledge, the route of *unsupervised* learning in the context of behavioral testing has not yet been explored. Yet, similarly to the advantages discussed above, it has potential to reduce human bias and allow the exploration of a huge space of patterns without making a-priori hypotheses about the data. In contrast to traditional methods of data analysis in animal behavior research, where a hypothesis is made to identify parameters for coding, using unsupervised exploration one can discover many new options and combinations.

This study aims to explore this idea, providing a concrete framework for its implementation in the context of behavioral testing. Due to the exploratory nature of this research, we apply clustering techniques to *movement trajectories*, which present a simplified representation of the dog behavior during testing. These trajectories can be obtained by automated tracking, therefore providing a completely automated pipeline. We evaluate our approach on a case study of "stranger test" behavioral testing, aimed to detect aggression and fear toward strangers. We demonstrate that our approach is able to identify clusters of dogs which are aggressive and fearful toward a stranger and those who are less so, providing concrete characterization of these groups in terms of objective features related to their movement. However, these results can only be viewed as preliminary work in progress due to the small amount of samples that were available to us in this dataset, and future extension of the validation to larger datasets is needed.

The rest of this article is structured as follows. Section 2 presents our case study, which will be also used as a running example for demonstrating the different aspects of our approach: a dataset of 30 dogs, tested in a "stranger test" protocol aiming

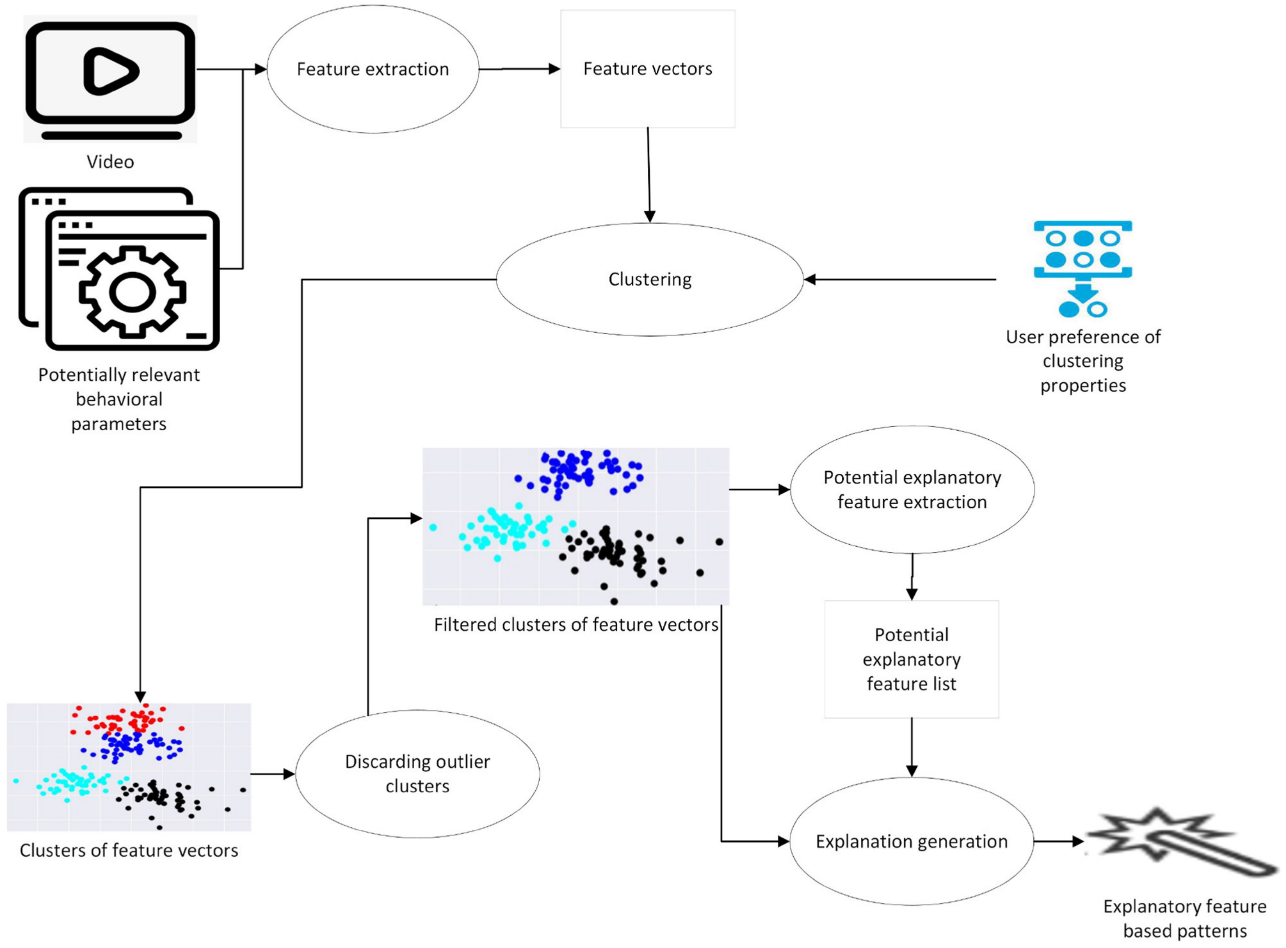

FIGURE 1 | A high level overview of the general approach.

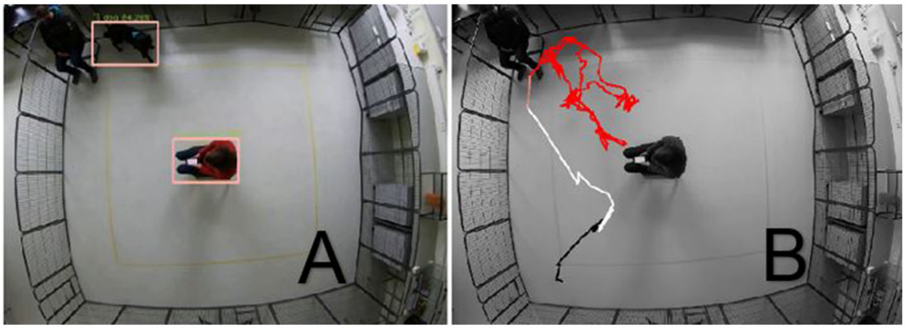

FIGURE 2 | (A) Detection; **(B)** trajectory extraction.

to test aggression and fear toward strangers. In Section 3, we describe the proposed clustering method and its implementation, using the "stranger test" case study as a running example. Finally, Section 4 summarizes and discusses some directions for future research.

2. THE "STRANGER TEST" CASE STUDY

Behavioral traits in animals are consistent patterns of behaviors exhibited in similar situations (31, 32). They are believed to be driven by personality (33), which is a combination of genetic, cognitive, and environmental factors (34). Assessment of personality traits in dogs is increasingly investigated due to its many practical applications in applied behavior. Some examples are determining suitability of working dogs [see, e.g., (23, 35–37)], identifying problematic behaviors (38, 39), adoption-related issues for shelter dogs (32). Jones and Gosling (40) provide a comprehensive review of past research into temperament and personality traits of dogs.

Questionnaires and rating scales are the most common way for assessing behavioral traits in dogs. The Canine Behavioral Assessment and Research Questionnaire (C-BARQ) is one of the most commonly used canine behavioral questionnaires (41, 42).

TABLE 1 | Features for stranger test.

Feature	Unit	Description
Time until approach	Seconds	Time from start to first approach of stranger
Duration of approach	Seconds	Time from start of the approach to coming in close proximity to stranger
Speed of first approach	Pixels/Seconds	Average speed of first approach
Trajectory length	Pixels	Length of all traveled trajectory
Trajectory length until first approach	Pixels	Length of the trajectory from start to coming to the stranger's proximity
Area	Pixels^2	Approximation of the area covered by the dog, using convex hull approximation
Intensity of use	Integer	Ratio between the total trajectory and the square root of the area covered by the trajectory
Total contact	Seconds	Time spent in proximity to stranger
Straightness	Decimal	Ratio between the distance from start point *S* to endpoint *F*, and trajectory length from *S* to *F*
Straightness until first approach	Decimal	Ratio between the distance from start point *S* to approach point *A*, and trajectory length from *S* to *A*
Contact ratio	Decimal	Percentage of frames in proximity to stranger

However, this and other owner-administered questionnaires are very costly in terms of time both for filling and processing efforts.

The "stranger test", developed by Joke Monteny, who also performed data collection at VIVES, Belgium, is a simple protocol aimed to test stranger-directed behavior of dogs in a simple, standardized setting. We present a short overview, while the full details of the protocol are out of scope of the current study. The test was conducted indoors, in a fenced arena, with the stranger sitting in the center in a marked, fixed location, with a GoPro video camera fixed on the ceiling, covering the whole test area.

The testing phase lasts 40 s, with the dog unleashed in the arena, and the initial contact between the dog and an unfamiliar person is recorded. No actions of the test person are performed straightly toward the dog.

Our initial dataset consists of 30 trials. The dog participants were recruited *via* social media in Belgium. The inclusion criteria were: between 1 and 2 years old, and properly vaccinated and no known health issues. The participants' owners were requested to fill a Dutch version (43) of the C-BARQ questionnaire. The questionnaire identifies the following factors, which will be used in our study: (1) Stranger directed aggression (SDA), (2) Owner directed aggression (ODA), (3) Stranger directed fear (SDF), (4) Non social fear (NSF), (5) Separation related behavior (SRB), (6) Attachment seeking behavior (ASB), (7) Excitability (EXC), and (8) Pain sensitivity (PS).

3. THE CLUSTERING METHOD

The suggested method takes as input a set of video recordings, representing behavioral testing trials of different animal individuals. Based on the testing protocol, a set of potentially relevant features are decided upon by domain experts. To make the discovery of patterns fully automatic, we assume the features can be automatically extracted from the video (we demonstrate a concrete way of doing so below). However, also manual coding could be appropriate in this context.

The method is an implementation of a commonly used data analysis pipeline based on unsupervised clustering techniques from Data Science. To build the bridge from Animal Behavior research methods to Data Science research methods, we make the observation that *behavioral parameters*, (manually or

Before normalization and scaling:

Statistics	Time until approach	Duration of approach	Speed of first approach	Trajectory length	Trajectory length until first approach	Area	Intensity of use	Total contact	Straightness	Straightness until first approach	Contact ratio
Average	5.84	11.38	142.249	3634.68	175.54	70025.96	16.43	29.70	0.07	0.51	0.61
Std dev	10.38	11.12	121.79	1393.67	158.69	78391.18	6.57	11.53	0.05	0.21	0.24
Min val	1.43	0.00	0.00	1416.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Max val	46.00	42.00	655.08	6454.66	606.54	336746.94	33.40	46.60	0.25	0.86	0.95
25%	2.37	3.32	73.79	2747.47	88.54	26043.41	11.67	24.06	0.04	0.43	0.49
50%	3.05	8.01	103.62	3510.47	120.54	42146.80	16.73	30.20	0.07	0.54	0.63
75%	3.31	14.48	172.34	4565.46	209.15	78441.36	20.09	37.70	0.09	0.64	0.80
count	28										

FIGURE 3 | Descriptive statistics (before normalization and scaling).

TABLE 2 | Generated clustering scenarios list.

Scenario	PC num	S-score	Cluster num	Filtered cluster num	Num of samples
1	1	0.537	4	2	21 - 14(c-0), 7(c-3)
2	2	0.324	4	3	27 - 11 (c-0), 8 (c-1), 8 (c-3)
3	3	0.272	5	2	23 - 8 (c-0), 14 (c-1)
4	4	0.255	6	3	24 - 6 (c-0), 10 (c-1), 8 (c-3)

Bold are the chosen clusters for analysis.

automatically) coded in behavioral studies, can be thought of as machine learning features which can be used for clustering. This shift is not only related to terminology, but is deeply rooted in different research methods in the two disciplines. While behavioral parameters are a small set, carefully chosen by human experts, usually serving to prove or refute a certain hypothesis (1), unsupervised approaches in Data Science do not assume a fixed hypothesis and do not require a-priori choice of features—there are numerous ways for automatic feature selection, some of which we employ in our approach.

Figure 1 presents a high level overview of the pipeline, taking as input a set of video trials, and potentially relevant behavioral parameters which can be turned into features for clustering. Examples of such parameters are, e.g., trajectory length or time until a certain event in the trial. The output of the pipeline is the identification of "similarly behaving" individuals, together with a pattern: e.g., animals in cluster 1 have higher speed of movement and shorter trajectories. Such patterns can then be linked to behaviorally meaningful insights in the context of the specific protocol.

Next we describe the pipeline stages and how they are implemented in more details.

3.1. Feature Extraction

Building a bridge from the notion of behavioral parameters in Animal Behavior to features in Data Science, we ask: what makes a behavioral parameter a good feature? Since our main goal is to automatically produce insights into patterns found in the data, what makes a behavioral parameter a good feature is *measurability*: e.g., the availability of a method for accurately measuring the feature values for each video is important. In our case study, all of the chosen features were derived from movement trajectories, that were automatically tracked using the BLYZER tool (29, 44–46). The tool gets as input videos of trials, automatically identifies dog in a frame, and produces its movement trajectory, in the form of time series data saved in a machine-readable data (JSON format). It also has a module for computation of features from a library of available features, (such as average speed of the object, average distance between two objects, etc.). **Figure 2** shows the automated detection of objects dog and stranger, and the visualized trajectory traveled by the dog in the trial.

For the purposes of our cases study, we extended this module with features identified as potentially relevant for the "Stranger Test" protocol, as shown on **Table 1**.

Remarks:

1. Start point S is the location of the dog at the beginning of the trial; approach point A is the location of the earliest point found in proximity (below a chosen threshold) to stranger; end point F is the location at the end of the trial.
2. Intensity of use is an animal movement metric used in (47). We decided to include this feature due to its usefulness in (30) in the context of dog behavior analysis.
3. Stranger proximity is defined as being found within a certain threshold from a circle surrounding the stranger.

Figure 3 presents some descriptive statistics of the considered features.

3.2. Clustering

We use one of the most commonly used clustering algorithms, k-means (48) with the usual Euclidean distance. However, applying clustering as is will result in clusters which will not be characterizable in terms of the chosen features due to the high dimensionality. To reduce the number of dimensions (see (49, 50) on common ways to deal with the curse of dimensionality), we use PCA analysis (51). PCA analysis produces linear combinations of the original variables as a set of x/y axes, also known as principal components, or PCs. Thus, after a PCA model is created, we have a set of PCs that serve as a mean to reduce the dimensionality of the original variables. In our implementation, we start first by generating all possible scenarios of dimensionality reduction using PCA. Thus, Each scenario includes a particular case of dimensionality reduction using PCA. This follows by the training of a k-means model with a discovered optimal k on the created PC's, i.e., for each PC we perform clustering with its optimal k (52). More specifically, we run each scenario described above and produce as an outcome a table with the results of the different scenarios, the table contains the following information per each scenario denoted in different rows per each scenario:

1 Amount of PC'S—the amount of PC's used for training the k-means model
2 Silhouette score—the silhouette score (53) of the trained k-means model
3 Number of clusters generated, i.e., the chosen k for the k-means model optimized by the elbow method (52)

Although we did not put any limits on the number of clusters, only scenarios where an optimal k could be found using the elbow method are included in the final list of possible clustering scenarios. Moreover, at this stage, clusters smaller than a pre-defined threshold are discarded as outliers.

3.2.1. Clustering "Stranger Test" Trials

Preprocessing. The cut videos were pre-processed to validate the videos encoding, aspect ratio (width × height) and frames-per-second (FPS). Each video was re-encoded, using FFmpeg8[1], with ending result of MP4 encoding, aspect ratio of 1280 ×

[1]See: http://ffmpeg.org//

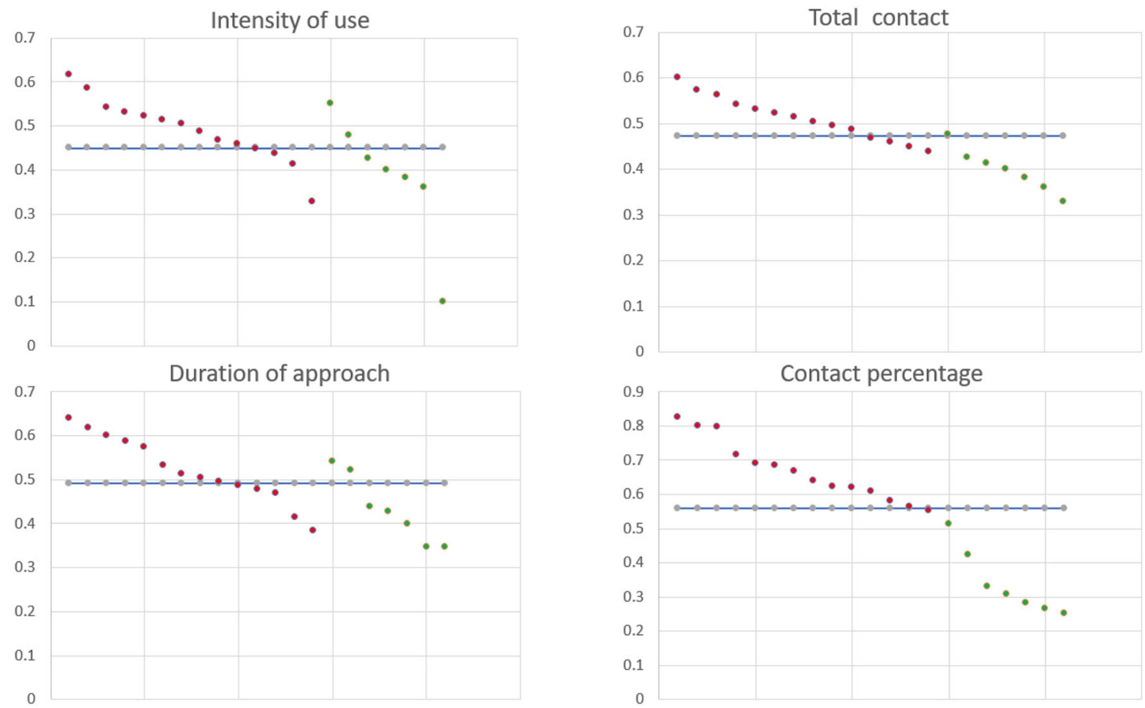

FIGURE 4 | Patterns of Scenario 1: Cluster 0 red dots, Cluster 3 green dots.

960 and 30 FPS, respectively. Additionally, to remove noise and increase the detection rate across the video frames, post-processing operations supported by the BLYZER platform (such as smoothing and extrapolation) were applied to each video. We then used BLYZER to track the dogs movement from the videos and save their trajectory data. In the final dataset we included only trials which satisfied the following criteria: (a) The dog was identified by BLYZER with average certainty threshold above 70% across all the video frames. (b) The dog had full C-BARQ data. After this stage, 2 participants were filtered and we were left with 28 videos. Feature vectors from the pre-selected features shown on **Table 1** were created for each video. They were then normalized and scaled with the standard sklearn python libraries (54).

Clustering. Table 2 presents the generated cluster scenario list. We only chose the first scenario for further analysis due to the maximal silhouette score, indicating a good separation between clusters, and a low number of clusters: after filtering, only two clusters were left. We present in the **Appendix** a more in-depth analysis of the scenarios, showing plot and matrix representations of the data projections along the PCs.

Pattern Discovery. In the chosen scenario, 2 clusters remained after filtering: C_0 of size 14, and C_3 of size 7.

The next stage is generating a list of *potential explanatory features*, i.e., includes all features that have a high (above certain threshold; we chose it as the median importance across all the features used in the PCA model) importance in the created PCs. We choose only the features that have importance above the median for at least one of the PC's in the model.

The features from the list that "explain" one or more of the clusters produce explanations (patterns) in the way formalized below. To provide intuition, for instance, in our example the explanations look as follows:

- Cluster 0 - **High** intensity of use, **High** total contact, **High** duration of approach and **High** contact ratio
- Cluster 3 - **Low** intensity of use, **Low** total contact, **Low** duration of approach and **Low** contact ratio

Figure 4 shows the distribution of the feature values among the two clusters of scenario 1, showing a good separation in terms of the four selected features. **Figures 5**, **6** demonstrate the clusters' distribution along two chosen explanatory features for scenarios 1 and 2, respectively.

Formalization of explanatory features.

The output of our approach is a list of *clustering scenarios*, i.e., suggested divisions of the samples into clusters (some samples may be discarded due to belonging to outlier clusters), together with (whenever possible) a characterization of the clusters in terms of *explanatory features*, which we define next. Intuitively, explanatory features provide an intuition for what is different in each identified cluster.

Definition 1. ***(cluster)*** *Let V be a set of video samples, representing behavioral testing trials, $F = \{f_1, ..., f_k\}$ a set of features. A cluster is a subset of the set of feature vectors.*

Notation: For a feature $f \in F$ and a cluster C, we denote by $\mathrm{mean}(f)_C$ the mean value of f in C. For a set of clusters $\mathbf{C}$, we denote by $\mathrm{mean}(f)_{\mathbf{C}}$ the mean value of f across $C \in \mathbf{C}$.

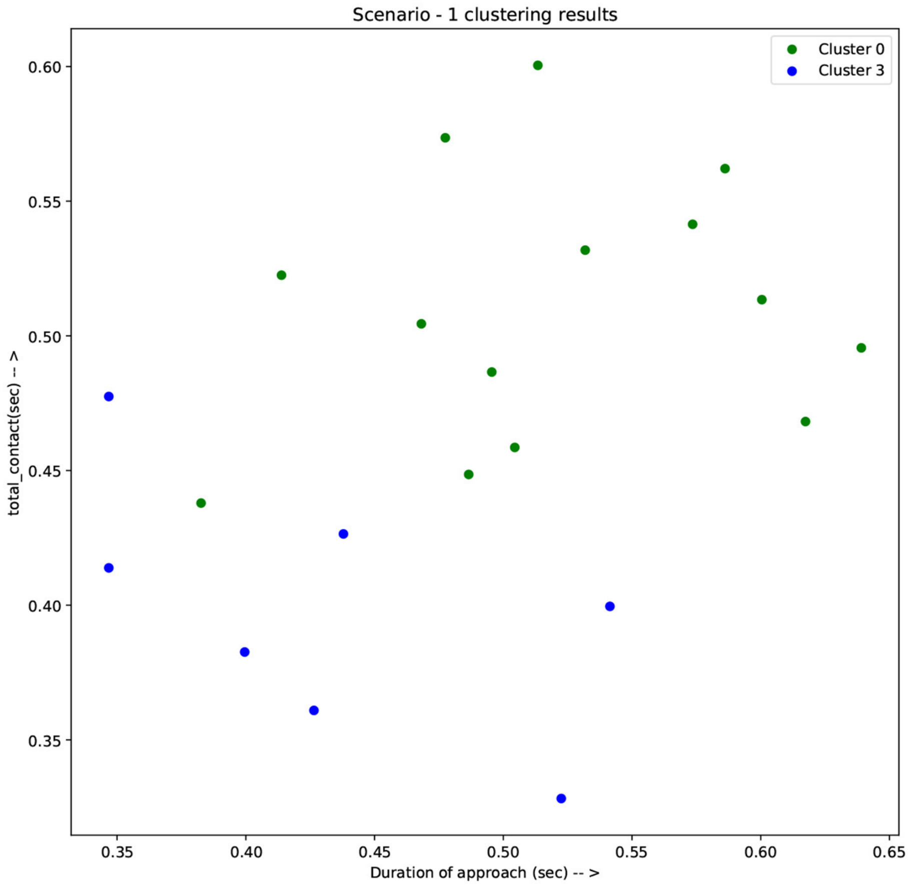

FIGURE 5 | Results of clustering scenario 1 along the axes of total contact and duration of approach.

Definition 2. (cluster separation by features and explanatory features) *Let* $\mathbf{C} = \{C_1, ..., C_n\}$ *be a set of clusters over the set of feature vectors* $F(V)$. *Let* $C \in \mathbf{C}$.

- *Let* $H(f)$ *be the number of samples* $c \in C$, *such that* $c_f \geq \text{mean}(f)_{\mathbf{C}}$, *and* $L(f)$ *the number of samples* $c \in C$, *such that* $c_f < \text{mean}(f)_{\mathbf{C}}$.
- *We say that* f $\uparrow$*-explains* C *if* $H(f) > L(f)$, *and* f $\downarrow$*-explains* C *if* $L(f) > H(f)$. *We denote by* $Exp(f)$ $H(f)$ *in the former case, and* $L(f)$ *in the latter.*
- *We say that* f *is* $\uparrow$*-explanatory for* C *if* f $\uparrow$*-explains* C *and* $\downarrow$*-explains* C' *for every* $C \neq C' \in \mathbf{C}$.
- *We say that* f *is* $\downarrow$*-explanatory for* C *if* f $\downarrow$*-explains* C *and* $\uparrow$*-explains* C' *for every* $C \neq C' \in \mathbf{C}$.
- f *is explanatory for* C *if it is either* $\uparrow$*-explanatory or* $\downarrow$*-explanatory for it.*

Intuitively, if a feature f is explanatory for a cluster C, the majority of members of C have values either higher than the rest of the clusters, or lower than the rest; thus f lends itself to provide a justification (or "explanation") for C being chosen as a separate cluster from the rest.

Comparison of patterns to C-BARQ. We have considered a clustering scenario, in which well-separated clusters were found and characterized in terms of features related to objective parameters such as time until approach, trajectory length, etc. The most crucial question, however, is what behavioral meaning these clusters have, if at all. Finding an answer is highly protocol-specific, a general recipe clearly does not exist. In our case, however, we can use the C-BARQ questionnaire data for better understanding the nature of the clusters and linking them to such behavioral characteristics as fear of stranger, using the SDF and SDA factors of the C-BARQ.

The differences among clusters were not found significant (Mann Whitney U test). This could be explained by small sample sizes. However, **Figure 7** presents the descriptive statistics for the different C-BARQ factors for scenario 1 (clusters C0 and C3), from which it is evident that C0 contains dogs scoring more in SDF (stranger directed fear), SDA (stranger directed aggression), and PS (pain sensitivity) than cluster C3. While the first two factors are clearly related to stranger-related behaviors, pain sensitivity relates to fearful responses to potentially painful procedures (e.g., during veterinary examination), and is also potentially related to fearfulness. **Figures 7–10** further

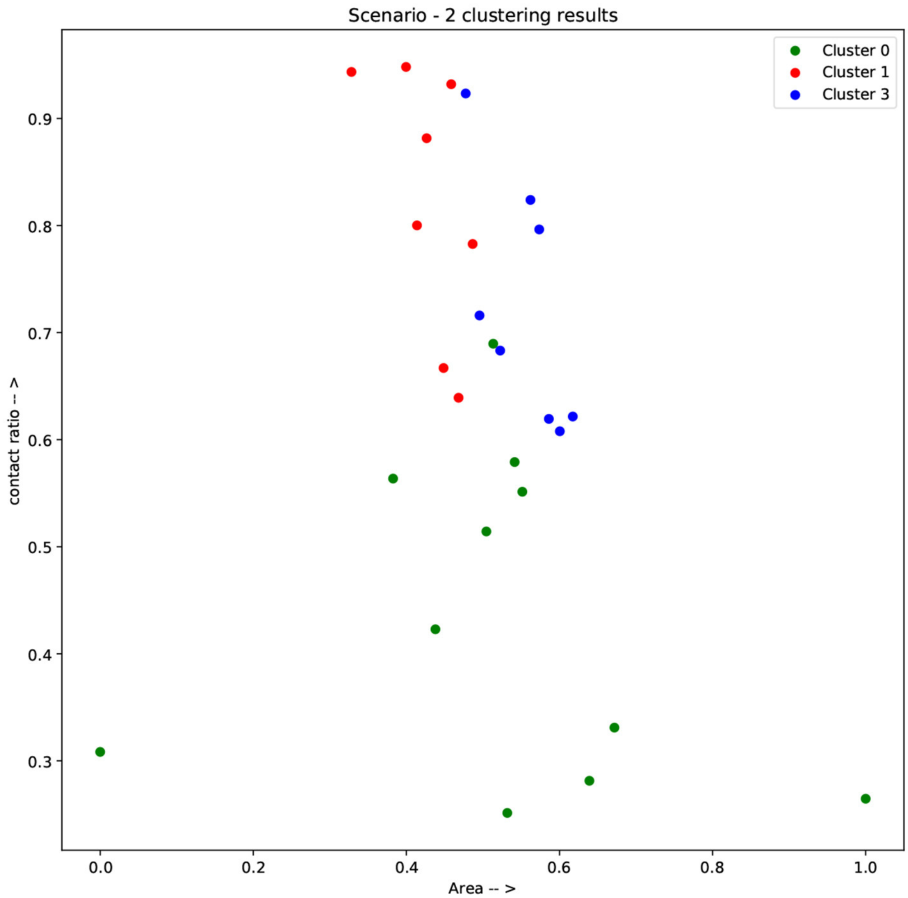

FIGURE 6 | Results of clustering scenario 2 along the axes of contact ratio and area.

Descriptives

	SDA (C0)	SDA (C3)	SDF (C0)	SDF (C3)	NSF (C0)	NSF (C3)	PS (C0)	PS (C3)
N	14	7	14	7	14	7	14	7
Mean	0.314	0.186	0.564	0.100	0.357	0.400	0.521	0.471
Median	0.0500	0.00	0.300	0.00	0.200	0.00	0.300	0.00
Standard deviation	0.459	0.308	0.656	0.265	0.424	0.643	0.714	0.993
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	1.30	0.800	2.00	0.700	1.20	1.60	2.30	2.70

FIGURE 7 | C-BARQ factors descriptive statistics for scenario 1.

demonstrate the differences in SDF, SDA and PS for scenario 1, the largest one being SDF. This confirms that our method separated well between dogs with higher SDF, and lower ones in terms of objective features: less dogs fearful to strangers had lower values of intensity of use, total contact, duration of approach and contact percentage. Thus, these features are potentially interesting for forming and testing further hypotheses.

4. SUMMARY AND FUTURE RESEARCH

In this study we investigated the potential of unsupervised clustering techniques for discovering and explaining patterns in behavioral testing data obtained by analyzing animal trajectories. We have suggested a general approach which can be fully automatized (except for the choice of meaningful features that

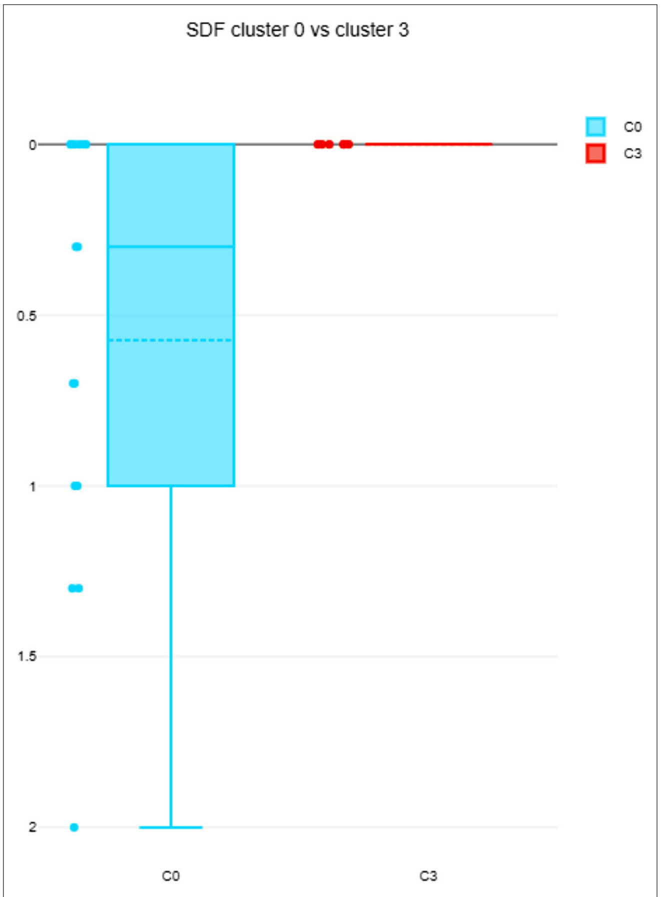

FIGURE 8 | SDF comparison between C0 and C3 (scenario 1), dotted line is the median, solid line in the box is the mean.

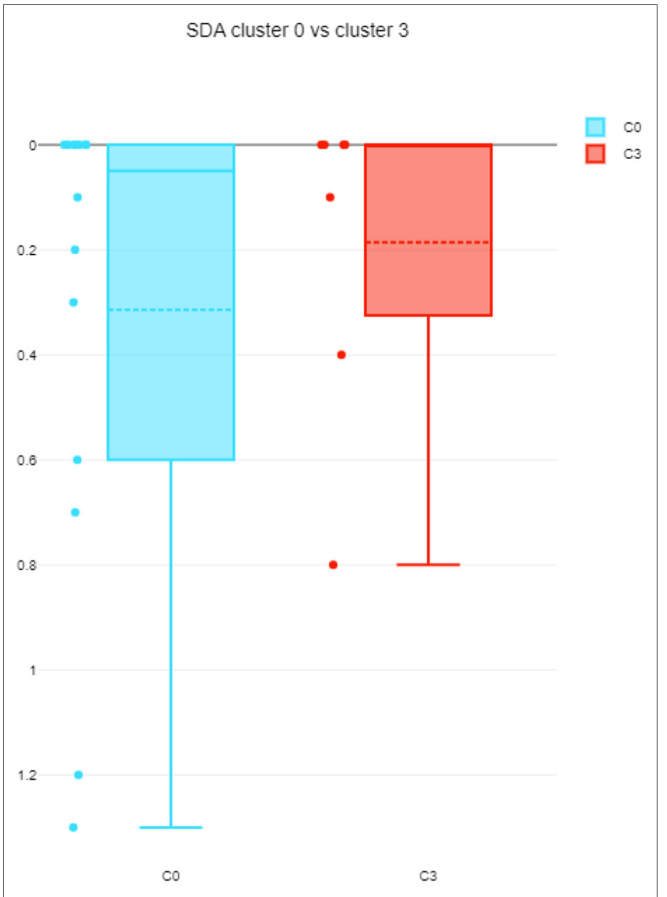

FIGURE 9 | SDA comparison between C0 and C3 (scenario 1), dotted line is the median, solid line in the box is the mean.

should be done by domain experts). Based on this framework, we implemented a method using k-means clustering algorithm, which provided a list of potentially relevant features: (1) finds "good" clustering scenarios based on commonly used metrics, and (2) generates "explanations" (characterizations) of these clusters based on these features. We evaluated the usefulness of our framework in a case study of 30 dogs tested in a "stranger test" for discovering aggression and fear toward stranger. The resulting clustering scenario discovered two clusters which were characterized by high/low intensity of use, total contact time and duration of approach. We compared the clusters against the C-BARQ owner-filled questionnaire which is a standard way for measuring stranger-directed aggression and fear, concluding that the two clusters were characterized by high/low scores on several factors of the questionnaire, specifically SDF, SDA, and PS.

Summing up, we would like to reiterate the benefits of using unsupervised clustering on trajectories of behavioral testing. Provided that a set of potentially relevant features is chosen, the method allows us to discover not only which trials are similar to which, but also in what sense they are similar, i.e., it characterizes the found similarity in terms of a small subset of the features. In the particular case of the "stranger test", out of trajectories of 28 dogs, (in the first scenario) two clusters of 14 and 7 dogs were discovered and characterized: the former dogs contacted the stranger more and approached him quickly, while the latter dogs contacted less and approached slower. The C-BARQ data revealed that the former cluster are the dogs scoring higher with stranger directed fear and aggression. Thus the clustering method not only found a separation between these two groups, but also "explained" potential higher aggressiveness to stranger in terms of, e.g., higher speed of approach.

This provides some indication that our method was able to capture clusters that are behaviorally meaningful, and can be applied as exploratory method before forming and testing specific hypotheses concerning a behavioral testing protocol. One such exploratory finding could be that it would be important to look at speed of approach and time of contact if we are interested in aggression and fear of strangers.

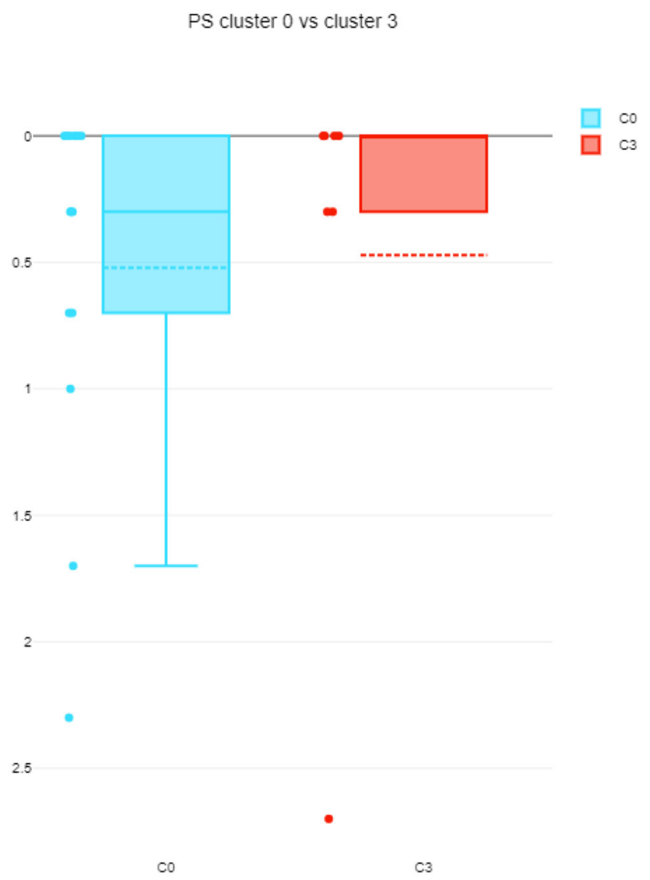

FIGURE 10 | PS comparison between C0 and C3 (scenario 1), dotted line is the median, solid line in the box is the mean.

We hope that this study can help promote a bridge between the disciplines of Data Science and Animal Behavior, by showing the potential use of unsupervised approaches which are under-explored in the latter discipline.

Despite the encouraging results mentioned above, it should be stressed that the low number of available samples in our dataset is a notable limitation of our study. Therefore, the clustering results cannot be viewed as validated, but rather as work in progress which requires further validation with larger number of data samples. The pipeline presented in the article, however, serves as a demonstration of the idea behind the approach, and a concrete way to implement this idea.

The results of this exploratory study open up numerous directions for future research. First of all, the k-means algorithm used in our tool can be replaced by more sophisticated methods, that will also allow for a more fine-grained analysis of the clustering outcomes. Secondly, ways to (semi)-automate the feature selection process can be explored. Thirdly, explore ways for outlier analysis and extract information from the samples that are considered as belonging to an outlier cluster, one way might be the usage of learning outlier ensembles (55, 56), Finally, we only considered here spatio-temporal data of a simple type of trajectories extracted from videos. Much more complex representations such as landmarks, segments, or fusion of audio and video data can be explored.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The study was reviewed and approved by Vives University College of Roeselare, Belgium. Written informed consent was obtained from the owners for the participation of their dog in this study.

AUTHOR CONTRIBUTIONS

JM and LB: data collection. TM and AZ: data analysis and manuscript writing. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fvets.2022.884437/full#supplementary-material

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Evaluating Cognitive Enrichment for Zoo-Housed Gorillas Using Facial Recognition

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The use of computer technology within zoos is becoming increasingly popular to help achieve high animal welfare standards. However, despite its various positive applications to wildlife in recent years, there has been little uptake of machine learning in zoo animal care. In this paper, we describe how a facial recognition system, developed using machine learning, was embedded within a cognitive enrichment device (a vertical, modular finger maze) for a troop of seven Western lowland gorillas (*Gorilla gorilla gorilla*) at Bristol Zoo Gardens, UK. We explored whether machine learning could automatically identify individual gorillas through facial recognition, and automate the collection of device-use data including the order, frequency and duration of use by the troop. Concurrent traditional video recording and behavioral coding by eye was undertaken for comparison. The facial recognition system was very effective at identifying individual gorillas (97% mean average precision) and could automate specific downstream tasks (for example, duration of engagement). However, its development was a heavy investment, requiring specialized hardware and interdisciplinary expertise. Therefore, we suggest a system like this is only appropriate for long-term projects. Additionally, researcher input was still required to visually identify which maze modules were being used by gorillas and how. This highlights the need for additional technology, such as infrared sensors, to fully automate cognitive enrichment evaluation. To end, we describe a future system that combines machine learning and sensor technology which could automate the collection of data in real-time for use by researchers and animal care staff.

Keywords: facial recognition, gorillas, animal welfare, machine learning, zoology, cognitive enrichment

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1. INTRODUCTION

Animal technologies in zoos have a long history; they reflect society's changing perceptions of animal intelligence and welfare, and technological advancements and fashions. The use of technology in zoos can be traced back to the research of Hal Markowitz beginning in the late 1970s and the birth of "behavioral engineering" (1, 2). However, the concept of zoo animals interacting with technology for the purposes of enrichment has experienced a renaissance over the past two decades (3–5). Contemporary animal-computer interaction (ACI) usually involves animals directly interacting with components such as touchscreens (4, 6), buttons or joysticks (7, 8), and therefore animals need to be trained to use the technology. Animals may also directly experience technological feedback systems in the form of lights, tones or vibrations (9, 10).

Cognitive enrichment is a form of enrichment that aims to challenge the evolved cognitive skills of animals to enhance their welfare, yet it remains under-provisioned in many zoo settings (11). Previous research has identified cognitive enrichment as being particularly applicable to great apes under human care following decades of study into their cognitive abilities as compared to humans, and their swift adaptation to novel phenomena (12). We believe there is great potential to embed technology within cognitive enrichment and there are several possible avenues for realizing this. Digital interfaces can augment how cognitive challenges are provided to animals in their enclosure (e.g., the contrast between a tangible and digital maze, for example), and furthermore, provide more novel and repeatable experiences across time (13). Technology also creates opportunities for instant feedback and to automate processes such as food reward presentation (13–15). For the focus of this paper, however, we are interested in the use of technology to automatically log an animal's response to a cognitive enrichment device, foremost to save researcher time and effort, but also to prevent human observation from influencing animal behavior. Cognitive enrichment requires us to simultaneously measure how the animal is performing cognitively (i.e., their learning, memory, problem-solving skills), and their welfare state (i.e., if their wellbeing is positively affected by the enrichment). In other words, we must evaluate the cognitive challenges presented by enrichment phenomena and to know whether it is eliciting the intended cognitive skills, as well as any emotional or behavioral affect it is having upon the animals involved (16). Cognitive enrichment devices may therefore generate relatively "big data" that zoo-based researchers and animal care staff are not accustomed to collecting. It thus follows that if some, or all, of this data collection could be automated, we can maximize our understanding of the cognitive and behavioral implications of such enrichment devices.

Full, empirical enrichment evaluation requires data such as (i) which individual/s are present, (ii) their duration and frequency of enrichment use, and (iii) how the enrichment is being used. These observations are particularly important for cognitive enrichment where enrichment use may not correlate with reward depletion (e.g., an animal may spend a long period of time using enrichment without successfully extracting many rewards). Researchers often have limited time available to observe animals, which in turn can limit the time enrichment is provided to animals and/or scientifically evaluated. The collection of these data, however, is time-consuming as it is typically undertaken live ("online") by researchers. The collection of these data can be automated using radio frequency identification (RFID) tags. RFID tags are worn on a collar or implanted into the skin and have been used to monitor several laboratory primate species, such as rhesus macaques (*Macaca mulatta*) (17); common marmosets (*Callithrix jacchus*) (18); guinea baboons (*Papio papio*) (19, 20). However, there are several reasons why this approach may be deemed unsuitable. Primarily, it classifies as invasive research and may therefore be in conflict with the researchers' code of ethics. Additionally, in our opinion, RFID tags pose a risk to the safety of great apes and implants are notoriously difficult to maintain in primates due to overgrooming (FE Clark, personal communication).

Machine learning offers the potential to automate collection of empirical data using non-invasive techniques. In recent years, machine learning has been widely applied within the field of animal biometrics and several machine learning systems have been developed specifically for great apes. These systems address a wide range of tasks including; individual detection (21), pose estimation (22), and behavior recognition (23). However, in the study presented in this paper, we focus on individual identification. Facial recognition technology for humans has long been prominent within machine learning and computer vision (24, 25). In particular, deep convolutional neural networks (CNNs) (26), exemplified in frameworks such as DeepFace (27), form the basis of most modern facial biometric frameworks (28). Great apes share similar facial characteristics with humans because of our close evolutionary lineage (29). Thus, a number of methodologies in animal biometrics (30) follow approaches for human face recognition closely. Based on these approaches, a number of machine learning systems have been developed for the detection and recognition of great apes in both captive and wild environments (31–33).

In this paper, we extend the development of a new machine learning system for the facial recognition and individual identification of the Western lowland gorillas (34) housed at Bristol Zoo Gardens for specific use with a cognitive enrichment device. This research was undertaken as part of a larger research project called Gorilla Game Lab, a collaborative and interdisciplinary venture between Bristol Zoological Society and the University of Bristol. The project brings together researchers from the fields of animal welfare science, animal psychology, computer vision and machine learning, and human-computer interaction. Together, we evaluate the efficacy of our system and examine and discuss its potential to automate aspects of the traditional evaluative approach, human observation. We report upon the merits of each method, with regards to time and resources, expertise, the value of the resulting data, and to ultimately compare their efficacy. Finally, we speculate about the future use of our facial recognition system within a complementary ecosystem of technologies that would allow for greater automation of enrichment analysis within future zoological environments.

2. METHODS AND MATERIALS

2.1. Study Duration and Phases

Data collection took place between May-July 2019. The design and evaluation of the enrichment device employed in this study was published in (13) and (35), respectively. The implementation, training and evaluation details of the machine learning model can be found in (34).

2.2. Study Subjects and Housing

Study subjects were a troop of 7 Western lowland gorillas (*Gorilla gorilla gorilla*) housed at Bristol Zoo Gardens (**Table 1**). Gorillas were housed as one group in the "Gorilla Island" exhibit, comprising a large outdoor island (2,048 m^2) and an indoor enclosure (161.9 m^2). Information on gorilla husbandry and feeding is provided in (35).

2.3. Ethics Statement

Data collection was undertaken with the approval of Bristol Zoological Society and the University of Bristol Animal Welfare and Experimental Research Boards (codes UK/19/021, 84663). Gorillas interaction with the enrichment device was voluntary, and subjects were not food deprived or confined to certain areas of the exhibit during data collection.

2.4. Enrichment Device

The Gorilla Game Lab enrichment device is fully described in (35). In summary, it consists of a wooden frame holding 12 removable puzzle modules, in addition to associated video (**Figure 1**). The device operated independently from the technology; gorillas could use and solve the device without it being connected to a power source or sensors. The technology (to be described in Sections 3.2 and 3.3) was placed behind physical barriers so it could not be tampered with by the gorillas.

The device frame (850 × 650 × 80 mm) and 12 puzzle modules (200 × 200 × 60 mm, arranged in 3 rows and 4 columns) were constructed from plywood, and each module had a front sheet of transparent acrylic with drilled finger holes (30–40 mm) or stick tool holes (15 mm). When placed in the frame, modules were connected to each other *via* 30 mm holes on each side. Components were laser-cut and slotted together with adhesive-free joints so that they could be assembled and re-assembled easily. (13) describes the overall premise of the device design but to summarize, we intended for the gorillas to manoeuvre monkey nuts from the top of the device to the bottom through the interconnected modules. The bottom row of modules had larger openings in the acrylic sheets to allow removal of nuts. The modules varied in design, containing vertical or diagonal ledges, dials, and sliding drawers made from wood and black or white plastic. The device therefore challenged the gorillas' cognitive and motor skills in a number of ways including the stimulation of stick tool use (sticks were provided in the form of clumps of tree branches during data collection).

2.5. Data Collection Schedule

The device was presented to gorillas indoors in a ground-level area of the enclosure for 1 h between routine feeding times (11:00–12:00 h). It was attached behind the cage mesh (gauge 100 × 50 mm) with D-shackles so that the front of the modules sat directly behind the mesh. The device was presented 12 times. The same 12 modules used in Phase 1 were presented [see (35)], but in three sets which were swapped between the left, middle, and right columns between trials.

2.6. Behavioral Observation

We opted to video record behavioral observations using high-quality cameras positioned at appropriate angles (i.e., non-invasive and discreet but positioned to maximize the view of the gorillas and the device). Although behavioral observations can be captured "live" and by eye, there is only one chance to collect the data and the presence of the researcher may produce an additional environmental effect. Moreover, video recorded

TABLE 1 | Information on gorilla study subjects at Bristol Zoo Gardens.

Name	Sex	Age (years)	Rearing type
Jock	M	35	Parent
Kera	F	13	Hand
Touni	F	10	Parent
Kala	F	8	Parent
Kukena	F	7	Parent
Afia	F	2	Hand
Ayana	F	1	Parent

FIGURE 1 | Gorilla Game Lab cognitive enrichment device. A 3D finger maze consisting of 12 puzzle modules. The modular design allows a camera to be fitted inside or on top of the modules. In turn, this allows footage of the gorilla engaging with the device to be recorded.

footage can be revisited and reviewed by multiple observers, who are able to co-construct a thematic analysis of events rather than relying upon a singular interpretive lens.

2.6.1. Video Camera Footage

Gorilla behavior was captured using two HD cameras with internal batteries. An action camera (GoProHERO 7, GoPro, Inc., CA, United States) was placed on top of the device behind the cage mesh. It faced outwards toward the gorilla/s using it. This camera was switched on during device installation, and left to record footage until the device was uninstalled 1 h later. A second larger camera (Sony HDR-CX405 Handycam Camcorder, Sony Corporation, Tokyo, Japan) was positioned on a tripod in the indoor visitor viewing area, approximately 2.5 m from the device. This camera was manually operated by a researcher who could make adjustments to its location, height and angle during a trial. This was in response to the gorilla and visitor movements and changing natural light levels. It recorded device use "over the shoulder" of the gorilla but at an angle so as much device use could be recorded as possible. Data were stored on SD cards and later downloaded to hard drives. An information sign in the visitor area was used to explain the gorillas were being filmed for a research project.

2.6.2. Video Coding

Video footage was replayed through Windows Media Player® version 10 (Microsoft©, NM, United States). One researcher scored all the footage. All gorillas within an arm's reach of the device were coded from footage from the inward facing camera (Handycam), but on occasion footage from the outward facing camera (GoPro) was needed to confirm if gorillas were looking at the device. The following data were scored using continuous sampling (36, 37) for each gorilla within arm's reach: frequencies and durations of device use (observing/contacting); strategy (observe, types of hand, and mouth use); and module/s used; successes (extraction of food rewards). All data were entered into Microsoft Excel for summary, visualization, and analysis.

2.7. Machine Learning

In this study, a deep learning object detection model, YOLOv3 (38), was employed to perform simultaneous facial detection (i.e., localization) and identification of gorillas. That is, YOLOv3 predicts the location of the facial region and the identity of the individual gorilla. As discussed, the system was intended to automate monitoring of device usage (for example, frequency, duration, and order of engagement). Broadly, this was undertaken in two stages; (i) dataset generation and (ii) model implementation and training. Each of these phases is described in the following sections.

2.7.1. Dataset Generation

Machine learning models require data that they can *learn* from. That is, datasets of images or video which are annotated with information of interest (i.e., species, location, identity, etc.) about the animal subjects. Therefore, it was necessary to curate a custom dataset comprising a representative sample of images for each gorilla in the troop (see **Figure 2** for an overview of this phase). The footage gathered for the machine learning aspect of the project was not obtained from the camera in the GGL device, as shown in **Figure 1**, but from the 4 custom-built modules, as described below.

Data collection. Four modules were designed to securely hold GoPro (versions 5 & 7) and Crosstour Action cameras that could be safely installed in the gorilla enclosure. The camera modules were distributed throughout the gorilla enclosure. Each of the modules were positioned near the Gorilla Game Lab device and other enrichment objects to obtain close-up footage of the gorillas. Two of the cameras were situated near the Gorilla Game Lab device, allowing representative footage of the gorillas engaging with the device to be captured. To maximize the footage gathered for each individual gorilla and allow for a balanced dataset to be generated each of the cameras recorded footage simultaneously. The zookeepers at Bristol Zoo observed that enrichment devices are dominated by higher-ranking members of the troop. If the higher-ranking members of the troop used the enrichment devices for the duration of the data collection session then no footage of the lower- ranking members would be captured. It was therefore important to devise a strategy to gather enough data for each individual. Data collection sessions took place twice per week from 11:00 to 13:00 h over a period of 6 weeks in study phase 2. During each session, each camera recorded approx. 2 h of footage RGB video at 1,280 $\times$ 720 pixels and 30 FPS.

Data Processing. The raw footage obtained from the cameras was retrieved as 30-min segments. Video segments were played back and edited into several sub-segments, each containing footage of the dominant gorilla in frame. The background of the footage was blurred using software to remove any humans (visitors, staff) inadvertently captured (although this was rare due to the lighting through the enclosure glass). After each segment was processed, suitable frames containing un-occluded front facial images were selected for labeling with location and identity. As a result of the erratic movements of the gorillas (i.e., rapid changes in poses, movement into spaces occluded by the mesh, tampering with the camera-housing modules, etc.) it was necessary to perform this process manually.

Labeling is essential for supervised machine learning models. It is the process of generating ground truths and is therefore required by the model's learning algorithm. In this project, an image label includes the class, corresponding to each gorilla's name, and a set of coordinates that specify the center (x, y), height (h) and width (w) of the enclosing bounding box relative to the input image size. Image annotation was undertaken manually with the help of primate keepers at Bristol Zoo Gardens using the LabelImg tool.[1] This ensured the identities of individual gorillas were labeled correctly. Each of the selected images was annotated with the class (i.e., the gorillas identity) and location of the corresponding gorillas face, as illustrated in **Figure 3**. Only frames that were sufficiently different were selected to ensure diversity.

[1]https://github.com/tzutalin/labelImg

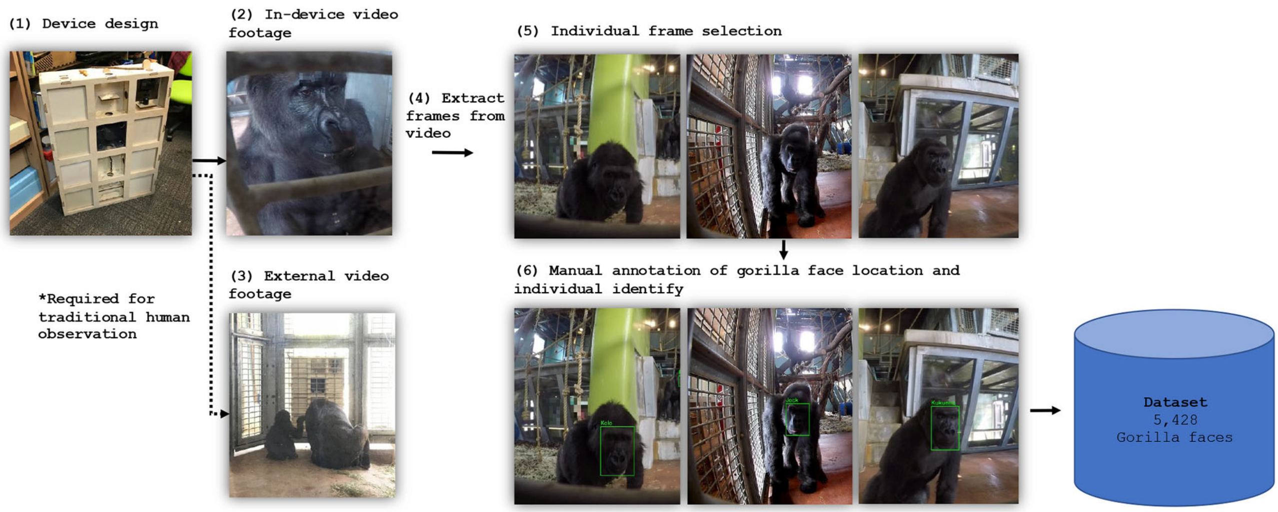

FIGURE 2 | Dataset generation. Cameras recorded front-facial footage of the gorillas (2). Individual frames were extracted from the video footage (4), assessed for suitability and selected for labeling (5). This resulted in 5,248 individual frames being manually annotated with bounding box and identity information (6). Note that (3) forms part of the human observation pipeline.

The complete dataset was further processed to generate training and validation datasets; the training and validation sets are prepared by randomly sampling 80 and 20% of the images gathered for each gorilla, respectively. This was intended to preserve any class imbalances and ensured the validation set was representative of the complete dataset. The dataset was also partitioned into five-folds to allow stratified cross-validation to be performed. This was done by randomly partitioning the entire dataset into five independent folds, each comprising 20% of the dataset. Random sampling is performed for each class to ensure imbalances are preserved between folds. This allows each image to be used in the k^{th} validation set once and used to train the model $k-1$ times.

2.7.2. Model Implementation

The model's ultimate objective is to ingest data (i.e., an image of a gorilla) and predict information of interest (i.e., facial region location and identity of the gorilla). The model learns to do this through the process of *training*. During training, the model is exposed to input-target pairs, where inputs correspond to data (i.e., an image of a gorilla) and targets correspond to information of interest (i.e., the corresponding facial location and individual identity). Through training, the model learns to extract features from the inputs which allow them to be mapped to the targets i.e., allowing facial region location and individual identities to be predicted from input images. Therefore, once the dataset (which comprises input-target pairs) had been prepared, as described in **Table 2**, we began training YOLOv3 on the task of facially recognizing individual gorillas in single frames. Once the standalone performance of YOLOv3 had been optimized, a multi-frame approach which utilizes temporal information to assist with ID's was developed. Details of both single-frame and multi-frame applications are given below (see **Figure 4** for an overview of this phase).

To train YOLOv3 the freely available Darknet software (38) was used and several mechanisms known to improve performance were employed. First, we use a model already trained to classify 1,000 different classes on the ImageNet-1000 dataset (39). This is know as *pre-training*. It provides the model with some basic prior knowledge of what is important when classifying images and is task-agnostic. Additionally, the *k*-means algorithm was applied to the training dataset to generate anchor boxes. Anchor boxes are used as a reference (38) from which predictions can be made by the model. By generating them using the training data, the model is provided with task-specific prior knowledge of facial localization information. We also applied several augmentation methods. This included random transformation of the training images using saturation, exposure, hue distortion, cropping and flipping. Furthermore, instead of fixing the input image size the model randomly chooses a new image resolution size every 10 batches. These augmentation methods enable the model to classify apes regardless of variation in images (for example, input dimensions or varied lightning conditions).

YOLOv3 was then trained on the dataset assembled previously. The specific training details are as follows. We used stochastic gradient descent (40) with momentum (41) of 0.9, batch normalization (42), learning rate decay (43) (an initial learning rate of 0.001 reduced by a factor of 10 at 80 and 90% of the total training iterations), batch size of 32 and an input resolution of 416×416 RGB pixels. The trained model forms the backbone of the facial recognition system by performing both localization and identification of gorilla faces. The output of the model is illustrated in **Figure 5**.

To further improve performance, we developed a multi-frame approach based on the single frame detector. The multi-frame approach functions by performing detection sequentially on multiple frames. As the performance of the detector is

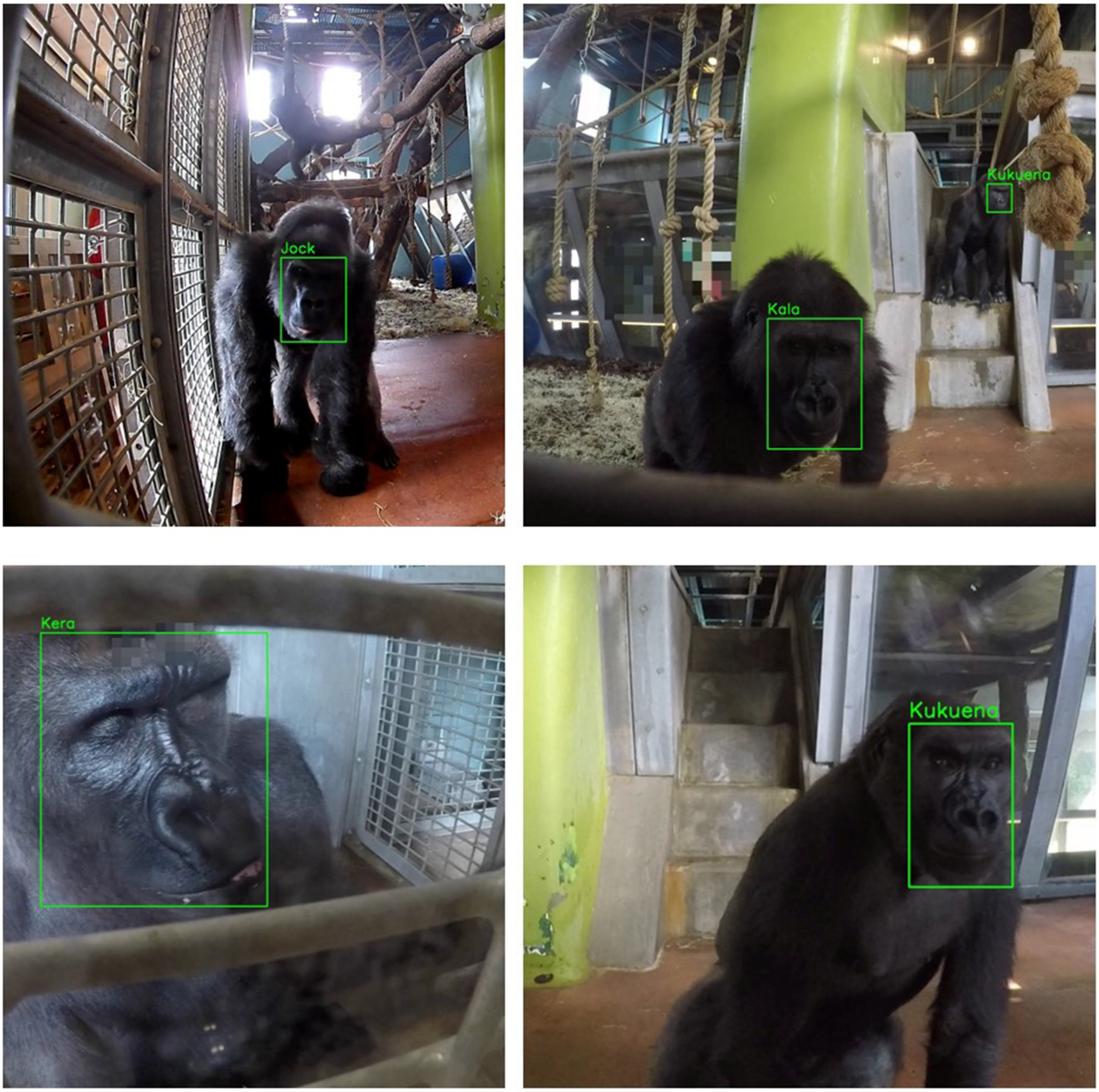

FIGURE 3 | Gorilla face annotation. The figure shows a collection of images that were annotated during the dataset generation process. The green boxes were manually annotated (or drawn) onto the images to indicate the location of the gorillas face. This was done by dragging a rectangle over the facial area from top-left to bottom-right. In these images the name of the gorilla (or *class*) is shown for clarity.

high (approx. 92% mAP) when applied to a single frame, the probability of generating incorrect predictions over several frames is low. Therefore, voting on the gorilla identity across frames yields improved performance. However, for this approach to be effective it is necessary to ensure that detections relate to the *same* individual across all frames. To do this we associate apes based on the similarity of their bounding boxes [i.e., intersection-over-union (IoU) of facial location] between frames, given gorillas will not move significantly from one frame to the next. Specifically, the trained YOLOv3 model was applied to individual frames of a sequence (i.e., video) where X_t denotes the frame at time step t. All detections in X_t and X_{t+1} were then input into a simple algorithm that associates apes *across* frames, leveraging temporal information to improve predictions. The algorithm associates apes which show the highest pairwise IoU, a measure of overlap between boxes, and exceeding an IoU threshold $\theta = 0.5$. As the location of a gorilla is unlikely to change significantly between frames, association provides reasonable certainty that an individual gorilla in X_t and X_{t+1} is the same provided the IoU requirements are met. The resulting association chains represented tracklets (see **Figure 6**). Their length ranged from a single frame to 10 frames. For each tracklet, identity classification was evaluated *via* two methods: (1) maximum class probability; the highest single class probability is used as the identity of the gorilla for detections across all time steps, or (2) highest average class; the highest average probability is used as the identity of the gorilla for detections across all time steps.

3. RESULTS

3.1. Behavioral Observation

The researchers found they could correctly identify a gorilla 100% of the time but it was not instantaneous; it took on average 5–10 s to identify individual gorillas from the inward facing video footage. On many occasions, a researcher began coding video footage of an "unknown" gorilla using the device, and waited until they could see a distinguishing characteristic (the face or a current body scar) to retrospectively confirm the gorilla's identity. Rarely, it was necessary to cross-check the footage from the outward facing GoPro camera to get a close view of a gorilla's face. It took on average 10–12 min to code 1 min of video footage. This refers to footage when a gorilla was using the device. When the device was not in use, there was nothing to code and the video was simply fast-forwarded on to the next bout of use.

3.2. Machine Learning

In this section, the results for the single-frame and multi-frame recognition models are reported, respectively. We use an evaluation protocol, the generation of train-test splits, that is standard within machine learning. In this protocol 20% of the manually annotated video footage is withheld. That is, the data is not seen by the model during training. This ensures that evaluation occurs on unseen data and that results are reported fairly. The test set comprises 1,105 images, as reported in **Table 2**. The facial location and gorilla identity in these images were labeled by a human with the assistance of the Primate Division at Bristol Zoo to ensure that all identities were assigned correctly. YOLOv3 is then applied to each of the images in the test set to generate facial location and individual identity predictions. These predictions were then evaluated against the human ground truth to measure model performance. We report performance using several benchmark evaluation metrics: individual average precision (AP), mean average precision (mAP), precision, and recall. **Table 3** reports single frame classification performance of YOLOv3.

Table 4 reports multi-frame classification performance *via* precision, recall, and mAP for the test set, where the best performing single frame detector was used as the backbone of the system. The results reported utilize voting across a maximum tracklet size of 5, a stride of 1 and an IoU association threshold of 0.5. The multi-frame detector with maximum voting achieved the highest mAP, however, there was only a marginal difference between the maximum and average voting algorithms with less than 0.5% difference between all three of the reported evaluation metrics. Both multi-frame detection approaches outperformed the single frame detector across all metrics. The mAP improvements achieved by the average and maximum voting algorithms when compared with the single-frame detector were 5.2 and 5.4%, respectively.

TABLE 2 | Complete dataset.

Gorilla name	Training	Validation	Total images
Afia	614	157	771
Ayana	489	126	615
Jock	387	101	488
Kala	578	148	726
Kera	776	196	972
Kukena	747	190	937
Touni	732	187	919
Total	4,323	1,105	5,428

The dataset comprises 628 video segments and 5,428 annotated facial images (sampled from the corresponding video segments).

We perform stratified five-fold cross-validation on both single-frame and multi-frame identification systems. We trained each fold for 24,000 iterations owing to time and computational restrictions. The three identification systems, single-frame and multi-frame identification with average and maximum voting schemes, achieved 89.91, 95.94, and 96.65% mAP, respectively.

4. DISCUSSION

4.1. Traditional Observations

Traditional *post-hoc* coded video footage had a number of advantages and disadvantages in this study. The overarching advantage was that a researcher could record behaviors not directly classified as device usage but still crucial for the evaluation of cognitive enrichment; for example self-scratching and social play in close proximity (within one arm's length) of the device. These behaviors could not be detected through facial recognition. Behavioral observation is also "free"; it costs the researcher their time and some initial training to identify behaviors accurately but does not require any expensive technical equipment. While we used video cameras in this study, a researcher could have directly recorded gorilla behavior by eye if they wished.

Although the traditional approach was able to shed insights into how the device was being used, challenges remained. Firstly, the time required to analyse even a short duration of footage was substantial. Furthermore, the coding undertaken in this study could have been made more complex. For instance, to not just consider the direct interactions between gorillas and the enrichment device, but also to provide further depth of detail regarding the wider affect of the device upon the troop and their welfare. This raises questions regarding the feasibility of traditional approaches, particularly in under-resourced zoos without dedicated animal welfare teams or in circumstances where these teams must dedicate time to supporting multiple species.

There were also difficulties *in situ*. It was difficult for the researchers to use the video footage to code fine-scale data on how the gorillas were using the device. It was straightforward

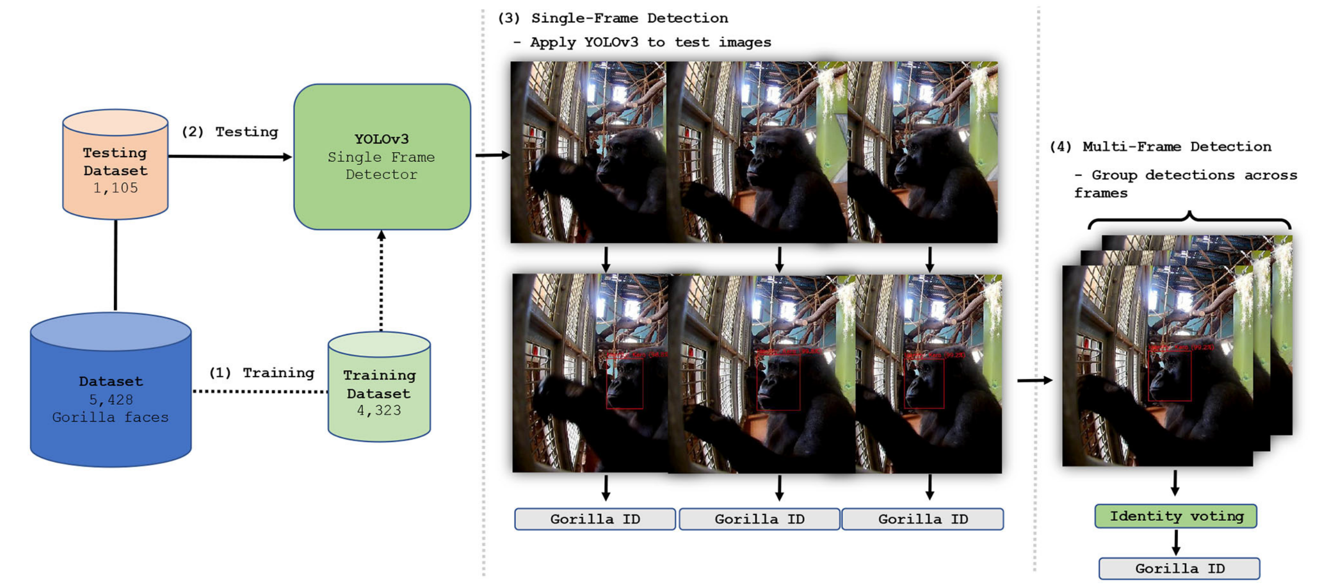

FIGURE 4 | Facial recognition model implementation and training. The dataset was used to train (1) and test (2) a YOLOv3 detection and classification system. The system was tested as a single frame recognition system (3), and a multi-frame system, (4) yielding facial location predictions and gorilla identities.

to record which of the 12 modules a gorilla was contacting and if a stick tool was present, but the precise motor skills being used and the number of finger/stick insertions was not always reliable, mainly due to the gorilla's posture and their body occluding most of their hand. Fluctuating light levels in the enclosure also contributed to shadowing and difficulty observing the modules. Another issue was potential human disturbance and gorilla responses to camera equipment. Even though the video camera was positioned in the public area of the enclosure (and was theoretically of no greater disturbance than normal visitor presence), the presence of a researcher/camera assistant in this area may have affected the gorilla's behavior. We were limited to using one small camera and tripod because the silverback male gorilla "Jock" had responded negatively to large camera rigs in the past. A small camera setup with no rigging or automation meant that the camera had to be manned constantly throughout 1 hr trials, increasing the time and effort of researchers.

4.2. Machine Learning

The experiments show that individual identification of gorillas can be performed robustly. The YOLOv3 object detector can be trained to perform simultaneous localization and classification of individual gorillas on single frames. Additionally, identification performance can be further improved by utilizing multiple frames. The single and multi-frame approach achieve 92.01 and 97% mAP, respectively. Therefore, the facial recognition application is capable of accurately identifying which, and to what extent, individual gorillas are engaging with the cognitive enrichment device; this allows usage frequency and duration to be monitored automatically. This can be done by applying the facial recognition system to new video footage and collecting the detections. By sampling the detections every second it is possible to automatically generate usage statistics. To illustrate this, our system was applied to a 30-min segment of unseen video footage collected at the zoo and detections were sampled every second, as described above. The detections were then processed using Python scripts to automatically generate usage statistic figures. **Figure 7** shows the proportion of time each of the gorillas spent engaging with the device and **Figure 8** indicates the order and frequency of use. The 30-min segment was manually verified by human observation.

There are, however, several aspects to consider with respects to the machine learning pipeline. The use of such a system introduces many interesting scenarios and where interpretation the of data is unclear. For example, only one gorilla can interact with the device at a given time. However, there are many scenarios where multiple gorillas are detected in frame. In most cases simply filtering scenarios where a gorilla is detected for a very short duration could remedy this scenario. However, there are instances where the gorilla interacting with the device is occluded and only the observing gorillas are detected. This could indicate incorrect periods of engagement by the observing gorilla. Similarly, juvenile gorillas frequently accompany more senior members of the troop for long duration's while they are engaging with the device. This can lead to multiple detections which occur simultaneously and do not represent true engagement. Examples of both these scenarios are shown in **Figure 9**.

Additionally, there are several key practical considerations to raise. Firstly, curating a custom dataset to train YOLOv3 is resource intensive, although usage data (frequency and duration) may be retrieved automatically thereafter. As a result of the erratic movements of the gorillas in their enclosure (i.e., rapid changes in poses, movement into spaces occluded by the mesh, some tampering with the camera-housing modules, etc.) it was necessary to manually view and select appropriate

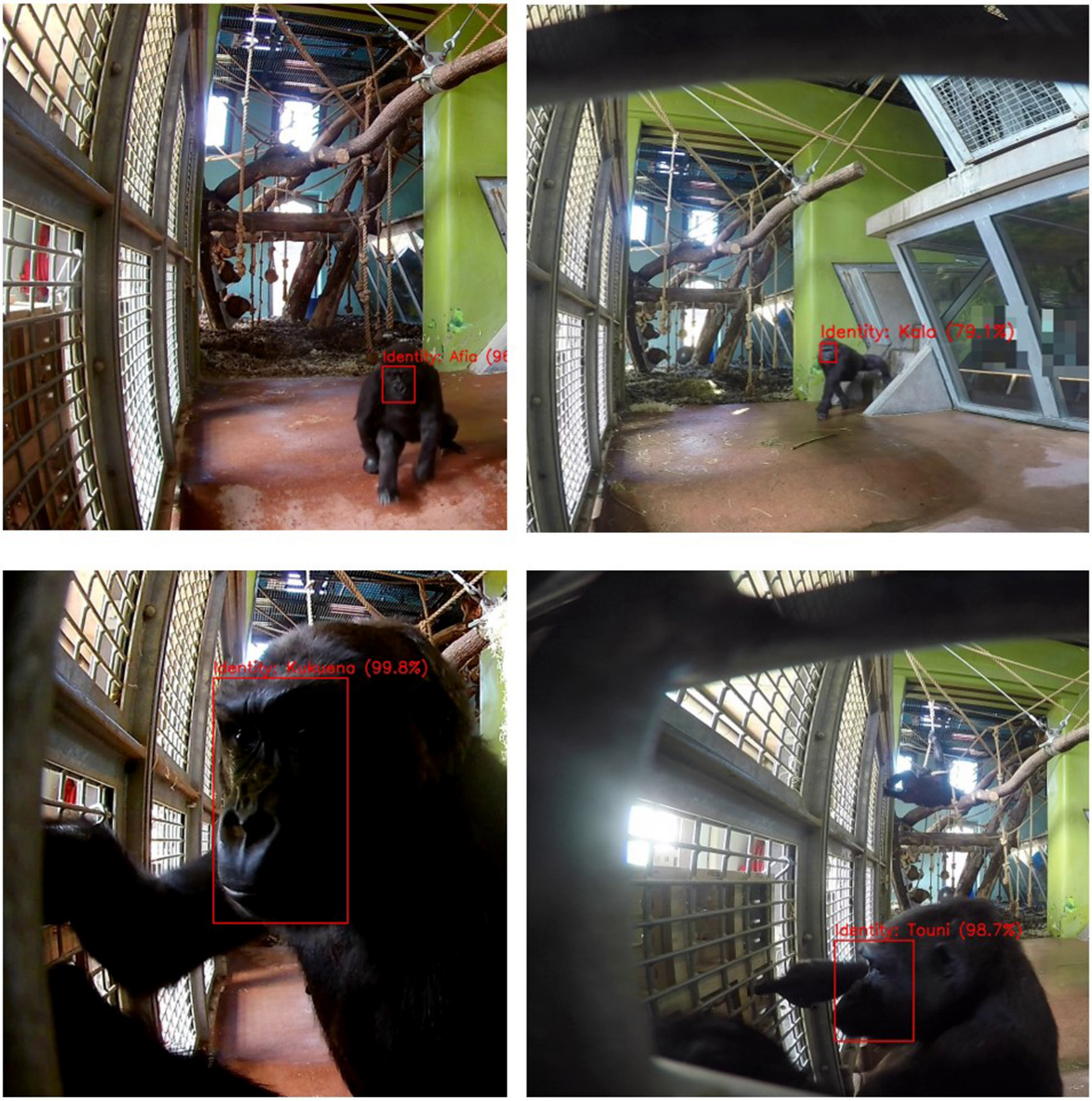

FIGURE 5 | Single frame detection. The figure shows a collection of images of gorillas interacting with the Gorilla Game Lab device (on the left of each image) after processing by the facial recognition model. The red boxes represent facial localization predictions. The gorilla identities are also predicted by the model with the prediction confidence indicated as a percentage in brackets.

images. It was estimated that approximately 150 h were required to curate the dataset. Therefore, long-term projects, intended to span several months or years, would benefit from the described machine learning pipeline. However, short-term projects, lasting only several weeks, may be better suited to traditional behavioral observation. With that being said further experimentation shows that acceptable performance can be achieved with significantly less data (see **Table 5**), depending on the performance requirements of the study. Secondly, it does not automate collection of data such as strategy, module/s used or success. To collect this type of data, another method would need to be employed (such as observation, for example). Although this could be done alongside the described machine learning system, the time savings would not be as significant.

Another important consideration is data management. Video footage recorded at high resolution (i.e., HD footage recorded at 30 FPS) has a large memory footprint. In this study, 30-min segments require approximately 5 GB of disk space.

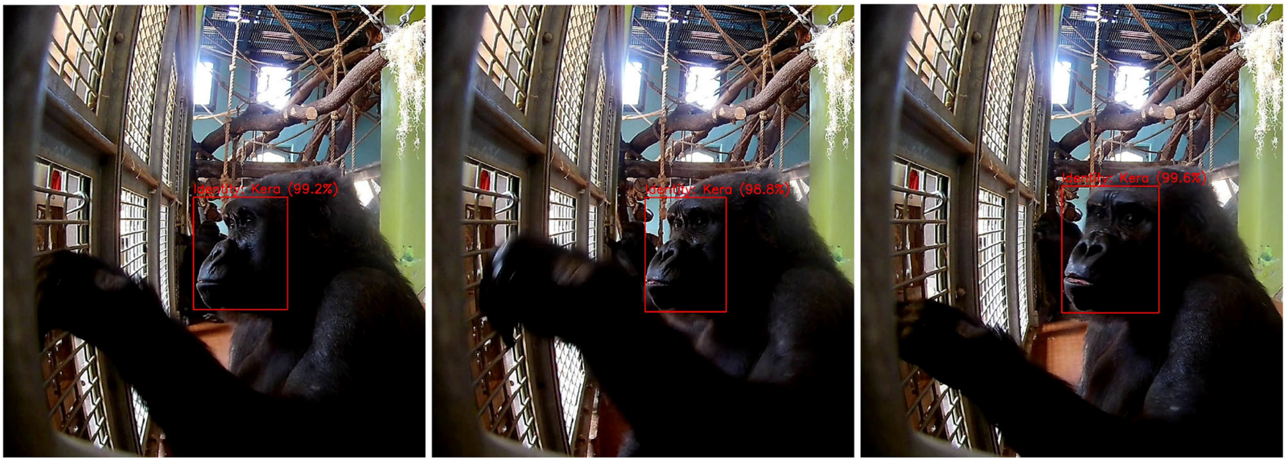

FIGURE 6 | Tracklets and voting strategies. The figure shows a sequence of three frames (at time steps t_1, t_2 and t_3) of a gorilla engaging with the Gorilla Game Lab device. The red boxes represent model predictions with the identity and confidence shown above the box, as in this figure. In this sequence of frames the true identity of the gorilla is Kera. The maximum voting strategy uses only the highest detection confidence (99.6%) at t_3 to assign an identity across all time steps. The average voting strategy uses the highest average probability for *each* detected gorilla identity, where the mean is always calculated using the total number of time steps.

However, not all footage is necessarily of interest; there are large segments where no interaction is occurring. It is possible to utilize the machine learning system to identify segments containing no activity so they can be discarded, relieving some of the storage requirements. In any case, data storage should be considered ahead of time. In particular, studies which require all original footage to be retained should ensure a suitable storage solution is in place. In cases where it is not necessary to retain the original video footage, the meta-data produced by the machine learning system can be stored in light-weight storage formats such as JSON or XML. This storage format requires approximately 200 MB per 30-min segment. This could be further reduced by removing data points relating to periods of inactivity. Additionally, this data can be further condensed into summary statistics (i.e., total usage duration, usage order and usage duration for each gorilla interaction) and is all that is required to produce visualizations such as **Figures 7**, **8**. Human data protection is also of utmost importance. In our study, even though we did not use any human data, we removed any small possibility of humans being identified in the background of footage using blurring software (Section 2.7.1). When working with animal image capture, researchers must make sure they have a procedure in place to deal with any inadvertant capture of human data.

Additionally, there are several key technical points to consider. Firstly, the dataset on which the model was trained and evaluated was gathered over a relatively short period of 6 weeks. Therefore, it is still possible that there is an overall lack of diversity in the data. For example, there will be large variations in lighting conditions, depending on the time of year, which may affect the performance of the system. It is uncertain therefore what, if any, the effect of this narrow data collection window has on the performance of the model and for future applications. Secondly, it is uncertain how changes in the appearance of gorillas over time will affect system performance. The appearance of the younger members of the troop will change relatively quickly as they grow and their facial features mature. It is possible that this could reduce the accuracy of the detector. The faces of the older members of the troop will also change as they age. Additionally, the behavioral patterns of the troop members may change over time and the class imbalances which exist in the dataset may no longer be reflective of the troop's dynamics. The device will need to be trialled over a long enough period for the effects of this to be evaluated.

TABLE 3 | Single frame YOLOv3 identification performance.

Gorilla	AP (%)	Precision (%)	Recall (%)
Afia	91.3	85.0	87.0
Ayana	74.9	84.0	68.0
Jock	98.5	98.0	92.0
Kala	92.7	95.0	89.0
Kera	97.2	96.0	92.0
Kukena	92.9	89.0	88.0
Touni	96.9	90.0	95.0
Mean	92.1 (± 8.0)	91.0 (± 5.5)	87.3 (± 9.9)

The table depicts testing results for each of the individual gorillas.

TABLE 4 | Multi-frame detector performance.

Detection	mAP (%)	Precision (%)	Recall (%)
Single	92.1 (± 8.0)	91.0 (± 5.5)	87.3 (± 9.9)
Average	97.3 (± 2.5)	95.1 (± 4.7)	91.1 (± 6.5)
Maximum	97.5 (± 2.2)	95.4 (± 2.7)	91.2 (± 7.9)

Performance is shown for both average and maximum voting schemes. The performance of the single-frame detector is included for comparison. Note that the maximum voting scheme achieves the best performance across all evaluation metrics.

Using the machine learning method, being able to identify the presence of specific individuals using the device helps to create a simple picture of the degree to which they are undertaking cognitive enrichment. This in itself could be used as a general marker of enrichment engagement for animal welfare staff within zoos. Additionally, the system is able to log the presence of gorilla interactions with enrichment across much larger time frames than would be possible with traditional observations alone. For example, while it may take 5–10 s to identify the gorillas in a single frame of footage manually, the same can be achieved by the facial recognition system in a fraction of this time. Additionally, the facial recognition system can operate continuously (and without downtime), irrespective of personnel, for as long as required. Yet, the machine learning method presently falls short of the behavioral observations with regards to the lack of qualitative understanding (i.e., the nature of gorilla interactions, approaches to problem solving, degree of success, or failure, etc.) generated about how the enrichment device is being used. With the variability of the challenging environment (e.g., camera occlusion, individual differences in movement, and approach to using the device), at present it is technically infeasible for our facial recognition to automate the analysis of gorilla behavior. Thus, the future direction of the project will consider a further ecosystem of technologies to understand this.

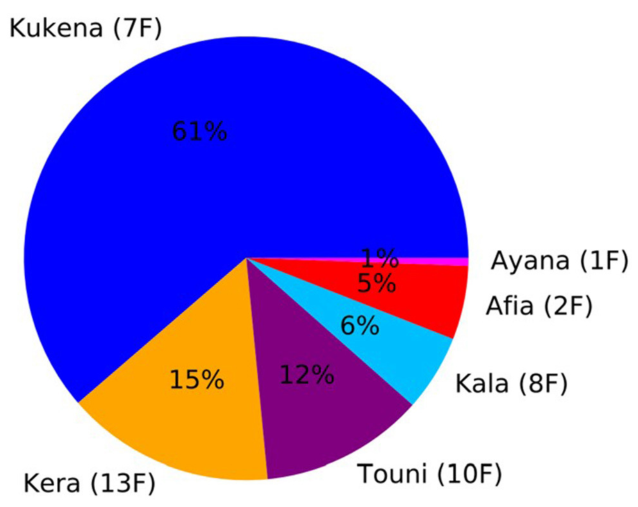

FIGURE 7 | Usage Pie Chart. The figure shows the proportion of time spent by each gorilla engaging with the Gorilla Game Lab device over a 30-min segment. The age and sex of the gorilla is indicated in brackets (i.e., 1F indicates a 1 year old female). Kukena, 7 year old female and daughter of Jock, the male silverback, engages with the device the most. Ayana, 1 year old female, engages with the device the least.

4.3. Future Directions

4.3.1. Exploring Integrated Sensors

The facial recognition technology can robustly identify individuals and therefore be applied to determine which gorilla is engaging with the device and for how long. However, as stated, it does not provide any detail as to how the gorillas are engaging with the device. Thus, triangulating the facial recognition system with additional technology may produce richer insights. Sensor technology can detect physical phenomena, such as changes in light, temperature or pressure, and convert them into a machine readable signal. We speculate that sensor technology could be integrated into the device to automate tracking of gorilla device usage by monitoring each of the device's sub-modules individually. For example, by positioning a sensor in each of the sub-modules. Signals received from a sensor would indicate activity or interaction with a particular sub-module. Data on the individual usage of each sub-module would allow important cognitive and behavioral information to be deduced. For example, long periods of interaction with a specific module, relative to others, may indicate the difficulty level is too high.

We are conducting further research using infrared and piezo sensors and consider their efficacy for understanding enrichment device interactions in a small number of evaluations. In these evaluations, sensors were placed in each of the devices' sub-modules. The gorilla participants were presented with a maze of modules, of varying difficulty levels, which they were required to solve sequentially. It was necessary for each of the participants to extract a nut from the maze in the shortest possible time. At this stage, there is unfortunately no meaningful data that

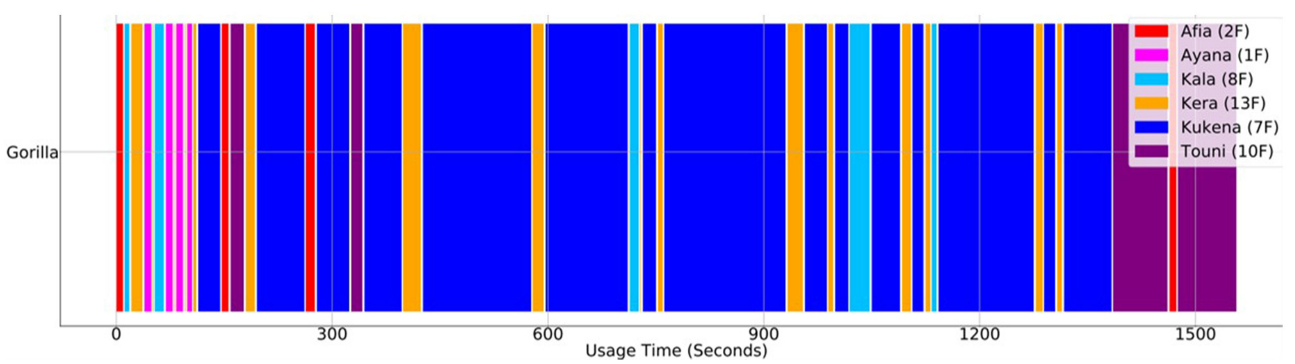

FIGURE 8 | Order, Frequency & Duration of Use. The figure shows the order, duration and frequency each gorilla engaged with the Gorilla Game Lab device over the same 30-min segment as shown in **Figure 7**. The age and sex of the gorilla is indicated in brackets (i.e., 1F indicates a 1 year old female).

FIGURE 9 | The figure shows cases where the detections do not represent true instances of interaction with the Gorilla Game Lab device. The image on the left shows a scenario where the gorilla interacting with the device is not detected due to crouching but the observing gorilla is. The image on the right shows simultaneous detection of the engaging gorilla and the observing juvenile gorilla.

can be used to understand how the gorillas engaged with the device from the piezo sensors. This is a consequence of sound propagating through the device and obfuscating the results. For instance, a knock, scrape or manipulation in one module may show up across the adjacent module's sensors, without targeted interaction, leading to a lack of precision. On the other hand, preliminary results from the infrared sensor technology suggest that it is possible to gain an indication of how the gorillas are engaging with the device. The benefit of the infrared beam method for tracking gorilla device use was reliability; due to the size of the nuts being relatively regular, the infrared beam was very likely to register a nut falling between two modules. This allowed the timestamp of a triggering event to be logged and for the duration of maze use to be calculated. Subsequently, the average usage time per maze module could be determined.

4.3.2. Toward a Zoo-Based Ecosystem of Technologies

As we build toward the triangulation of facial recognition and sensor technologies, we consider the wider implications this may have for the animal-centric design approaches. WAZA recommend that enrichment should be changed when appropriate to provide sufficient challenge and choice (44) and, thus, there is a push toward fine-tuning animal technologies toward the preferences of individual animals. In marrying facial recognition with efficacious sensor technologies, we aim to generate richer accounts of gorilla interactions with enrichment devices. This may allow us to develop more individually relevant experiences as a product of understanding the cognitive and affective consequences of our design decisions. We envisage that by combining the facial recognition and sensor technologies it would be possible to automatically determine windows of engagement for each gorilla and calculate the time spent on each maze during this window. With this information it is possible to build a personalized view of each gorilla and their individual enrichment needs that is based around their competencies and preferences. This would, in turn, allow more suitable configurations of maze modules to be presented to the gorillas and ultimately inform the design of new modules and future device iterations or modifications. A suite of evaluative technologies, as described above, would allow zoo keepers to infer optimal times to change enrichment and provide insight into the types of changes required.

TABLE 5 | Performance is shown for both average and maximum voting schemes.

	Proportion of training data			
	10%	20%	40%	80%
mAP	75.44 (± 12.2)	82.55 (± 9.94)	90.14 (± 6.66)	**92.02** (± 7.42)

The performance of the single-frame detector is included for comparison. Note that the maximum voting scheme achieves the best performance across all evaluation metrics (as shown in bold).

While greater sensitivity to the enrichment needs of individual animals is a worthy endeavor, with the differences in resources between zoos, there is a need to make any ecosystem of technologies as accessible as possible for animal welfare staff. WAZA recommend building "staff skills, internal culture and commitment to enrichment strategies and activities" into daily management (44). Hence, in future directions of our design research, we must package our ecosystem of technologies to fit neatly within the daily animal welfare routines and culture of the zoo. One of the shortcomings of the methods outlined in this paper is their retrospective nature. Ideally, the gorilla identification and sensor data would be logged and displayed in real-time, allowing welfare staff to respond much more quickly to animal enrichment needs.

To make this accessible, we speculate that a virtual environment that can triangulate and present the facial recognition and sensor data could provide additional analytical automation. A second avenue of our ongoing research is the development of a dashboard application that could be used to allow the current and historical data to be visualized. Preferably a number of different "views" would be available to the user, allowing individual or troop-level statistics to be displayed. An application of this nature could provide keepers with the ability to assess (and possibly respond to) individual or collective enrichment needs with greater autonomy. Additionally, it may help to promote engagement with new enrichment strategies by allowing keepers to observe the effect of new maze module configurations or device modifications on the troop. Similarly, a greater understanding of how individuals in the troop engage with enrichment may lead to more effective and efficient deployment.

While, the sensors and wider triangulation of technologies may inspire new evaluative technologies for enrichment in zoos, they must undergo further development and rigorous evaluation. Data obtained from direct observation and sensors can yield very different results, so ultimately it is wise to use both if a research project can afford to do so, and until such a time that machine learning can fully replace live observations (45). Further thought is also required to ensure that our ecosystem of automated technologies can be deployed at scale and in zoos with varying resources. We recognize that this research project brings together an interdisciplinary team that would be hard to recreate and, thus, it is essential that our work builds toward accessible approaches. We look forward to presenting more detailed results of these avenues of research in future publications.

4.3.3. Wider Implications of the Current Research

The system described in this project was developed specifically for gorillas. As described previously, methods for great ape facial recognition more generally have been borrowed from the human domain. They are assumed to be effective owing to similarities in their facial characteristics. Therefore, a similar system, dependent on facial recognition, could be implemented for other members of the great ape family, namely orangutans and chimpanzees. In particular, there is strong evidence to support the successful implementation of chimpanzee facial recognition systems (29, 31, 33). Similarly, there is evidence to suggest such a system may generalize and be effective for monitoring other primate species (46, 47). Additionally, such systems do not need to rely on facial recognition. Machine learning models can be trained, using the same protocol, to perform individual identification based on other features, such as full-body images (48, 49). This may be particularly useful where coat patterns, size and pose, rather than facial appearance, are more individually discriminative features. Furthermore, such a system is also suitable for use in other captive settings like sanctuaries, farms, and laboratories where granular individualized data may be of value in monitoring animal welfare. Lastly, machine learning could be used to generate data beyond individual identification; it also has the potential to generate detailed information on animal pose (22) and behavior (23, 50).

DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: https://data.bris.ac.uk/data/dataset (and search BristolGorillas2020).

AUTHOR CONTRIBUTIONS

OB and TB developed and validated the machine learning system and handled all machine learning data. SG, FC, KB, and PB developed and implemented the cognitive enrichment device. FC and KB developed the behavioral observation protocol, and behavioral data were collected by ER. SG structured the first draft of the manuscript. All authors contributed to the conception and design of the study, manuscript revision, read, and approved the submitted version.

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Towards Machine Vision for Insect Welfare Monitoring and Behavioural Insights

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Machine vision has demonstrated its usefulness in the livestock industry in terms of improving welfare in such areas as lameness detection and body condition scoring in dairy cattle. In this article, we present some promising results of applying state of the art object detection and classification techniques to insects, specifically Black Soldier Fly (BSF) and the domestic cricket, with the view of enabling automated processing for insect farming. We also present the low-cost "Insecto" Internet of Things (IoT) device, which provides environmental condition monitoring for temperature, humidity, CO_2, air pressure, and volatile organic compound levels together with high resolution image capture. We show that we are able to accurately count and measure size of BSF larvae and also classify the sex of domestic crickets by detecting the presence of the ovipositor. These early results point to future work for enabling automation in the selection of desirable phenotypes for subsequent generations and for providing early alerts should environmental conditions deviate from desired values.

Keywords: machine vision, deep learning, insect farming, black soldier fly, domestic crickets, sex classification

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1. INTRODUCTION

Insects are currently a component in the diets of two billion people around the world (1) and 2,111 known insect species have been recorded as being consumed by people (2). There is a good reason for this. Insects such as crickets and BSF, like other types of arthropod, are remarkably efficient in fixing biomass that is highly protein rich; they are also hardy and easy to breed (3), require little or no processing before consuming, and they have a relatively short growth cycle. This makes them attractive for breeding in regions of the world which suffer from food insecurity problems that affect food supplies for both livestock and human consumption as well as offering potential alternative protein sources for livestock feed *via* waste processing in mode developed areas.

Conversely, when we consider the issue of food insecurity, food waste is a financial, humanitarian, and environmental concern, demanding a sustainable and efficient solution to manage the ever-increasing volume of nutrition loss. Naturally, some insects feed on organic waste and turn it into biomass. They are able to consume low-grade organic waste and convert it into usable bio-products such as animal protein and lipids (4), which could feed livestock animals, such as fish, poultry, and pigs.

For these reasons alone, insect farming has attracted considerable interest from industry as well as within academia, and this interest is predicted to increase over the next decade. Evidence for the commercial validity of insect farming is that there are already multiple companies and startups around the UK, such as Entocycle, Better Origin, and Beta Bugs, who are professionally farming insects like Black Soldier Fly. However, this approach is not limited to the UK and has been used across the globe, e.g., the USA, Southeast Asian countries such as Indonesia and Thailand as well as many countries in Africa.

Insect farmers require knowledge of the growing conditions within each growing enclosure. In a large scale insect farm there could be many hundreds of growing enclosures. At such a scale the individual monitoring of growing enclosures will be less than practical. Therefore, an automated surveillance system which can provide essential information is needed. Such information could be: the number of insects, sex balance of the population, and size of individual insects within an enclosure, along with environmental conditions such as temperature, humidity, and CO_2 levels. This information from the system could be used to calculate other information such as activity/movement levels, amount of food remaining in an enclosure, and signs of pathogens/predators, to provide an autonomous closed-loop control system for each enclosure and also to provide management information direct to farmers.

In addition, to these somewhat obvious measures that can be leveraged cheaply from off the shelf IoT devices, the development of advanced instance level segmentation and identification algorithms, may allow us to begin to monitor individual interactions of insects at a level that has been prohibitive in the past, such as those identified in (5). In traditional livestock farming, we are seeing the emergence of long term identification and tracking systems. Example include pig farming (6) and in dairy herd management (7), allowing social networks to be analysed and more fine-grained approaches to welfare adopted. It is not beyond imagination that similar techniques can be applied to insect populations to bring about a deeper knowledge and appreciation of colonies, as well as being able to provide enclosure level information concerning the welfare of its inhabitants based on individual behaviours.

This article presents results from two pilot experiments involving BSF and domestic crickets. We report on the acquisition device hardware which is designed to be low cost, that when combined with state-of-the-art deep learning techniques allow us to count, size, and sex the insects. Although important previous work in the area of insect classification has been carried out by: Hoye et al. (8), Valan et al. (9), Blair et al. (10), Hansen et al. (11), there has been little prior work in the specifics of insect detection and sex classification, less on using real world images, and no known work for sex detection using real world images. Our motivation for focusing on size classification for BSF is in order.

2. MATERIALS AND METHODS

This section is broken into two subsections describing our work using machine vision on BSF and domestic crickets (*Acheta domesticus*), the first to measure the size of BSF larvae, the second to count and sex crickets. All machine vision code and data analysis software was written in Python 3.8 using publicly available libraries (Tensorflow, NumPy, scikit-learn).

2.1. BSF

There is a tendency of BSF farmers to favour larger flies as they have a higher reproduction rate, the larvae are bigger and thus contain more protein than smaller larvae. Manual selection of such traits at an industrial level is currently infeasible due to the high numbers of larvae making it economically unviable. We therefore look at the first stage of automating this process by training an object detector to distinguish those larvae that are larger than a given threshold and are therefore suitable for breeding, and those that are smaller and should be euthanised for protein.

The whole process of measuring, image capturing, and recording the sizes for the creation of this initial dataset was manual. The focus of this work was to validate that large pupa can be identified for selective breeding rather than precision measurement. Using machine vision for measuring objects is a classic use case, but often fraught with issues, such as lens distortion, occlusion, shadowing, etc. in unconstrained capture environments. As the larvae are non-rigid, the system needs to be able to also cope with this, so an overall deep-learning based classification system has been developed rather than a measurement tool. As such, the experiments have not been replicated (as might be expected in biological studies) – the larvae were grown, imaged and measured. Future work will commence the important work of investigating the effects of climate on their behaviour and having control experiments in place to allow statistical analysis through replication studies. Future work will focus on investigating whether it is also possible to determine the sex of the pupa reliably using machine vision, something which is currently extremely difficult to do manually. This is discussed further in Section 4.

2.1.1. Acquisition

Figure 1 shows the equipment used to capture images of BSF larvae. BSF larvae are negatively phototactic (i.e., they avoid strong sources of light) (12). Therefore, in order to image continuously over 24 h, Near Infra-Red (NIR) light sources (850 nm) were used to illuminate the environment without disturbing the larvae. This is an important consideration for any commercial implementation and here while we use the NIR images for analysis, the visible light source images could be used for sorting dried BSF pupae.

As there is no publicly available Black Soldier Fly dataset, a BSF colony was farmed to acquire images to train an object detection model. Thus, 500 BSF larvae were purchased to populate the colony. The BSF were kept at 27.6^{o}C temperature, 60–65% relative humidity, and fed a diet consisting of fresh vegetables, fruits, and plant-based products. The pre-pupae were collected daily from the storage section and placed in a location with controlled ambient illuminations (i.e., out of direct sunlight to ensure consistent illumination) to capture their images. An "ASHATA" IR camera module connected to a "Raspberry Pi 3 B+" was used to capture images. The camera was mounted at the height of 9 cm, which was empirically determined to ensure that the pre-pupae were of suitable size in the images. Images were captured with the maximum resolution possible, which was 5 MP (2592 x 1944 pixels). In total, 310 visible light and 310

NIR images of individual larvae were captured and used for classification experiments.

The object detection model chosen for deployment was an SSD-MobilenetV2 with an image resolution of 300 x 300 pixels as this lightweight model is capable of running on low power edge devices such as a Raspberry Pi.

A Train:Test:Validation split of 60:20:20 was used.

2.2. Crickets

2.2.1. Acquisition

Images were captured from a cricket growing facility in Calabar, Nigeria where researchers from the University of Calabar have been carrying out work into the commercial growing of crickets (*Acheta domesticus*) for agricultural purposes. An Insecto device, a system developed by SciFlair, Bristol, specifically for the monitoring of cricket enclosures, was used to capture these images. The device is equipped with a range of sensors for measuring: humidity, air pressure, CO_2, and volatile organic compounds (VOC); as well as a camera module, LED lamp, and internet connectivity. The device was mounted to the roof of one of the growing vessels so that the camera captured a top down image of the enclosure. A view of the bottom of the Insecto device is shown in **Figure 2**. An example of one of the images captured by the Insecto device can be seen in **Figure 5**. The Insecto device was configured to capture an image each hour it was powered on. These images were then uploaded to an internet cloud storage service. This image is used as input to the YOLOv5 model. The camera module used in the Insecto device is a Raspberry Pi Camera with a Sony IMX477 CMOS sensor. Each image captured was a 24 bit sRGB 4056 x 3040 pixel jpeg image.

In the period starting from the 12th of July until the 8th of August 2021, 195 images were uploaded to the cloud storage service. Of these 195 images a random sample of 100 images were selected in which the crickets were marked with bounding boxes using the Computer Vision Annotation Tool (CVAT), a free open source tool developed and made available by Intel (13). In total, 2,796 crickets were labelled. These labels were used to train the YOLOv5 object detector to count the insects.

The second stage, classifying the sex of the cricket, was performed by adding additional annotations to these bounding boxes based on the visible presence of an ovipositor as seen in **Figure 3**. It should be noted that crickets which received

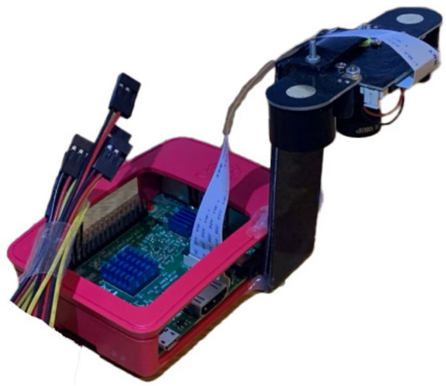

FIGURE 1 | Device for capturing images of BSF larvae—ASHATA IR camera module, connected to a Raspberry Pi 3 B+.

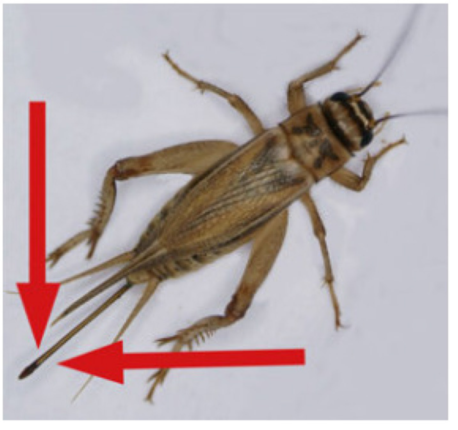

FIGURE 3 | An adult female Cricket, *Acheta domesticus*. Identifiable as female due to ovipositor (marked by red arrows). Image modified from (14).

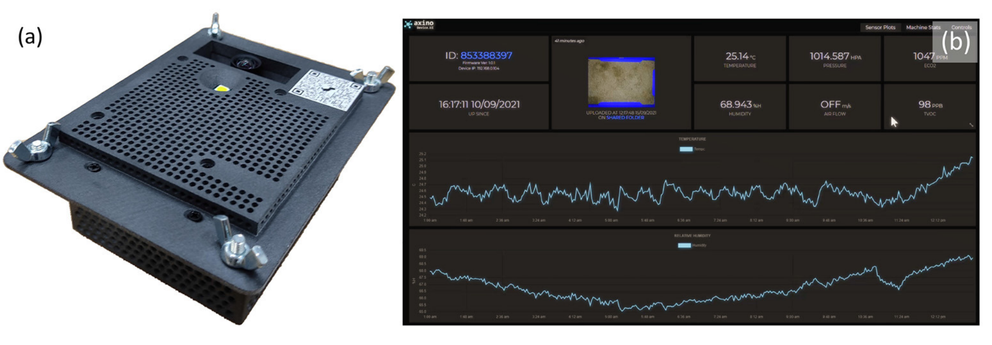

FIGURE 2 | (a) The "Insecto" device providing temperature, humidity, CO_2, air pressure, and volatile organic compound levels environmental condition information together with timelapsed image capture that was used to capture the images of crickets from the University of Calabar. **(b)** Screenshot of the data captured and displayed from a webservice.

a "Female" attribute with a "False" value likely included some images of females with occluded ovipositors, females which were too blurry to positively identify their ovipositors, and juvenile females/Nymphs with undeveloped ovipositors. Crickets without an ovipositor visible therefore cannot definitively be identified as male due to the presence of these immature female, occluded, and blurry instances. For this reason a Female[True/False] class was selected over Female/Male classes for the cricket annotation.

For the actual sex classification, feature extraction was performed using VGG-16 (15) with pre-trained ImageNet weights, and the outputs from the final convolutional layers are then used in an SVM for classification.

Again, a Train:Test:Validation split of 60:20:20 was used. The test dataset (20% of total dataset) contains 20 images taken from the cricket growing container with 268 cricket instances (100 female, 168 male) which were manually annotated.

We present our validation results in **Table 1** in terms of precision [Equation (1) what proportion of positive identifications were actually correct]; recall [Equation (2) what proportion of actual positives were identified correctly]; and F1 [Equation (3) the harmonic mean of the two which provides an additional measure of the accuracy]. The third row in **Table 1**, "Accuracy" presents the overall accuracy, i.e., the number of correct identifications out of the total number of images.

$$Precision = \frac{\text{True Positive}}{\text{True Positive} + \text{False Positive}} \tag{1}$$

$$Recall = \frac{\text{True Positive}}{\text{True Positive} + \text{False Negative}} \tag{2}$$

$$F_1 = 2 \times \frac{\text{Precision} \times \text{Recall}}{\text{Precision} + \text{Recall}} \tag{3}$$

3. RESULTS

Here, we present the results from our pilot studies for measuring the size of BSF larvae, distinguishing whether the larva is best suited to breeding or consumption, as well as counting and sexing crickets.

3.1. BSF

The size distribution of the BSF shown in **Figure 4**. An example output from the trained SSD-MobilnetV2 model is also shown in **Figure 4**. The trained model performs with a Mean Average Precision (mAP) of 0.87 which indicates that it is able to correctly classify the larvae in 87% of cases in the validation set.

3.2. Cricket Detection and Sexing

Figure 5b shows an example image with bounding boxes and confidence intervals overlaid after running inference with the trained model. The model was able to detect crickets with an F1 score of 86% when the confidence threshold was set to 0.525 (F1 vs. confidence can be seen in **Figure 5a**).

On the Calabar test set the VGG-16 network achieved very promising performance after 30 epochs of training. Results were achieved which gave an F1 score of 93% for the sex classification of the crickets as shown in the performance breakdown by class/sex in **Table 1**. The confusion matrix showing the comparison of Actual/ground truth data against the predicted class results is shown in **Figure 6**. Some discussion of the implications of these results can be seen in the next section.

TABLE 1 | VGG-16 sex classifier results on the Calabar dataset.

	Precision	Recall	F1	N
Female	0.91	0.91	0.91	98
Unknown	0.95	0.95	0.95	164
Accuracy	-	-	0.93	262
Macro Avg	0.93	0.93	0.93	262
Weighted Avg	0.93	0.93	0.93	262

Metrics are defined by Equations (1)–(3). N is the number of observations these are based on.

4. DISCUSSION

In summary, our results show the following:

1. High accuracy detection of live *Acheta domesticus* with 86% F1 score at 0.523 using YOLOv5.
2. High accuracy classification of real world *Acheta domesticus* to a sex level by further training a pre-trained convolutional neural network. Achieved F1 scores of 93% using VGG-16 with an SVM.
3. High accuracy detection of BSF larvae of 87% mAP using SSD-MobilenetV2.
4. Initial successful trials of the "Insecto" device to remotely gather images and environmental information using a low cost device with minimal setup and maintenance requirements.

This research shows that the application of deep learning models to both the detection of *Acheta domesticus* and classification of their sex is accurate enough to be useful for commercial cricket growing organizations. These results also have promise for deployment in camera traps to detect and classify other species to a species as well as classify sex from real world images.

While the accuracy of the cricket detector is reasonable at 86%, it can be seen in **Figure 5b** that some highly occluded crickets were identified by the detector and all non-occluded crickets were also identified. However, three instances of detection errors can be observed in this image which are indicative of the models performance on the rest of the dataset. The first error is a false positive with a confidence of 0.77 which is located to the right of the white container, the second is a pair of crickets enclosed by a single bounding box to the bottom right of the white container, and the third is a highly occluded cricket near the top region of the green leaves. These three instances represent the typical situations where the model fails: when crickets are highly occluded, when crickets are overlapping or on top of one-another, and where there are objects which have features which appear vaguely cricket-like and are next to green objects; it seems that the model confuses these with highly occluded crickets.

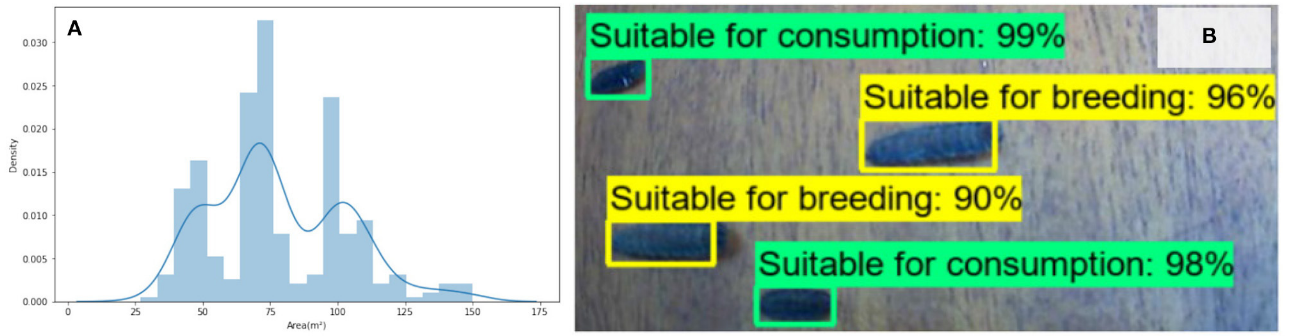

FIGURE 4 | (A) The tri-modal distribution of BSF larvae size. **(B)** Example image of BSF classification trained primarily on size, and confidence levels with mAP score of 0.87.

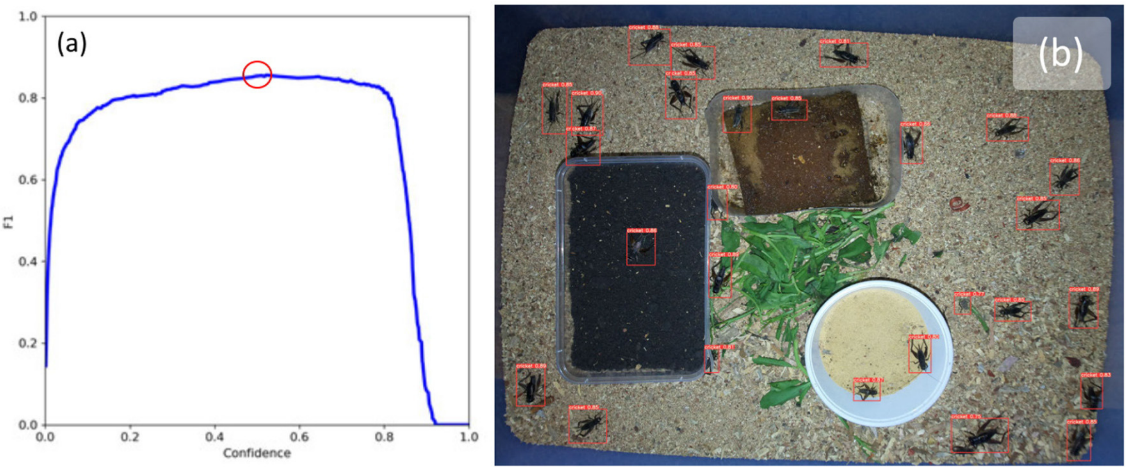

FIGURE 5 | (a) F1 confidence curve shows best F1 score of 0.86 with a confidence threshold of 0.523 (highlighted with red circle), and **(b)** example results of cricket detection using YoloV5 with confidence threshold set to 0.523.

It is likely that further improvements can be made by optimising the chosen architecture as well as providing larger amounts of training data. Typically, the errors result from highly occluded or tightly clustered/overlapping insects. A similar issue is described and mitigated by using a modified Mask-RCNN (16) for separating tightly clustered pigs by Tu et al. (17). The suggested approach should generalise well to crickets.

With regards to BSF larvae, our results demonstrate the feasibility of being able to separate colonies based on phenotypic traits (in this case size) with 87% accuracy. With a larger dataset, the performance of this is likely to be improved upon. It is hypothesised that this method causes the next generation to favour larger sized larvae. We, therefore, suggest that further work compares the generational effects of selective breeding through the automation of this process. It is therefore proposed that future work should perform a controlled group experiment, to acquire two similar BSF colonies and perform selective breeding on one of the colonies over a number of generations. Except for this, all the remaining conditions must be the same. Only then, the resulting performance plots could be compared to conclude the approach's effectiveness.

Although a possible product of a relatively small sample size, it is interesting that a tri-modal distribution is shown in the sizes of the larvae in **Figure 4A**. While the overall distribution is normal, the clear troughs either side of the modal peak are unexpected, and the reason for the outer peaks is not known but does infer that if this distribution is replicated across other colonies, and that these phenotypes are inheritable, then automated systems that rely on vision based sizing will be able to identify and separate individuals based on these size distributions. While it might be expected that the sizes would fall under a normal distribution, or that as suggested by Putra and Safa'at (18), that female pupae are larger, that a bi-modal distribution (corresponding to the sex), the presence of the central peak indicates other influences (perhaps based on conversion performance) are present.

While environmental data was captured successfully by the Insecto boxes in Nigeria, and the robustness of the device

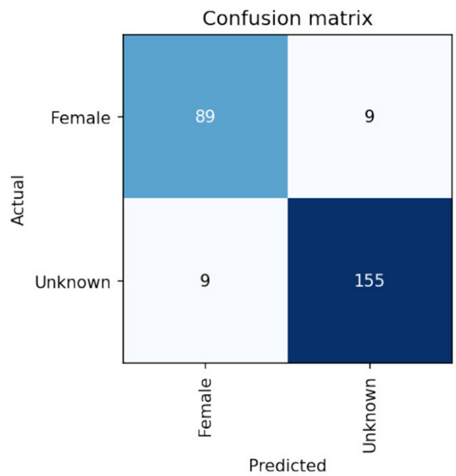

FIGURE 6 | Confusion matrix of sex classification from cropped detections using transfer learning based on VGG-16 base model weights showing 89 out of 96 females are correctly identified.

demonstrated, the actual data has not yet been analysed nor incorporated into any control loop. Future work will seek to automatically adjust local temperatures, humidity, and airflow in order to assess their impact on the colonies and develop optimal conditions for the insects to thrive. This type of low-cost, low-maintenance device could prove to be exceptionally useful for smallholder farms to monitor small scale insect farms that could provide a reliable source of protein for livestock in developing countries. It could also be used in large scale farms to remotely monitor conditions where manual inspection would be prohibitively time consuming. Future work will use the environmental monitoring data to provide a closed loop feedback system to maintain conditions, and be used to determine optimal parameters to increase yields in comparison to control groups which are controlled at the room level.

With minimal effort, it will also be possible to detect anomalous behaviour which may offer early indications of problems in a colony, for example disease which requires intervention. Using the object detection frameworks presented here, it would also be possible to assess whether an insect has not moved for a prolonged period of time and, if it is an isolated case, remove it from the tray or alternatively dispose of the whole tray if many such incidents are detected.

It should be acknowledged that there are limitations associated with this early work. For example, the sex classifier has only been tested on one species of cricket under relatively controlled conditions. This species has very visible sex characteristics, i.e., a large ovipositor. This means that the same level of accuracy is less likely for other species with less visible sex characteristics. It would be interesting to investigate the possibility of sexing BSF larvae using machine vision. While it is possible to sex adult BSF there is only limited work on attempting to sex pupae. Putra and Safa'at (18) showed that there was a significant correlation between the length of pupae and the sex (the longer the pupa, the more likely it was to be female) and reported classification accuracy of 62%. Through a longitudinal study it would be possible to generate a dataset of pupa that resulted in male or female BSF and then use a CNN in an attempt to extract more subtle features than the pupa length and increase the predictive accuracy. If this is found to be the case, then care must be taken when selecting individual larvae for subsequent generations, that sufficient numbers of the smaller males are included for viability. This also justifies the need to investigate more robust indicators of sex in BSF larvae rather than their size alone.

However, both experiments clearly show that machine vision can be used for counting, sizing and sexing insects reliably in typical insect farming environments and pave the way for a great deal of future work in which more complex features such as interactions (e.g., aggression or mating events) might be detected and recorded. This represents a considerable step forward towards automating such processes. It is possible to envisage such systems being able to guide robotic arms, perhaps with soft-robotic end-effectors to pick and place individuals between different colonies to balance overall numbers and ensure a balance of males and females as well as selection of individuals with desired phenotypes for future generations.

5. CONCLUSIONS

We demonstrate the efficacy of object detection and classification methods on two types of insects commonly farmed as sources of protein. We show that machine vision can be used for accurately counting, sizing, and sexing (in the case of crickets), where this important information can be used to effectively monitor colony health and potentially assist in automatically selecting desirable traits for future generations. This paves the way for further work in automated closed-loop insect farming and in exploring the ability to monitor insect behaviour at colony, and potentially individual levels.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available due to commercial sensitivities. Requests to access the datasets should be directed to mark.hansen@uwe.ac.uk.

AUTHOR CONTRIBUTIONS

MH corresponding author and PI of GCRF project, collated and oversaw project, and experimentation. AO cricket rearing and facilities, insect consultant, and wrote sections of the manuscript. RG cricket image analysis and wrote sections of manuscript. AK BSF rearing, image analysis and wrote sections of manuscript. MS Manuscript review. FT design and build of Insecto device and manuscript review.

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Is Seeing Still Believing? Leveraging Deepfake Technology for Livestock Farming

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Deepfake technologies are known for the creation of forged celebrity pornography, face and voice swaps, and other fake media content. Despite the negative connotations the technology bears, the underlying machine learning algorithms have a huge potential that could be applied to not just digital media, but also to medicine, biology, affective science, and agriculture, just to name a few. Due to the ability to generate big datasets based on real data distributions, deepfake could also be used to positively impact non-human animals such as livestock. Generated data using Generative Adversarial Networks, one of the algorithms that deepfake is based on, could be used to train models to accurately identify and monitor animal health and emotions. Through data augmentation, using digital twins, and maybe even displaying digital conspecifics (digital avatars or metaverse) where social interactions are enhanced, deepfake technologies have the potential to increase animal health, emotionality, sociality, animal-human and animal-computer interactions and thereby productivity, and sustainability of the farming industry. The interactive 3D avatars and the digital twins of farm animals enabled by deepfake technology offers a timely and essential way in the digital transformation toward exploring the subtle nuances of animal behavior and cognition in enhancing farm animal welfare. Without offering conclusive remarks, the presented mini review is exploratory in nature due to the nascent stages of the deepfake technology.

Keywords: deepfake, animal welfare, animal emotions, artificial intelligence, livestock health, digital farming, animal based measures, emotion modeling

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INTRODUCTION

Videos of politicians appearing to make statements they have never said in real-life, edited (revenge) pornography of celebrities, and movies with actors that have already passed away—deepfake technologies keep appearing in many different types of media, often while the audience is unaware of it. The term deepfake stems from combining the words "deep learning" and "fake," as the technology relies on machine learning technologies to create forged content. Deepfake is a type of technology based on artificial intelligence (AI) that allows fake pictures, videos or other forms of media to be created through swapping faces or voices, for example. Popularly, deepfakes carry a tainted representation due to their adverse misuses that can result in manipulation, misinterpretation, or malicious effects. However, the technologies behind it, in particular the Generative Adversarial Networks (GANs), have a handful of advantages when it comes to biomedical and behavioral applications, and can even reach uses beyond humans. The creative algorithms behind this booming technology allow big datasets to be generated and can level up AI technologies to e.g., identify emotions, behaviors and intentions, and subsequently to predict them timely. This therefore opens up the possibility to be applied to a broad scientific audience, including but not limited to animal science. With an ever-growing population size, the demand for livestock continues to increase, raising numerous concerns about its environmental impact, animal welfare and productivity. In this article, I explain the basics of deepfake technologies, its (mis) uses and how it bears the potential to be applied to agricultural practices such as livestock farming.

WHAT IS DEEPFAKE AND HOW DOES IT WORK?

Deepfake, just like other deep-learning algorithms, rely on neural networks which simply said, is a software construction that attempts to mimic the functioning of the human brain. Deepfakes require source data samples, and an encoder and decoder. A universal encoder is used to analyze and compare the key features of the source data, which can be an image, video, text or audio file. The data are broken down to a lower dimensional latent space and the encoder gets trained to find patterns. The decoder is a trained algorithm that uses the specifications of the target to then compare and contrast the two images. As a result, the algorithm superimposes the traits of the source onto the image of the target resulting in the forged data.

The main architecture that allows a high precision and functioning of deepfake technology is the generative adversarial network (GAN) which is part of the decoder (1). Generally, encoder is employed in the extraction of latent features of faces or region of interest from images, while decoder is used in the reconstruction of faces. In the process of swapping faces between the target and the source image while creating the deepfakes, two pairs of decoder and encoder would be required, where each is first trained on the source and then on the target image. What makes GANs so unique and accurate is the operating and working together of the generator and discriminator. The generator creates a new image from the latent representation of the source data (**Figure 1**). The discriminator on the other hand tries to distinguish between the newly generated and the original real data as accurately as possible and determines whether the image is generated or not. As both networks perform adversarial learning to optimize their goals based on their loss function, the generator and discriminator continue to work together to constantly improve its accuracy. The applicability is highly powerful due to the continuous performance improvements and vector arithmetic in latent space. Moreover, GANs can create new datasets with a similar distribution and statistics as the main dataset used to train the algorithm. The discriminator learns about the distribution of the data, resulting in a model that can output new, realistic samples.

Deepfake technologies have been used to create software's and applications that generate fake images, texts or videos. Examples of these are apps that reproduce text with someone else's handwriting ("My text in your handwriting"), perform face swaps between humans but also from human to animals ("FakeApp") and synthesize human voices ("Lyrebird"), amongst others. Open-source software's allow these technologies to be readily available to the public. Even though to date, it is still relatively intuitive to distinguish between real and fake, this distinction will start to fade as the technology advances. This development will increase the chance of misuse, manipulation, misinterpretation and spreading of fake news. Deepfake applications have therefore had a negative image due to the fear what may happen when falling in the wrong hands, to for example spread false information, pretending to be someone else or commit fraud.

However, the applications of deepfake technologies are not limited to (social) media purposes. The GAN model provides a sophisticated neural network with the big advantage that it can generate data based on a smaller, initial, real dataset. These frameworks have widespread uses, within fields such as biomedicine, behavior, affective science, but also beyond human applications.

USING DEEPFAKES AND GANS TO CREATE VALUE

Whereas the negative applications of deepfakes and GANs can be scary, there are many positive ways to apply these models to create value for numerous fields of science that in turn, benefit humans and society. First of all, GANs are proving their high value in medical settings, such as to (1) recognize pathogens (2), (2) support a better and more effective screening and diagnosing of disease and abnormalities due to complementing MRI and CT imagery (3, 4) and (3) predict the progress of disease (5). Moreover, research within medicine can be facilitated through creating synthetic patient data that not only benefits the scarcity of medical data sets through replicating real-like data (4), but it can also be efficiently used for sharing, research, and in deciding treatment protocols and targeted interventions without needing to worry about patient privacy (6). In addition to this, mental health of clinical patients can be addressed through creative solutions using deepfake. For example, human subjects whom have lost their own voice, such as ALS (amyotrophic lateral sclerosis) patients, can be regenerated with GANs by using recordings of their original voice. Their own voice can then be used to communicate, instead of a generic computer voice synthesizer, to give the patients back a part of their identity (7). Outside the context of medical applications, GAN can also be used as classifiers to detect and classify the subject's emotional response (8). It can be beneficial for a plethora of applications, including patient health monitoring, crowd behavior tracking, predicting demographics (9) and similar behavioral applications.

But the potential applications of GANs are not limited to humans. Biologists, ecologists and ethologists are starting to understand the limitless applications of GANs especially in settings where obtaining high quantity and quality of data are difficult or impossible. Using these networks, scientists from different disciplines are starting to explore methods to e.g., simulate the evolutionary arms race between the camouflage of a prey and predator (10), to automatically identify weeds in

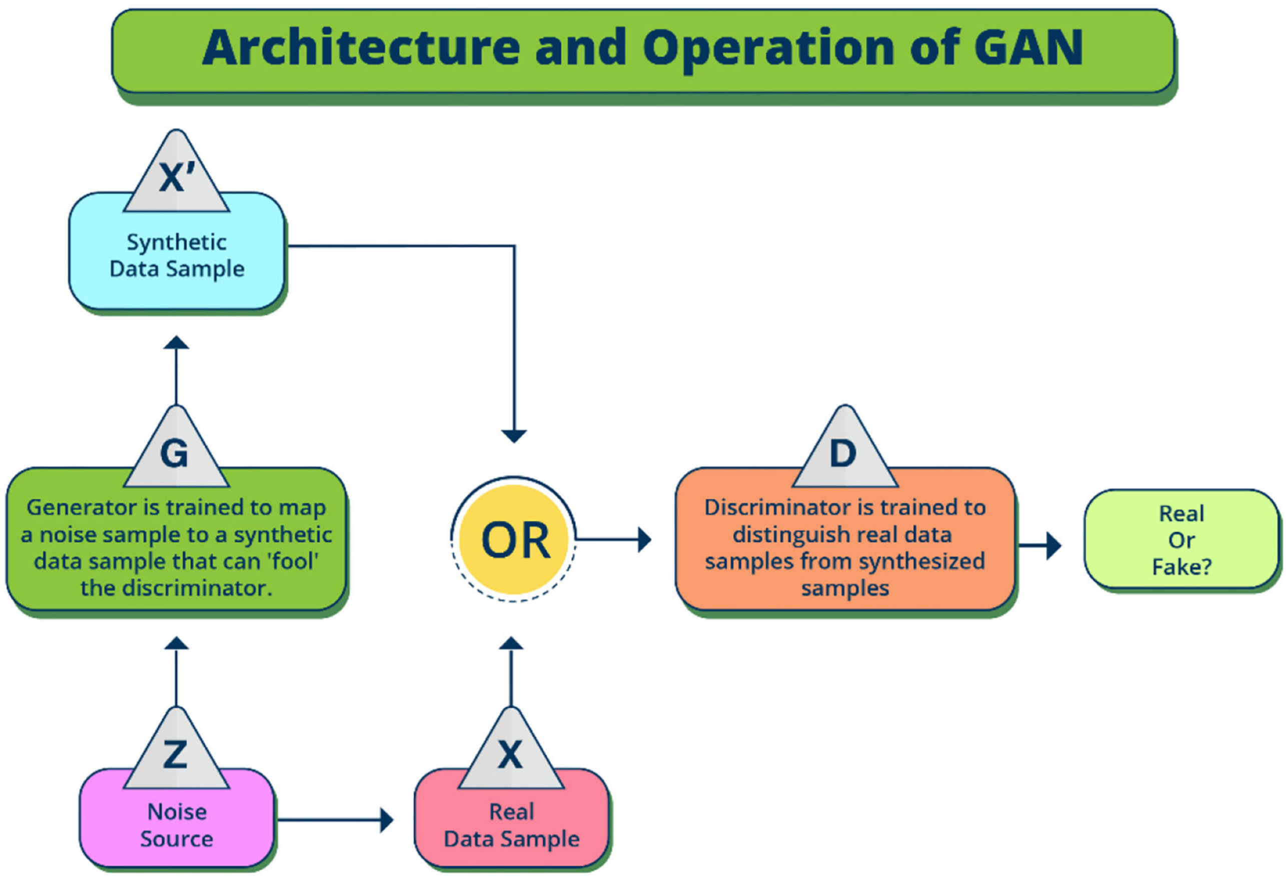

FIGURE 1 | High level description of the Generative Adversarial Network (GAN) flow architecture. Real data sample is the source, while the synthetic data sample is the target. Input noise is combined with the label in the GAN architecture, and the framework of GAN training allows the conditional GAN loss function in the generation of synthetic target images.

order to improve productivity within agriculture (11) and to augment deep-sea biological images (12). These studies highlight the possibilities of GANs and lead to the possibility of using these technologies within livestock farming, too.

USES BEYOND HUMANS—HOW GANS CAN CONTRIBUTE TO INCREASE WELFARE IN LIVESTOCK

As the global population is exponentially growing, it has been predicted that within a few decades, the demand for animal products will have doubled (13). This therefore puts a great pressure on the farming industry, that will need to keep up with the rising demand. The challenge to develop efficient processes of livestock farming is accompanied by a rising concern for animal health and welfare (14), in addition to environmental and societal concerns (15). Can GANs contribute to increase welfare in livestock, and as a consequence increase productivity, too?

Machine learning applications in animal science and the veterinary sector are predominantly focused on tracking activity and movement of the animals aimed at enhancing welfare or disease related measurements. In order to be able to use machine learning algorithms to, for example, automatically monitor animal health and welfare by screening and recognizing pain, stress and discomfort, large validated and annotated datasets are required. Physiological and behavioral measurements are able to reveal information about an animal's inner state. Animal emotions have been linked to particular vocalizations (16, 17), eye temperature (18, 19), hormone levels (20, 21) and facial expressions (20, 22, 23). These emotional states, such as fear, stress but also positive emotions like joy and happiness, remain however difficult to understand as they are complex and multi-modal.

AI algorithms can provide an automated way of monitoring animal health and emotions (24). This helps us understand animal behavior and stress that therefore can increase welfare by controlling and preventing disease and can increase productivity through helping famers decide on effective and productive strategies. However, validated and annotated datasets that are large enough for supervised machine learning algorithms are, however, limited and largely unavailable. Examples of specific medical conditions of farm animals and the related videos or animals are hard to come by and often require specialized sensing platforms and tools to collect. Due to this challenge, the advancements of applications of AI are still in the nascent stages in the farm animal sector. Supervised learning offers techniques to learn predictive models only from observations and maps an input to output by inferring a function from labeled data. Semi-supervised learning is concerned with using both labeled and unlabeled data to perform various learning tasks. Semi-supervised learning is a combination of unsupervised and supervised learning and uses a small amount of labeled data with larger unlabeled data (25).

There are a few methods to overcome the lack of high quality, labeled data. Semi-supervised learning helps *in situations* in which a large dataset is available but only a small portion of the dataset is labeled. Here, the challenge of insufficient datasets can be overcome by data augmentation methods. For example, augmentation techniques can include transformations such as translations by moving the image to left, right, up or down, by scaling such as zooming in or out, or by rotating the image to various degrees. Such techniques can help to expand the dataset size and is commonly used by data scientists for the data hungry ML models. But this standard method of enriching the dataset has several disadvantages; the produced images does not diverge far from the original image and may not add many varieties to enable the ML model or the algorithm to learn to generalize.

GANs have the potential to be used for enhancing the performance of the classification of algorithms in a semi-supervised setting, and it can address some of the barriers mentioned above. Training a GAN model has been successfully shown in augmenting a smaller dataset (2), such as for liver cancer diagnostic applications (26). It should be emphasized that the GAN based synthetic augmentation which uses transfer and deep learning approach is different than the basic (classical) data augmentation mentioned above. By adjusting the dimensions of the hidden layers and the output from the generator as well as input to the discriminator network, the framework was developed to produce satisfactory images of liver from the model. An accuracy of 85% was achieved by the GAN-created models in the liver lesion classification based on this method. In a similar way, GAN based data augmentation can be used to enhance the ability to classify animal disease and negative emotions such as stress and discomfort, that might lead to disease. A trained GAN model has the potential to predict diseases in farm animals and to recognize and avoid negative emotions such as stress and fear and promote positive ones. By creating bigger datasets with GANs with a similar distribution as the original datasets, machine learning algorithms could be trained to classify disease and animal emotional states accurately and efficiently, similarly as to how human emotions can be recognized by GAN models (8, 24, 27).

In addition to creating big fake datasets for classification, GANs could also be used to develop digital twins (28). A digital twin is a virtual representation of a real-world entity, such as a human or other animal. Based on input from the real world, the digital twin simulates the physical and biological state, as well as the behavior of the real-world entity. A digital twin of a farm animal will allow continuous monitoring of the mental, physical, and emotional state of the animals. In addition, modeling, simulating and augmenting the data allows the digital twin to be used to plan, monitor, control and optimize cost-, labor- and energy-efficient animal husbandry processes based on real-life data (29, 30). As a pre-cursor for the development of digital twin (digital avatar) of a farm animal, our group at Wageningen University has developed a methodology enabled by starGAN architecture in the generation of images of faces of cows and pigs (**Figure 2**). Using GANs to develop a digital twin will allow different situations to be explored and will help predicting its effects on the animals. It can, for example, be used to simulate and predict the effect of different housing structures or conditions, heat cycles for breeding or social settings on the positive and/or negative emotions of the animals, as well as on their productivity. Simulating different situations through digital twins will enable farmers to control and optimize processes within their operation, benefitting farming productivity, sustainability and animal health and welfare. Deepfake technologies can also offer a suitable non-animal alternative for biomedical research in the quest for provision of safe and effective drugs and treatments for both animals and humans.

Deepfakes (or virtual stimuli) have been suggested to help humans dealing with grief, by creating a virtual representation of the missing beloved (31). A similar approach could be taken to enhance animal welfare. Many farm animals are highly social, meaning that social comfort can play a large role in the mental wellbeing of the animals, but also that the maintenance of social organization is important for the entire population (32). The unnatural, monotone, high population-density setting of animal farms where animals are often regrouped and young are separated early from their mothers, can have adverse effects on their behavior and/or welfare (33). These effects range from stereotypies to high levels of (social) anxiety in early and later-life, and undesired behavior such as aggression that leads to conflict (e.g., tail biting in pigs, feather pecking in chickens) (34). Deepfake technologies can allow the display of videos of a (familiar) conspecific that simulates a companion, parent and/or dominant leader that brings back social organization which could serve as a tool to help fixing animal behavioral problems and in turn, enhance animal welfare. The interactions between an animal and its environment, including both conspecifics and humans are important to qualify and quantify. The GAN in combination with Machine Learning algorithms can learn about the different modes of animal communication that are important for the well-being of an individual, such as using facial expressions, vocalizations and body posture. Such features can aid in comforting one another and promote positive affective engagement with each other including affiliative interactions, sexual activity, bonding, maternal care and play behavior. These positive animal-to-animal interactive behaviors have been shown to play an important role in the positive welfare of (farm) animals (35). The trained model can then be used to optimize the digital representation in the form of e.g., a video that imitates such engagement, for example to assure young calves, chicks or piglets by a fabricated "mother" figure which aids a healthy development.

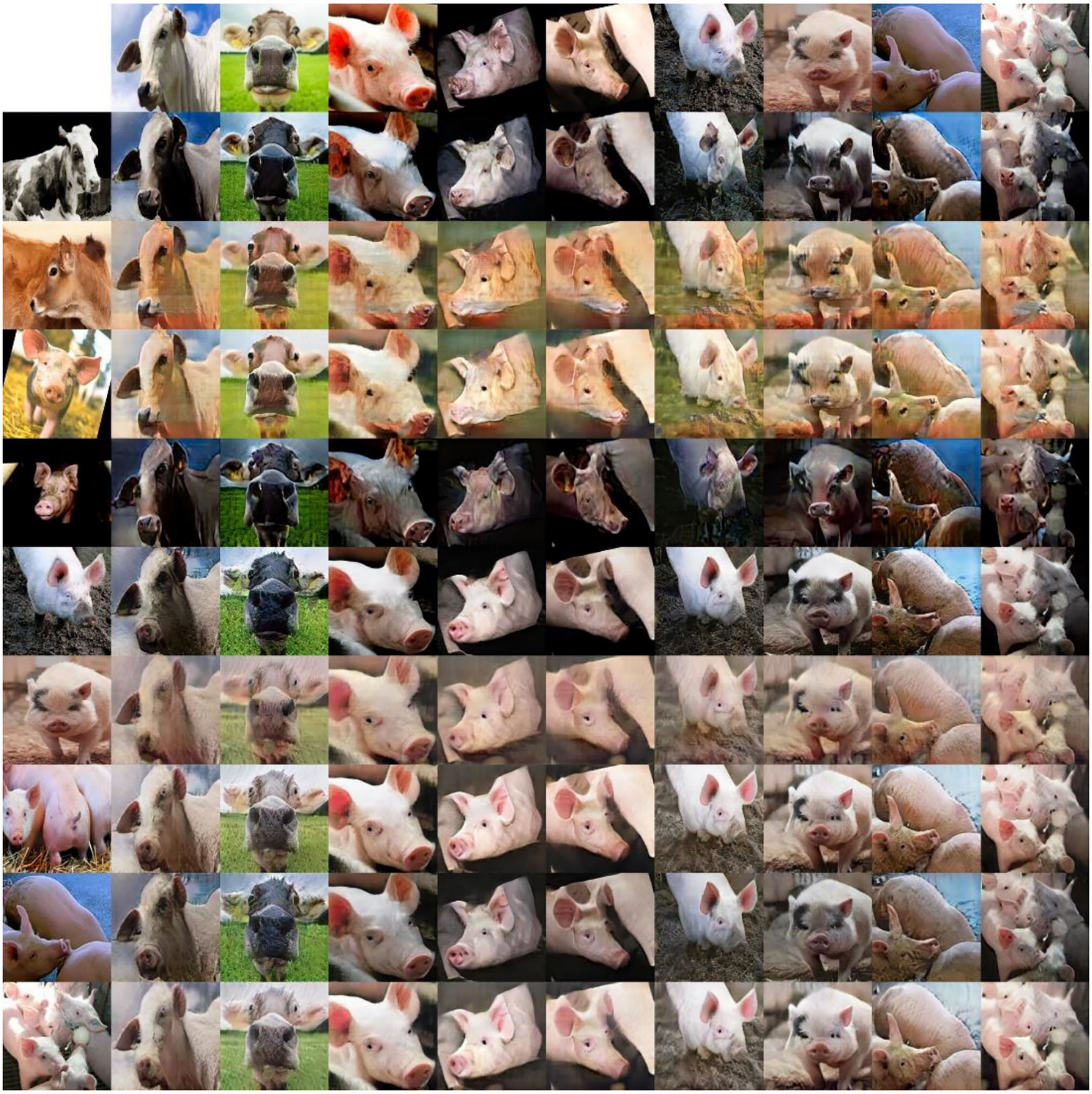

FIGURE 2 | Example application of Generative Adversarial Networks (GAN) in livestock farming. Images of faces of farm animals such as cows and pigs generated by several epochs by the StarGAN architecture-based model. Quantitative comparison of the cow/pig dataset trained model is represented in each row. The real-life cow and pig are depicted in the top first row and the left first column. The StarGAN translated the source images of cows and pigs into target domains, reflecting the styles of the reference images as a precursor for the development of digital avatar of farm animals (36).

CAN FEELINGS OF FARM ANIMALS BE VIRTUAL? EMOTION ELICITATION IN DIGITAL AVATARS

Exploring emotions in farm animals is very complex but a growing area of research. Researchers at Wageningen (https://farmworx.nl) in collaboration with ethologists and animal behavior scientists have been investigating the cognition and the behavior of the farm animals and thereby study the emotions of livestock. Typically, neuroendocrine, and hormonal markers such as dopamine, cortisol, lactate etc. are measured from the urine, saliva, blood, and hair of the farm animals in the cross validation for emotional indicators experiments. Several tests namely judgement bias tests, cognition experiments have

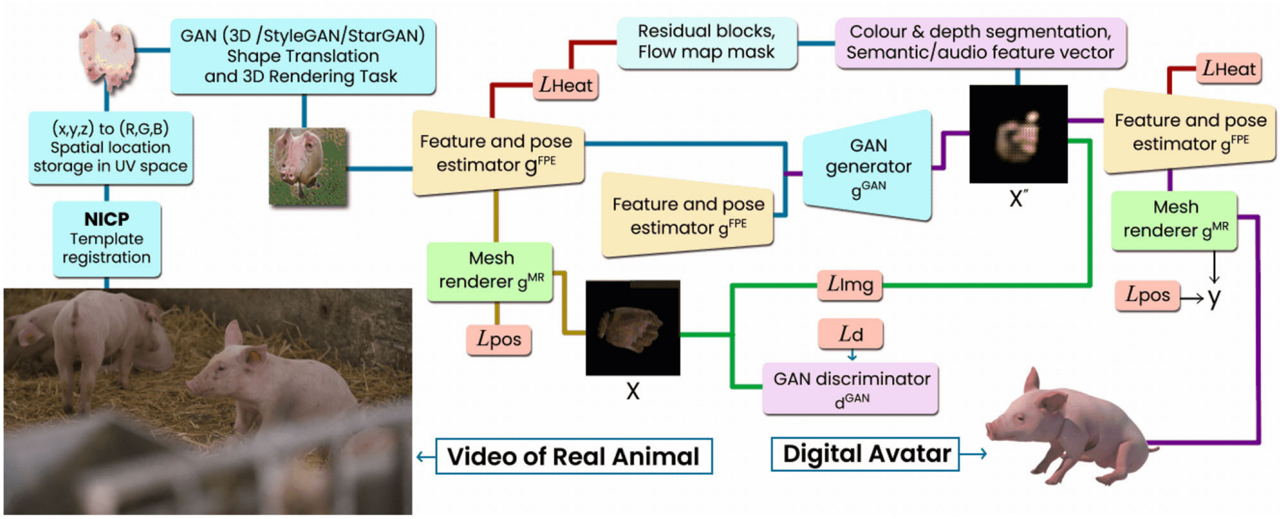

FIGURE 3 | 3D farm animal avatar digitization pipeline from real life video of a pig. Reconstruction of the geometry and texture *via* GAN model is followed by the generation of the full textured life like animal agent.

also been developed to study negative, positive, and neutral emotional states of farm animals. A facial recognition system was recently developed to be able to measure and understand the manifestations of emotional expressions on the faces of cows and pigs (24). In addition, from our group and from other research groups worldwide it has been demonstrated that a number of non-invasive indicators such as respiration rate, heart rate, body surface temperature variations and other bodily behavior cues can present information on the emotional (affective states) makeup of the animals.

In the journey of developing "Life-like Agents/Metaverse/Digital Avatars" with the noble intention of solving practical problems in animal welfare, it becomes essential to establish frameworks for farm animal emotional modeling. Through integrating models of emotions and features or personalities of individual farm animals, the process of development of Digital Avatars can become easier. Context sensitive and purpose-based features of emotional patterning in humans have been explored as a theoretical model for creating autonomous emotional systems (37). In order to facilitate the development of life like artificial agents to generate emotions of their own, multiple computational models based on appraisal theory of emotions have been explored for human biomedical applications (38). Using a set of numerical values *via* computation rules, emotions has also been modeled as parameters of the agent for social simulation (39). Currently research is underway from our Farmworx research group in developing multimodal approaches-based emotion modeling for social interactions in cows and pigs. Deep fake technologies development in animals especially farm animals is in the nascent phase and hence no efforts has been made in emotional modeling for digital twins yet. However, with the advent of methodological frameworks being established in humans and the inspirations from the advancements of human affective computing, this gap in the farm animal emotional modeling will be addressed sooner.

VOICE MANIPULATOR PRODUCES SPEECH FROM TEXT

There is a definitive need for developing automated vocalization detection and reader systems for farm animals to enhance welfare (17). Vocalizations of animals such as cows, pigs and chickens can be in real-time translated to easily understandable text for animal caretakers and farmers to perform on the spot interventions. By taking the digitized audio recording and through processing and altering it *via* AI enabled algorithms, the sounds of farm animals such as grunts, squeals, coughing, sneezing, rooting, barking, panting can be measured and read continuously and non-invasively. In addition, the link between the emotions or affective states of farm animals and their vocalizations can be elucidated with the aid of deepfake enabled technologies. In this endeavor, fundamental research has been explored by application of computational methods in projecting animal vocalizations into latent representational spaces for visualization, characterization, and generation of signals in the investigations of ecologically relevant acoustic features (40, 41). Although the above-mentioned studies do not include livestock, but the vocalization has been explored only in bats and songbirds, the findings and the developed methodologies sets the path for future exploration of voice manipulation through deepfake approaches in domesticated production animals.

An advantage of using deepfake technologies is that other non-human animals, too, can be individually identified through their voice (42–44). Deepfake technologies that can base the generated data on a small fragment of the vocalization of an individual's mother, for example, will therefore be able to create a realistic mother figure rather than a general vocal sample. Outside of the mother-offspring context, vocal contagion of (positive) emotions can also be positively reinforced using the same technologies. The affective state of individuals can be influenced by its environment, and the literature shows that non-human animals can be affected by not only conspecific vocal expression of emotion, but also by human vocal expressions (45). This opens up the potential for deepfake technologies to positively influence farm animals through emotional contagion, promoting positive emotions.

Indirect evidence of discrimination and social recognition capabilities of farm animals and livestock has been investigated before. Examples include heifers' ability to visually discriminate their own species from other species (46); sheep recognizing unfamiliar and familiar human faces from 2D images (47) and female horses demonstrating the long-term memory by identifying the keeper from photographs after 6 months (48). Cattle use their sense of vision in the discrimination of conspecifics and demonstrated their ability to visually discriminate between familiar and unfamiliar conspecifics which were represented as 2D images (49). Moreover, with the rapid advancement of digital farming in which farmers have to be less present with the animals, also displays of positive interactions by "fake" farmers can be used to improve animal welfare. Such positive interactions could be used to reward good behavior, comfort the animals by reducing stress which in turn, have the potential to avoid unwanted behavior. These virtual farmer activities can therefore promote habituation, associative learning, social cognition and bonding, which could also enhance the human-animal relationship which is important for positive welfare outcomes as well as productivity (50).

A video, of course, is merely a digital visual and maybe auditory representation of this conspecific, meaning that the physical and olfactory components of the virtual conspecific are lacking, which might limit its effectiveness. A better understanding of the cognitive framework and awareness of farm animals (51), and inter-specific differences between cognitive abilities are important to understand the potential effectiveness of 2D digital representations. It is essential to understand what cues are important to create a realistic virtual animal, and what senses are used to process the information. Future technologies might even develop 3D robotics using a combination of AI technologies including deepfakes, that could create a more realistic representation of another individual. Interactive systems based on advanced technological systems keep growing within domestic animal farms. Deepfake technologies can aid the development of animal welfare technologies through supporting interaction, activity, and sociality, putting the focus of the farm on its animals, their well-being and enriching activities. **Figure 3** shows a research path in the development of digital avatar of farm animal based on GAN from real-life video of a pig. Exploratory experimental studies are required to test the effects of introducing a virtual conspecific and/or a sophisticated robot to enhance mental well-being and sociality in farm animals.

TYPES OF GANS—WHICH ONE IS MORE SUITABLE THAN OTHERS?

With the invention of GAN in 2014 (52), the generative models are becoming not only popular with several research applications but also showing impressive results in integrating audio, visual and text for large number of practical use case scenarios. Because of the success in the vision, several formulations of GAN namely StyleGAN, CycleGAN, pixelGAN, DiscoGAN, IsGAN and many more have been developed by researchers. It is not possible to objectively evaluate the progress of the training and the quality of the model developed by the GAN due to lack of objective loss function. Hence, formulation and the choice of GAN can be evaluated based on the output quality of the generated synthetic images or videos. In addition to inspecting the generated synthetic videos and images manually, Frechet Inception distance (FID) and inception score are some quantitative ways (53, 54) to assess the robustness of the GAN models.

WHAT NEEDS TO BE DONE TO FACILITATE DEEPFAKE RESEARCH AND WHAT ARE THE LIMITATIONS THAT NEED TO BE ADDRESSED?

In order for deepfake technologies and their applications to be fully explored, it is important that the negative stigma on the technology are addressed first. See **Table 1** for a summary of current and potential applications of deepfake technologies, both positive and negative ones. Many people are hesitant and scared due to the immense implications fake media can have when used to manipulate, misinterpret or abuse (55). The legal framework has yet to catch up with the proliferation of deepfakes. However, a comprehensive legal framework, if developed, would enable the deepfake recognition software to outcompete deepfake media creation, in ensuring that fake can always be recognized from real. Next, creative solutions for a range of different fields of science should be promoted to change the negative outlook on deepfake applications and highlight the positive uses of the yet relatively unexplored possibilities it opens up. Regardless of the particular application, it is important to not only have a recognized and well-established legal framework, but also an ethical one. The inherent nature of deepfake technologies is to create fake content, which is then used to deceive either humans, animals or machine learning algorithms. The ethical consequences have to be addressed by professionals from different disciplines to allow a broad understanding of the consequences of using deepfake.

ANALYSIS OF POTENTIAL FAILURES OF DEEPFAKES FOR LIVESTOCK FARMING

The biggest challenge is that the animal may perceive as presenting itself in the 'fake' world but in fact, the animal is still very much physically available in the real farm. The possibilities of the inability of the farm animal to distinguish between Digital Avatar and a 'real' flesh-based animal may lead to behavioral issues such as isolation or lack of adequate social interactions with other species. It may be possible that the farm animals may experience cybersickness (due to eye strain, dizziness) manifesting in the form of physical health or behavioral variations while engaging with digital avatars. Although this is an unexplored territory in livestock research,

TABLE 1 | Summary of current and potential applications of GANs and deepfake technologies.

Application	Positive or negative?	Explored yet?	References
(Revenge) celebrity pornography	Negative	Yes	(56)
Spreading fake news	Negative	Yes	(57)
Creative editing for entertainment	Positive	Yes	(58)
Recreating handwriting and/or voices	Positive or negative	Yes	(59)
Manipulating images	Positive or negative	Yes	(60)
Human disease identifying, monitoring, and predicting progress; diagnostic information preservation	Positive	Initial stages	(61)
Farm animal disease identifying, monitoring, and predicting progress	Positive	No	–
Data augmentation for machine learning for low quality or quantity images	Positive	Initial stages	(62)
Data augmentation for machine learning in livestock farming	Positive	Initial stages	(31)
Improving therapy—Cyberpsychology	Positive	Initial stages	(63)
Identification and classification of weed species in agriculture	Positive	Initial stages	(11)
Identification and classification of animal emotions	Positive	No	–
Creating digital twins to monitor behavior and physiology of farm animals	Positive	Only in theory	–
Creating virtual conspecifics to increase mental well-being of farm animals	Positive	No	–

it is possible to overcome cybersickness due to deepfakes by manipulating the frame rates and refresh ratio while presenting for smooth engagement. Animal's living environment and the infrastructure such as the stable or industrial production facility or indoor farms should be accounted for while designing and developing the digital avatars.

Potential of farm animals colliding with farm structures or walls or even humans such as animal caretakers during the interaction with metaverse has to be considered. This could be due to the digital avatar reacting to the live animal or responding with exaggerated movement. One way to avoid the collision is by allowing the design features to consider developing complicated boundary spaces for the animals to interact with. This way, a trigger might induce the awareness of the presence of boundary and prevent the animal to go out of the boundary. Additional research is warranted to overcome the barriers associated with depth perception while designing deepfakes. Because farming environment and stable are dynamic and composed of full of structures, feeding stations and machinery, design factors must look at ways to incorporate the cluttered environmental conditions in which the animals interact with digital avatars.

TECHNICAL RISKS AND POSSIBLE SOLUTIONS

The field of view of farm animal's eyes varies between species. For example, the typical field of vision for cattle is 330° while for pig it is 310°. Generally speaking, unlike humans' farm animals such as cows and pigs can prioritize lateral monocular vision and thereby increase the panoramic view while decreasing the bifocal vision. Hence, the deepfake technologies developed for humans cannot be easily translatable or adapted for livestock farming applications. To avoid compromising the viewing experience and to overcome the screen-door effect, the resolution limit of the animal's visual system, the visual angle and acuity factors should be considered in the designing of digital avatars. In addition to the field of view and efficiency, brightness, form factor, vergence accommodation conflict are additional technical challenges in the process of development of deepfake technologies as experienced in the human applications (64). Holographic projection has been suggested as a way to overcome the form factor in the augmented reality for human gaming applications (65). By manipulating the light field displays and the light fields along with the possibility of using contact lenses, the vergence accommodation problem can be overcome (66, 67). Developing digital avatars and deepfake technologies for livestock by deriving inspirations from human based solutions has to overcome anthropomorphism.

Regarding the accuracy, efficiency and added value that deepfake technologies can bring to livestock farming, it is important to highlight the extremely high quality of the real data that is required to train the models with. The model learning should be well-supervised and validated to ensure no wrong classification or labeling is created within the algorithm. Empirical evidence or studies within livestock farming is currently absent as GANs and their applications are still in their infant stages and have to date only been explored in a few scientific contexts.

SUMMARY

In conclusion, similar to all AI implementations, deepfakes also have positive and negative impacts. The potential positive effects of deepfakes are still new areas that are under exploration, and as such, it may require some time for these technical architectures to mature and being vastly implemented in the public domain. Their contribution to biomedical and behavioral applications, on top of agricultural practices, demonstrates that few of these applications might soon surface and help balance the adverse impacts of deepfakes. However, at higher stakes, various standardizations and security measures will be required, along with implementations of such technologies to ensure that no manipulations can take place. Pilot studies and explorative experiments are necessary to allow a better understanding of what deepfake technologies can mean for scientific purposes beyond us humans.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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Passive, Active, and Proactive Systems and Machines for the Protection and Preservation of Animals and Animal Species

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Digitalization and automation are expanding into many areas, resulting in more widespread use of partially and fully autonomous machines and robots. At the same time, environmental and other crises and disasters are on the rise, the world population is growing, and animals are losing their habitat. Increasingly, machines and robots such as agricultural vehicles, autonomous cars, robotic lawnmowers, or social robots are encountering animals of all kinds. In the process, the latter are injured or killed. Some machines can be designed so that this does not happen. Relevant disciplines and research areas briefly introduced here are machine ethics, social robotics, animal-machine interaction, and animal-computer interaction. In addition, animal welfare is important. Passive and active machines—as they are called in this review—are already appearing and help to observe and protect animals. Proactive machines may play a role in the future. They could use the possibilities of full automation and autonomy to save animals from suffering in agriculture or in the wild. During crises and disasters and in extensive nature reserves, they could observe, care for, and protect animals. The review provides initial considerations on active, passive, and proactive machines and how they can be used in an animal preservation context while bearing in mind recent technical and global developments.

Keywords: animal ethics, machine ethics, animal-machine interaction, animal-computer interaction, animal welfare, robotics, artificial intelligence

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INTRODUCTION

Digitalization and automation are expanding worldwide. Increasingly, automatic and autonomous systems and machines are emerging, including self-driving cars, service robots, and social robots—not to mention industrial robots, for example in car production, where they were first used in the 1960s. At the same time, fundamental changes, crises, and disasters (both natural and man-made) are increasing, as is the human population, which is building cities and infrastructures everywhere while requiring a seemingly limitless supply of resources. As a result, the habitat of animals is being destroyed, individual animals are killed in this context, and whole animal species (as well as plant species) are becoming extinct. Industrialization, mechanization, and digitalization are one cause of this. However, they can also, to a certain extent, offer solutions. Currently, automatic and (partially) autonomous systems and machines are encountering animals more frequently with little thought by people and companies of how they can do so responsibly.

The systems and machines at issue in the present context meet animals intentionally or unintentionally, can or cannot distinguish between individuals or species, encounter domestic animals, working animals, farm animals, wild animals, or laboratory animals. They can exploit animals, modify animals, injure and kill animals, or help and spare animals (Bendel, 2014a). They function independently of animals (outside their bodies) or become part of them (inserted into the body in the form of chips and implants, for example in the context of animal enhancement). They can occur in the home, in the garden, in urban areas, in agriculture, or in the open countryside (even in the wilderness), are passive (mainly observing), active (e.g., responding to an animal), or proactive (e.g., interacting and communicating with an animal, or recognizing, caring for, and removing an animal for its safety). This review presents selected examples and distinguishes them according to the classifications presented, particularly focusing on passive, active, and proactive systems and machines. It shows that many existing automatic and (partially) autonomous systems and machines are passive or active in their relationship to animals. This review focuses on how machines and non-human living beings meet and how this can be *better* designed for the welfare of animals. It is mainly about, on the one hand, how to avoid damage that can be caused by machines by modifying the machines themselves and, on the other hand, how machines can protect and save animals from threats by humans and during natural or man-made crises and disasters. In order to conduct this discussion in a structured manner and to provide suggestions for future developments, the aforementioned systematization was introduced.

An example of a passive system is the use of drones that detect fawns in the field, helping to stop combine harvesters from running them over, or animal-like robots such as those invented by John Downer for animal monitoring as part of his wildlife films (which have been shown on BBC, the national broadcaster of the United Kingdom, for example). Active systems and machines—most of which have a passive component—include LADYBIRD from Switzerland, a prototype robot vacuum cleaner that pauses its work when it detects ladybugs, and HAPPY HEDGEHOG, a prototype robotic lawnmower that pauses its work when it encounters hedgehogs. The Wildlife Vehicle Collision Avoidance System developed in India is also of this type. It detects when deer approach the road and warns drivers with light signals. Spain's DTBird not only monitors the flight of birds, but also ensures that wind turbines are stopped when necessary to protect wildlife. In principle, the drones mentioned above could also give a command to an automatic combine harvester, which then interrupts its work, which would make them active rather than passive systems.

This review shows that a variety of passive and active systems and machines already exist, some of which are helpful for the protection and conservation of animal individuals or species. Research areas and disciplines such as animal-computer interaction, animal-machine interaction, machine ethics, and social robotics are all relevant to these. It is suggested that in some cases, and especially in the future, such systems will not be sufficient to account for the growth and spread of humanity and its impact on the earth's environment and ecology. The author argues that proactive systems and machines are needed to protect animals and their habitats in economically viable ways and to save species from extinction. This applies to both urban and agricultural areas, where autonomous systems and machines are proliferating and, for that reason alone, increasingly encountering animals. It applies also to the outdoor nature, by which is meant managed forests and plains as well as the increasingly rare (but perhaps expandable) wilderness.

One proactive solution is to have fully automated systems to protect animals. For example, one may intend rescuing fawns. A drone detects the animal in the field and reports this to the combine harvester, which immediately stops. A robot then picks up the fawn and brings it to safety (in current implementations, this is done by a human helper). Such a solution makes economic sense, for example because of the potential savings in personnel. Currently, however, it is not technically feasible. Another (much broader) vision is of greatly expanded reserves for animals and plants, necessitated by global destruction, in which robots play a passive and active role—or a proactive one, for example, by limiting a large spread of certain species by administering contraceptives, caring for plants or animals (in case of food shortages or injuries), or protecting plants and animals from poachers and vandals—one could cite a few more examples, although it must be emphasized that most of this lies far in the future. An advantage of these applications—apart from the economic potential—is that the animals are not disturbed by humans, do not take on their scent and thus are not rejected by their parents or other conspecifics, and are not habituated to human beings—and thus can continue to live in a natural way. If such a scenario were practicable, it would represent a paradigm shift. Automatic and autonomous systems and machines would not only be there to do specific jobs and to repair the damage they themselves have caused or to prevent their damage, but they would be useful helpers for all living beings.

DISCIPLINES AND CLASSIFICATIONS WITH RESPECT TO ANIMALS AND MACHINES

Fields of Activity and Disciplines With Respect to Animals and Machines

In the present context, various disciplines are involved, including above all, machine ethics, animal-computer interaction, and animal-machine interaction. Animal ethics and animal welfare are also relevant. In addition, the review lists robotics and artificial intelligence, which are important in the design and construction of systems and machines. Social robotics is also explained, a discipline that increasingly involves animals.

– Animal-machine interaction is the interaction (and communication) between animals and machines via an interface (Bendel, 2015). This is a relatively recent research field that is concerned with the design, evaluation, and implementation of machines such as drones, robots, and self-driving cars that interact with animals. It can build on the results of more specialized animal-computer interaction.

- Animal-computer interaction—a research area pioneered by Mancini (2021)—"aims to understand the interaction between animals and computing technology within the contexts in which the animals habitually live, are active and socialize with members of the same or other species, including humans" (Mancini, 2011). Computers, in turn, can be integrated into machines, so that the transitions to animal-machine interaction are fluid.
- The subject of machine ethics is the morality of machines, especially autonomous and semi-autonomous systems (Anderson and Anderson, 2011; Bendel, 2014b). The discipline can be classified under information and technology ethics or considered as equivalent to human ethics, focusing not on natural but on artificial moral agents. Representatives usually use the term *machine morality* in systematic terms similarly to the term *artificial intelligence* (in this case, the subject matter is meant, not the discipline). Machine ethics can be directed at humans or at animals. It can also be related to animal ethics (Bendel, 2013), since machines can be equipped with moral rules that apply to animals.
- Animal ethics deals with the duties of humans toward animals as well as the rights and values of animals (Singer, 2009). Over time, there have been many controversial debates, such as which animals can have which rights. Animal ethics is also concerned with the relationship between animals and (semi-) autonomous intelligent systems, such as artificial agents and certain robots (Bendel, 2014c). This review is not only about animal ethics, but also about animal welfare, the well-being of (non-human) animals.
- Robotics or robot technology is concerned with the design, development, control, production, and operation of robots, e.g., industrial or service robots. The purpose is often to extend the ability of humans to act (Christaller et al., 2001). Anthropomorphic or humanoid robots also involve the production of limbs and skin, facial expressions and gestures, and natural language capabilities. The focus of robotics is on physical robots with hardware and software.
- Social robotics, as a subfield of robotics and a neighboring discipline of sociology, psychology, and philosophy, to name a few, is concerned with sensorimotor machines created to interact with humans or animals, some of which are humanoid or animaloid (animal-like) in design (Bendel, 2021a). Examples include care robots, therapy robots, and sex robots. Entertainment and toy robots are also sometimes classified as social robots.
- The term *artificial intelligence* (AI) refers to a separate scientific field of computer science that deals with human thinking, decision-making, and problem-solving behavior in order to reproduce and replicate it using computer-based methods (Bendel, 2019b). In addition, animal thinking can be considered as a model or a completely different concept of intelligence (which does not correlate directly with either human or animal thinking) can be pursued. Machine learning and deep learning are playing an increasingly important role.

These disciplines have different backgrounds and degrees of maturity. It will be important to integrate them more to present an interdisciplinary or even transdisciplinary approach. Artificial intelligence and social robotics only have limited experience of interacting with and considering animals.

Affected Animals and Typical Situations

In this review, the focus is on different animals in different situations where machines are present. Machines and animals can be found in the home, in the garden, in parks, in urban locations, in agriculture, in the countryside (including the wilderness), and so on. Several types of animals are mentioned below, and the types of machines they may encounter are presented very briefly to keep typical situations in mind.

Pets come into contact with robotic vacuum cleaners indoors and robotic lawn mowers outdoors. They may have a close relationship with robotic toys or entertainment robots, e.g., robotic dogs like AIBO, as well as social robots that act as companions as if they were family members or friends. Increasingly, service robots (e.g., information, transportation, therapy, and care robots) are found in institutions, houses, and apartments (Bendel, 2017a), affecting the animals that live there according to plan. For example, automated feeding stations are used for hamsters or house cats that are left alone for a few days.

Various interactions are possible between technical systems and working and farm animals, e.g., between cows and milking machines or milking robots, and between farm animals such as cows and sheep and various components of housing, even if the latter are usually not technically very complex. Experiments are being conducted with virtual fences for farm animals, where the animals wear high-tech collars or devices on their heads that give them great freedom of movement but also prevent them from crossing a certain boundary by means of electric shocks (Fossgreen, 2017).

Wildlife (as well as livestock or working animals) can collide with harvesting and picking robots or other agricultural robots as they move through plantations, fields, and meadows. Scarecrow robots, such as those shaped like wolves, can also affect their activities. Many animal robots are being developed to perform functions in herds and flocks or "tasks" of animals as social beings or interacting organisms. The robots study groups of animals, influence them, try to direct and guide them, and make them behave in a certain way. Insights from swarm robotics—a research area dedicated to the coordination of multiple robots in a system—are essential here (Brambilla et al., 2013).

Robots that observe and control wildlife (working and farm animals, as appropriate), care for and feed them as needed, or euthanize and kill them in some extreme emergencies, are a vision of the future (Bendel, 2021a). Robots such as remote-controlled drones and animal-like robots have been used for years to observe, photograph, and film flora and fauna. Now, semi-autonomous and autonomous robots that can focus on specific plants and animals may be entering the scene.

Passive, Active, and Proactive Machines

The author distinguishes between passive, active, and proactive systems and machines (for the sake of simplicity, he sometimes speaks only of machines). This is not intended to create an irrefutable classification, but merely a helpful and fruitful one. What the author is addressing with these adjectives are the characteristics of machines and the relationship of those machines to animals. Passive machines, in principle, do not need a high degree of automation or autonomy, but may still exhibit one. Active machines require a certain degree of automation or autonomy, precisely so they can be active in a certain sense, namely to independently perform a certain task. Proactive machines depend on a high degree of automation or autonomy. The degree of automation or autonomy, together with the design of appearance, behavior, and sensory and motor capabilities determines the relationship to animals, whereby these can react differently. Examples of the types are given below.

– When the machine is passive, it observes, for example, domestic or big cats, it follows their trail and analyses their excretions, their movements, and their behavior. Normally it does not come too close to them, and when it does, it does so in a restrained and harmless manner. The passive machine tries not to interfere in animals' lives, either in a positive or negative way. In some cases, it remains completely invisible and barely perceptible; in others, it inserts itself into the social community as a creature-like element, without ultimately being able to make any significant contribution to it.
– When the machine is active, it spares, for example, a hedgehog or a swallow, sometimes instead of another animal to which it is not specialized. Often the machine itself presents a danger to the animal: it gets too close to it and threatens to collide with it. By modifying the normal machine, for example with approaches of machine ethics or animal-machine interaction in mind, one creates a special machine (called a moral machine in machine ethics), which in turn enables the protection of the animal, i.e., it has an at least partially positive effect (in the sense that a machine of this type can still pose a threat, simply by its presence, movement, and activity, but that it has been modified to avoid harming the animal as much as possible). However, an active machine could also protect a herd from wolves, for example. In this case, it is not a threat to one species, but a threat to another—however, the goal is not to kill these individuals, but to scare them away.
– A proactive machine does everything it can to help animals and to produce positive effects for them. While it has components of a passive or active machine, it goes far beyond their capabilities. Its most ambitious forms will only be feasible in the future, for example, systems which could not only detect fawns in a field and report them to the responsible parties, but also move the animals themselves to safety. This requires extensive sensory and motor skills. They could also be used to monitor, feed, and care for wildlife in vast nature reserves. In this way, wildlife is not habituated to or stressed by humans and can live their natural lives. Again, extensive sensory and motor equipment is required. In addition, a self-sufficient energy supply would be useful.

Of course, this is a wide-ranging classification, and one may wonder whether it covers everything and whether it is selective enough. However, it helps in further presentation and discussion, allowing the classification of existing prototypes and products. Moreover, it can be used to explain what capabilities machines and robots might have in the future.

TABLE 1 | Overview of the types with the examples covered.

Passive machines	Active machines	Proactive machines
Flying wildlife rescuer	Automatic feeding machines	(Partially) Autonomous system for households
Animal observation cameras	LADYBIRD	Autonomous system for deer protection
Robot spies	HAPPY HEDGEHOG	Rescuers in natural and environmental disasters
	Angsa robot	(Partially) Autonomous system for reserves
	Wildlife vehicle collision avoidance system	
	Robocar	
	DTBird	
	Super monster wolf	
	Robotic shepherd	

PASSIVE, ACTIVE, AND PROACTIVE SYSTEMS AND MACHINES

In this section, examples are given for all three types—passive, active, and proactive systems and machines. This cannot be an exhaustive list—rather, the prototypes and products listed are widely known or familiar to the author, and they were also selected with the assumed readership in mind, in order to provide it with a broad overview and a structured presentation. Of course, there will be many more, and many an obvious idea (such as saving fawns) that is being implemented by several research institutions and companies.

Table 1 provides an overview of the examples discussed, arranged according to the aforementioned systematization. It is no coincidence that the most examples are found within active systems and machines. This area is benefiting from the current boom in robotics and artificial intelligence. However, it will also become apparent that a particularly large number of prototypes can be found here.

Passive Systems and Machines

Fliegender Wildretter by DLR

Projects to protect animals in agriculture exist in large numbers. The main aim is to detect wild animals such as fawns in grain and corn fields in good time before a combine harvester could collide into them. Usually, a drone flies in front of the combine and tries to spot the potential victim. If it succeeds, a message is transmitted to a human, who takes further steps.

The Fliegende Wildretter (Flying Wildlife Rescuer) (from 1999 on) of the Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR) (German Aerospace Center), which can almost be called a 'classic', follows exactly this principle (Wimmer et al., 2013). A drone automatically flies over the field before or during harvest. It stores high-resolution thermal images and their location data every second. Rehkitzrettung Schweiz (https://www.rehkitzrettung.ch) also works with a drone. In both projects, the driver of the combine harvester must stop and the driver or a helper must remove the fawn from the field manually.

The Flying Wildlife Rescuer is a project in the context of animal welfare and animal-computer interaction as well as animal-machine interaction. It must be added that economic reasons also play a role. For example, the combine should not fail in operational terms and should not need to be cleaned. Every accident with a larger animal can mean a loss of earnings for the farmer. There is a chance that the system will become a standard solution for all cases of this kind.

Animal Observation Cameras

Cameras for animal observation are widely used. They are installed in forests, on individual trees, bushes, and rocks in the steppe and savannah or in other places. The main purpose is to monitor wild animals. Microphones are also used sporadically to record animal sounds.

According to its own information, KORA in Switzerland researches the way of life of predators and monitors the development of their populations (https://www.kora.ch). They also observe the impact of predators in modern cultural landscapes and work out the basics for a low-conflict coexistence of large predators like bears and wolves with humans. Cameras are used for animal observation. The memory cards are exchanged on a regular basis. There is automatic remote image transmission via SIM card only in some cases, which makes the project costly. Many recordings cannot be used for data protection reasons because strollers can be seen on them (Yürekkirmaz, 2022).

The animal observation cameras are mainly an animal observation project. The observation can be done without interference and disturbance from humans (if one ignores the installation of the cameras and the replacing of the memory cards). The system is a standard solution for all cases of this kind. However, there is some room for improvement, for example with regard to the automatic transfer of images.

Robot Spies

Monitoring systems and robotic spies are used for animal observation, mostly in the wild. They are either abstractly designed or modeled on the nature of the animals to inconspicuously blend into the community or even attract animals to better observe and analyze them, but without disturbing them. They are either enhanced cameras or multimedia systems that can move and protect themselves or complex robots that adapt to their environment.

Filmmaker John Downer has created artificial monkeys, wolves, hippos, turtles, alligators, etc., to observe appropriate wildlife and obtain spectacular images (http://jdp.co.uk). His robots are very intricately designed and resemble the animals they mimic in almost every detail. They can often move their limbs and move forward on four legs. Behind their lifelike eyes are cameras for observation. Most robotic spies will be remote-controlled robots, but there is nothing to stop autonomous robots from being used as well. The important thing here is that the artificial animal always aligns itself with the animal of interest to fulfill its purpose. Regarding the BBC series "Spy in the Wild," the mentioned website states:

> In one of the most innovative natural history series ever presented, Spy in the Wild deploys over 30 ultra-realistic animatronic Spy Creatures to go undercover in the animal world. [...] These robotic look-alikes make all the right moves to not only be accepted by animals but also interact with them, providing revelatory insights into their world.

If one watches the films, one gets to see how the animals are disinterested or how they curiously approach the robots, touch them, nudge them, try to ensnare them, and—in the case of a turtle—try to mate with them. Thus, the artificial creatures are sometimes obvious foreign bodies, sometimes supposed conspecifics, which raises the question of deception and cunning, which is otherwise dealt with mainly in relation to humans (see the remarks of Bendel and Kreis in Schulze et al., 2021)—and what already marks the transition to active machines.

The robot spies are mainly an animal observation project. The observation can be done without interference and disturbance from humans (if one ignores the transport of the robots). In addition, animal-machine interaction, animal-computer interaction, and social robotics are required as disciplines. There is a chance that the robots will become a standard solution for all cases of this kind. However, it is costly to create them and there are few uses for them.

Overview of Passive Machines

Table 2 provides an overview of the passive systems and machines covered. Indications of the machine type, development status, type of problem solution, and influence on animal welfare are also given.

Active Systems and Machines

Automatic Feeding Machines

Most commonly, cats and dogs live in households—besides hamsters, guinea pigs, and fish, which are restricted in their freedom of movement. While dogs are quite dependent on humans, this is less the case with cats, provided they can leave the house and are used to taking care of themselves. Dogs, in principle, can also supply themselves, but rarely do so as domestic dogs—they must first become wild dogs that roam around looking for scraps or chasing small animals. Automatic feeders provide a basic food supply. There are simple versions for pets—feeding robots, on the other hand, are found mainly in stables.

Sure Petcare's microchip feeder (https://www.surepetcare.com) is designed for multi-pet households where food theft by other animals is a problem. It ensures that specific food is eaten by the correct animal and is suitable for wet and dry food. An automatic closing lid ensures that food stays fresh longer. The Feeder robot is a WiFi-enabled automatic pet feeder, according to https://www.litter-robot.com/feeder-robot.html. The website says: "You can operate this automatic pet food dispenser through unit control or the AutoPets Connect app,

TABLE 2 | Overview of passive machines.

Passive machines	Machine type	Development status	Problem solution	Animal welfare
Flying wildlife rescuer	Monitoring drone	Prototype	Prevents the chopping of fawns in the field	Protects fawns in fields May disturb other animals like birds
Animal observation cameras	Monitoring cameras	Product (standard solution)	Helps to observe and count wildlife	May disturb wildlife when setting up and changing memory card
Robot spies	Robot with cameras	Product (individual solution)	Helps to observe and film wildlife	May disturb wildlife when setting up and changing memory card

which offers customizable programming options for your pet's mealtime needs from the convenience of your phone—even when you're not home!"

Automatic feeding machines are an animal welfare and animal-computer interaction or animal-machine interaction project or product. Some cats and dogs will not be satisfied with being fed by a vending machine. It is important to them that the owner feeds them and has social interactions with them before or after the process. However, in the temporary absence of humans, this solution is better than no food at all. The system is a standard solution for all cases of this kind.

LADYBIRD

Indoor household robots encounter pets as well as small wild animals, especially insects. In some cases—with specialized robots—the pets are to be entertained and kept moving (Bendel, 2021a), in other cases—this concerns various service robots—they are simply disturbed and distressed by the robot. Beetles, spiders, caterpillars, etc. are in particular danger—the machines are capable of injuring and killing them. This can be prevented by programming certain rules into them, given suitable sensors and actuators.

LADYBIRD is the prototype of an animal-friendly—more precisely, ladybug-friendly—vacuum cleaner robot (Bendel, 2017b, 2019a). Back in 2014, the design study, which provided rough information about the desired appearance and planned functions of the device, was created and published via the website https://www.maschinenethik.net. The idea was repeatedly mentioned at lectures, in publications and interviews. On the one hand, it met with goodwill among listeners and readers, on the other hand with media and scientific interest, because the sense and purpose of a simple moral machine became visible and the concern of machine ethics could be made understandable. Years later, a fundamental work on machine ethics would begin with this very example of a moral machine (Misselhorn, 2018). In 2015, an annotated decision tree for LADYBIRD was created.

In this modeling, the activity of hoovering is assumed (Bendel, 2017b). It is checked whether something is in the path of the vacuum cleaner robot. If this is the case and it is an animal, it is clarified what size it is. A cat is not problematic given the size of the suction tube or nozzle, but a ladybug is. In this case, the operation is immediately stopped. The moral assumptions are crude and simple. They do not have to be shared by everyone. They do not even have to be, because different devices can be offered, the customer can be made aware of the extensions and limitations via product information, labels, and certificates at the time of purchase, and they can be offered to modify the device if they have divergent needs. For example, some people get out the vacuum cleaner to suck up spiders or basement woodlice. They would be helped if LADYBIRD made an exception for these animals. Admittedly, this goes against the animal friendliness approach. If no living creature is affected, other possible circumstances are included in the modeling.

In 2017, LADYBIRD was prototyped as part of a practical project at the School of Business FHNW (Bendel, 2019a). The three-person team, supervised by the author, used the annotated decision tree described above. It built a color sensor into the machine as a recognition system. Other desired and useful components—such as motion sensors or systems with size measurement or image and pattern recognition—were not considered because the business computer scientists had too little experience in these areas and too little time. The result was a primitive robot that could at least illustrate the concern and the implementation possibilities. It recognizes an abstracted ladybug, stops in front of it, and emits a beep—realized by the team as a woman's cry for reasons unknown. LADYBIRD was presented at the AAAI 2017 Spring Symposium "AI for Social Good (AISOC)" (Bendel, 2017b).

LADYBIRD is a project within the framework of machine ethics (together with animal ethics). The main purpose was to show how machine ethics can be used in a simple but effective way and how a simple moral machine can be implemented. In addition, animal welfare is important in the project, although one may question whether it is a pressing issue. It has been suggested that such a solution may also turn against animal welfare, for example if (despite being beneficial predators) spiders are considered collateral damage or are deliberately sucked in. There is a chance that the animal-friendly component will become a standard solution for all cases of this kind.

HAPPY HEDGEHOG

Household robots for outdoor use, such as robotic lawnmowers, encounter domestic, and farm animals, but especially small and large wild animals, such as hedgehogs, martens, snakes, and birds of all kinds. These are at risk—the machines can injure and kill them. This, in turn, can be prevented by programming certain rules and using certain sensors and machine learning capabilities. Other service robots such as pool robots are hardly a danger to animals.

HAPPY HEDGEHOG (HHH) is the prototype of a pet-friendly—or more precisely hedgehog-friendly—robotic lawn mower (Bendel et al., 2021). Thus, the author revisited the idea of LADYBIRD in 2019. With the ladybug-friendly robot, meanwhile, the main point was to illustrate the principle—to show that moral rules can be implanted in (simple) machines and thus turn them into (simple) moral machines. In reality, ladybugs on the floors of apartments and houses are not a pressing problem. Yet, of course, some insects could be saved in this way. Hedgehogs killed by robotic lawnmowers are indeed tragedies. Probably thousands die in this way every year worldwide, mostly young specimens that are surprised by the machine and cannot or will not go on. These may be few compared to the victims of the same species in road traffic, but it is a suffering that can be avoided without much effort. An annotated decision tree did not exist in this case. But the four-person team that took on the challenge this summer as part of a hands-on project based on the LADYBIRD project.

HHH is technically more advanced than its predecessor (Bendel et al., 2021). Like LADYBIRD, it drives around autonomously. It is equipped with a thermal imaging camera. This allows it to spot living creatures and warm objects in its path. When it encounters them, it pauses and applies its second method while pointing its relatively high-positioned camera at the unknown object. Using machine learning—the team had fed it with more than 300 hedgehog images—it was able to detect hedgehogs in the lab setting with ease. When it does, it stops working for an extended period. At this point, it would be useful for it to send a message to the owner. A signal tone as with LADYBIRD is only recommended to a limited extent, since when operating a lawn mowing robot—especially on larger areas such as golf courses—there is not always someone around. In principle, HAPPY HEDGEHOG can also be trained with other animal images, such as foxes, birds, and insects.

HHH is a project within machine ethics (in cooperation with animal ethics). The project LADYBIRD should be continued and the predecessor robot be improved. Moreover, it is about animal welfare and, in this case, about a real, urgent problem whose solution was strikingly simple, even though the use of such a robotic lawnmower may prove to be a complex challenge in practice (e.g., hedgehogs turned the other way, tall, dense grass, or dirty lenses). There is a chance that the animal-friendly component will become a standard solution for all cases of this kind.

Angsa Robot

Household robots for outdoor use also include cleaning robots for lawns, a small but interesting market when you think of swimming pools, soccer fields, or golf courses. They encounter domestic and farm animals, but especially small and large wild animals. Very small animals such as slow worms, frogs, snails, and insects are at high risk—the machines can injure and kill them. This, too, can be prevented by installing appropriate sensors, actuators, and AI systems.

A cleaning robot for lawns is being developed by the German company Angsa (https://angsa-robotics.com). According to the manufacturer, the artificial neural network built into the robot enables reliable detection of small and partially hidden objects. It is trained, according to the website, using its own data set of real garbage images. For example, the prototype can distinguish cigarette butts and French fries from other objects such as leaves, dirt, or insects. Targeted removal guarantees protection against damage to surfaces or insects.

Angsa robot is a project in the context of animal welfare. Certainly, insect-friendliness serves the company's marketing—but it is a real, pressing problem, especially since, for example, the mass death of bees leads to a loss of plant biodiversity. Machine ethics was not explicitly involved or mentioned as a discipline here, but one can also situate the project in this context. There is a chance that the animal-friendly component will become a standard solution for all cases of this kind.

Wildlife Vehicle Collision Avoidance System

Many accidents occur on the roads, not only due to the collision of conventional or automated vehicles, but also due to the collision of conventional and automated vehicles and animals. Cars and trucks are an especial danger when driving at high speed on rural roads and highway. Some modern cars, such as the Tesla Model S or Mercedes S-Class, brake for large animals to prevent damage to the vehicle and injury to the occupants. Another option is to warn the driver. This can be done via the vehicle itself (e.g., using sounds or light signals) or via an external system.

The Wildlife Vehicle Collision Avoidance System is a prototype from a research facility in India (Kurain et al., 2018). The goal of the external system is to use light signals to alert drivers to wildlife at an early stage. Delineators on the side of the road use infrared sensors to detect animal movement within a range of 5–12 m. The images in the researchers' paper show that deer are most commonly in view. The system then warns drivers by illuminating LED lights. The system is useful where animals regularly cross the road. It will be especially effective at night when animals are barely visible and at the same time the signals are clearly visible from a distance.

The Wildlife Vehicle Collision Avoidance System is a project in the field of animal welfare, animal-computer interaction, and animal-machine interaction. In addition, economic and operational considerations will also play a role here—an accident with a larger animal damages the vehicle to the point of total loss and potentially paralyzes traffic, possibly resulting in the deployment of police and ambulances—as well as potentially seriously harming the driver. It is unclear whether the solution will prevail. It is very costly to install such systems in all places where there is wildlife crossing.

Robocar

On the road, many accidents occur not only due to the collision of vehicles, but also due to the collision of vehicles and animals. Some modern cars brake for large animals to prevent damage to the vehicle and injury to the driver. Small animals, on the other hand, are simply run over, but this could be avoided by certain rules and novel technologies—built directly into the vehicles (Bendel, 2014a), although legal regulations—such as the ban on braking for small animals—would have to be adapted at most. That some of them, like hedgehogs or toads, are worthy of protection is already proven by the warning signs at the roadside, which, however, are unlikely to have any effect.

Robocar is a design study from 2014 that was linked to the 2016 modeling (Bendel, 2016a). The idea is that the robotic car or a car with Advanced Driver Assistance Systems (ADAS) can break for or avoid small animals. An annotated decision tree with moral assumptions and justifications leads to a different option depending on the situation. Nowadays, safely driving over between tires, possibly combined with a slight evasive maneuver, is an option even for medium-sized animals. For example, an S-Class Mercedes can raise itself 8 cm in the event of an impending accident to better protect occupants in the case of a side impact—this could also be made useful for animals.

Robocar is a project in the context of animal welfare and machine ethics (in collaboration with animal ethics). It is, as mentioned before, purely conceptual. It has been presented not only at scientific conferences, but also at car manufacturers such as Daimler and Audi. There, however, the author's impression is that the killing of small animals is considered collateral damage—at least no activities were subsequently announced that would solve the problem. As indicated, the law may also prohibit braking for small animals, depending on the country. There is a chance that the animal-friendly component will become a standard solution for all cases of this kind. However, this only applies if people are protected at the same time. For example, the system should only become active when there is hardly any traffic on the roads.

DTBird

Wind turbines are widespread in countries such as Germany, Denmark, and Spain or in the USA—for example in Texas, Iowa, Oklahoma, Kansas, California, and Illinois. They can kill birds and bats through their moving rotors. It is especially dangerous when flocks get too close. But individual birds of prey such as hawks are also at high risk. The animals cannot properly judge the movements of the turbines and are caught by the rotors. In some areas, there are dozens or hundreds of towers with rotors, making it difficult for animals to fly through unharmed.

DTBird is used for bird monitoring and collision avoidance at wind turbines (May et al., 2012). Optical sensors are deployed to automatically detect birds. A display in a control center shows the user the size of the birds and, if detected, the species. The system can emit warning sounds and stop the rotors. While detection and analysis basically work well, even for more distant birds, stopping the rotors immediately is almost impossible, and it is simply up to the laws of physics whether the bird survives or not. However, it is possible to gain some time with additional measures, such as scaring by sounds or light signals. DTBat, as the name suggests, focuses on bats.

DTBird is a project in the context of animal welfare, animal-computer interaction, and animal-machine interaction. There are also economic considerations, because in extreme cases, a bird strike can damage the equipment—think of large birds like storks or geese. In principle, falling birds can also injure other animals or even humans, and the carcasses can in turn attract other birds and potential bird prey, creating a vicious spiral. There is a chance that the system will become a standard solution for all cases of this kind. However, the overall system must respond more quickly to approaching birds and shut down faster.

Super Monster Wolf

Both fields and herds are threatened by animals, by pests or predators. In one case there is the loss of the harvest, in the other the loss of herd animals and thus the profit from wool, leather, milk, and meat. Accordingly, protective measures have been devised from time immemorial. For the first case, traditional scarecrows are often sufficient. However, robots can also be used as bird and animal scarecrows. These can also keep the animals away from other plants, such as those that might be dangerous to them.

The Super Monster Wolf was developed in 2017 by JA Kisarazushi (a Japanese agricultural association) and the University of Tokyo. It uses infrared sensors to detect animals approaching a rice field. The German magazine *Golem* wrote about it on August 28, 2017:

> It drives away deer, birds, wild boar and even bears by making loud noises: at up to 95 decibels, it can howl, hiss, talk like a human, mimic gunfire—in total, the machine can handle 18 different sounds. The sounds are supposed to vary so that the animals to be driven away don't get used to them. (Pluta, 2017, own translation)

However, according to the author of the magazine, the wolf cannot run after other animals. It stands on solid metal legs and can only turn its head back and forth with its red eyes illuminated by LEDs. The power for sensors, LEDs, motors and sound generator—according to the author of the magazine—is supplied by a solar module. Obviously, the robot is not particularly nice to animals, so it is not an animal-friendly machine in the classical sense.

The Super Monster Wolf is a project in the context of animal-machine interaction. Animal welfare comes into play when the animals are kept away from dangerous plants. In addition, economic considerations can be made, for example, in terms of the plants that are not harmed and the profits that are maintained by protecting the crop. It is unclear whether the solution will prevail. It is very costly to install such systems in all places.

Robotic Shepherd

Both fields and herds are threatened by animals, by pests or predators, as already explained. With a view to protecting herd animals, shepherds work with herding dogs. However, one can also replace herders or herding dogs (or both) with robots. This is by no means trivial, since herders and herding dogs have a social and hierarchical relationship with each other and with the herd animals. The question is whether to model this or rely on novel configurations.

In May 2020, the media was interested in the video "Autonomous farm work—enter the robots" from Rocos—Robot Operations Platform (https://www.youtube.com/watch?v=RBLnAhzPpTQ), showing a Boston Dynamics robot trying to be a herding dog. The artificial quadruped could be seen running toward a flock of sheep. *The Verge* magazine said: "Now, it's clear that the video is mostly a fun teaser rather than a serious claim by Rocos (or Boston Dynamics) that robots will soon be replacing sheepdogs." (Vincent, 2020) According to the magazine, it raises

TABLE 3 | Overview of active machines.

Active machines	Machine type	Development status	Problem solution	Animal welfare
Automatic feeding machines	Automat	Product (standard solution)	Feeds pets and farm animals in the absence of the owner	Provides pets Human contact is missing Animals must get used to automat
LADYBIRD	Vacuum cleaner robot	Prototype	Prevents the sucking in of insects such as ladybugs	Protects insects like ladybugs
HAPPY HEDGEHOG	Robotic lawn mower	Prototype	Prevents chopping hedgehogs	Protects hedgehogs Robot may hurt other small animals
Angsa robot	Lawn cleaning robot	Prototype/Product	Prevents harming insects and other small animals	Protects insects and other small animals Robot may hurt other small animals
Wildlife vehicle collision avoidance system	Warning system	Concept/Prototype	Warns of approaching deer	May disturb and irritate animals with light signals
Robocar	Modeling	Concept	Allows braking for small animals	Protects small animals
DTBird	Warning and intervention system	Product	Warns of birds and stops wind turbine	Protects birds System may hurt other animals
Super monster wolf	Scare robot	Prototype	Scares away wild animals from the field	Protects fields with its plants and animals
Robotic shepherd	Shepherd robot	Prototype	Helps herding herds	Protects sheep or goats

an intriguing question: If this were the case, "how well would the robots fare" (Vincent, 2020)? "Terrible" is the clear answer from sheep farmer and author James Rebanks. "The robot might be an amazing tool for lots of things but it is worthless and unwanted as a sheepdog…" (Vincent, 2020).

The robotic shepherd is a project within the framework of animal-machine interaction. One must add, however, that it was probably—as the review also suggests—a fun or marketing video. In serious projects, animal welfare is at play, as herd animals are protected from wild animals. In addition, economic considerations can be made, for example, in terms of animals that are not harmed and can be put to use (such as obtaining wool). It is unclear whether the solution will prevail. It is very costly to install such systems in all places and of unclear benefit for the animals concerned.

Overview of Active Machines

Table 3 provides an overview of the active systems and machines covered. Again, information of the machine type, development status, type of problem solution, and influence on animal welfare is given.

Proactive Systems and Machines

(Partially) Autonomous System for Households (Vision)

In many households there are cats and dogs. While dogs are quite dependent on humans, this is less the case with cats, provided they can leave the house and are used to taking care of themselves. Dogs can in principle also take care of themselves, but they rarely do so as domestic dogs—they must first become wild dogs, which admittedly only happens when the owner abandons and leaves them or they are born and grow up without human care. The described feeders provide a basic supply, but cannot offer petting, entertainment, or training. A problem that may become more prevalent in the future is that pet owners are not consistently able to care for their pet, whether they are ill, absent, or cut off from their home due to environmental disasters.

One ambition in this area is a fully automated, multi-component system for mammals, amphibians, and reptiles in the home. An automatic feeder could provide food and water to the animals. An autonomous robot could pet the animals, brush and wash their fur, and play with them. It could speak in the owner's voice and use a human voice to prompt the animals to perform certain actions, such as sitting down—as shown by studies at Yale University (Qin et al., 2020). Remote access would allow the owner to show himself on the display and speak directly to the animal. While an automat could be constantly plugged in, a robot—like some social robots and service robots do—could return to its charging station on its own.

The (partially) autonomous system for households would be a project in the context of animal welfare and animal-computer interaction, as well as animal-machine interaction. One must also make critical considerations here: Not all pets would be able to cope with the absence of humans in the long run—but for a few days, such systems could be a solution. The animals need to get habituated to the robot during the preparation period, so that they can get accustomed to the robot and have positive experiences by interacting with it. In some cases, the animals could live lives that are as species appropriate as possible, and they could gain pleasure and enjoyment from natural behaviors. Social robotics is gaining momentum in this area. This is because it is about the machine getting very close to the animal and making it feel comfortable. It is unclear whether the solution will prevail. It is very costly to install such systems in all places and of unclear benefit for the animals concerned.

Autonomous System for Deer Protection (Vision)

The systems described for detecting deer in fields and rescuing them are in the majority not fully automatic or autonomous. They depend on an attentive driver who receives and implements the warning, or at least on a helper who retrieves the fawn from the field. Ultimately, these are very costly projects that must first cover their costs. In the future, combines may need to drive autonomously for various reasons and suitable personnel may not always be available. The Coronavirus pandemic has shown that shortages of skilled workers quickly arise in certain areas.

A proactive solution in this context would be fully automated animal rescue systems. For example, fully automated fawn rescue systems could be developed as a continuation of the aforementioned work. A drone spots the animal in the field and reports this to the combine—then a robot picks up the fawn and brings it to safety (in existing projects, a human helper does this). One advantage of this would be that the animal would not take on the scent of a human and could immediately return to the care of its mother. Such a solution also makes economic sense, provided that the costs of procuring and operating the robot are kept within reasonable limits. At the moment, it is technically hardly feasible, mainly because of insufficient mechanical capabilities of current products.

The autonomous system for deer protection would again be a project in the context of animal welfare and animal-computer interaction as well as animal-machine interaction. Again, it must be added and emphasized that economic reasons also play a role. For example, the combine should not break down and should not need to be cleaned. At the same time, the previous cost-intensive process requiring manual labor should be automated, which can save money under certain conditions. It is unclear whether the solution will prevail. It is of unclear benefit for the animals concerned.

Rescuers in Natural and Environmental Disasters (Vision)

In the future, crises and disasters could increase further. These include floods, wind damage, and fires, which have been increasingly experienced around the world since the turn of the millennium, and some of which were man-made. In the Coronavirus pandemic, service robots and social robots helped patients by bringing them food and medicine, and relieved caregivers by measuring patients' fevers and disinfecting objects in rooms (Bendel, 2020).

In many crises and disasters, especially natural disasters, animals become trapped in homes and on remaining patches of earth and in recently formed crevices and pits, and they become acutely threatened by disease, flash floods, and fire. Humans will expend all the power they have on their own kind, using both their physical strength and the capabilities of machines and robots. Partially autonomous and autonomous robots would be an option for injured and threatened animals. They could carry them to safety, care for them, and doctor them. In doing so, unlike with humans, the goal would not necessarily be to help every individual or even to perform justifiable triage. Rather, similar to what Bendel (2016a) has argued for in regards autonomous driving, the sum of the saved must be appropriate. Improvements and implants in the sense of animal enhancement could also help living beings cope with changing environmental conditions (Bendel, 2021b).

The rescuers in natural and environmental disasters would also be a project in the context of animal welfare and animal-computer interaction as well as animal-machine interaction. It must be repeated that economic reasons also play a role, and this in a context where enormous costs are caused by the destruction and the removal of the destruction. In addition, the aim is to relieve rescue workers who have a priority to take care of humans. From that point of view, not only the animal is in focus here, but also the human being. There is a chance that the system will become a standard solution for all cases of this kind. However, technical development must continue to progress for this to happen.

(Partially) Autonomous System for Reserves (Vision)

Nature reserves are an opportunity for animals and plants. However, they are usually just small areas that are permeable to people and even vehicles. To some extent, this is necessary because even nature reserves need to be supervised and maintained when the ecological balance is disturbed. One idea, given the prevailing trend of expanding urban areas and settlements and declining biodiversity, would be to greatly expand the areas and make them more difficult or impossible to access for humans—at least for those whose presence is not necessary for conservation (Bendel, 2021a). Human contact is in many cases harmful to animals and plants. This applies not only to poachers, but also to tourists and locals.

The principle of the nature reserve is thus reversed, so to speak, and one could almost say that from now on humans live in reserves so that the environment is protected from them. In this version, semi-autonomous and autonomous robots would play a passive and active role, for example by observing animals and providing them with food and water—and in some cases also a proactive one, by limiting a large spread of certain species, e.g., by administering contraceptives, taking care of plants or animals (in case of food shortage or injuries), or ensuring the protection of plants and animals from the grasp of poachers and vandals, as it were as a shield or assistant to the animals. An advantage of these applications—apart from the economic potential—is that the animals do not take on the scent of humans, are not rejected by parents or conspecifics, and are not habituated to humans—and can therefore continue to live naturally. Care must be taken when using remotely controlled or autonomous flying machines and robots, namely drones—they cause stress in some animals (Ditmer et al., 2015). In addition, they have difficulty flying into forests.

The (partially) autonomous system for reserves could benefit from machine ethics. Some of the machines will have to make moral decisions, such as when an animal is injured and the question arises of whether to kill it. But such decisions can also be made by humans if the volume of cases is not too large, such as from a control center. Otherwise, it is still about animal-computer interaction, animal-machine interaction, and animal welfare. There is a chance that the system will become a standard solution for all cases of this kind. However, technical development must continue to progress for this to happen. In addition, appropriate political and legal conditions must be created.

TABLE 4 | Overview of active machines.

Proactive machines	Machine type	Development status	Problem solution	Animal welfare
(Partially) Autonomous system for households	Automat/Support robot	Vision	Feeds and takes care of pets in the absence of the owner	Provides pets Human contact is missing Animals must get used to automat/robot
Autonomous system for deer protection	Support robot/Monitoring drone	Vision	Prevents the chopping of fawns in the field	Protects fawns in fields Robot could scare animals Robot may hurt other animals
Rescuers in natural and environmental disasters	Support robot	Vision	Provides and cares for wildlife during a disaster	Provides wildlife Robot could scare animals Robot may hurt other animals
(Partially) Autonomous system for reserves	Support robot	Vision	Provides and cares for wildlife in reserves	Provides wildlife Robot could scare animals Robot may hurt other animals

Overview of Proactive Machines

Table 4 provides an overview of the proactive systems and machines covered. Again, indications of the machine type, development status, type of problem solution, and influence on animal welfare are given.

DISCUSSION

In this section, the author discusses the proposed types and presented examples of robots, with respect to the protection and preservation of animals and animal species. Challenges and opportunities that have been shown in the presentations are addressed, always referencing the classification of passive, active, and proactive robots.

Passive, Active, and Proactive Machines

Sufficient examples could be located in all three categories—passive, active, and proactive machines. Despite this, most robots or machines that enter into a certain relationship with animals, partly in the form of prototypes and partly in the form of products, fall into the passive or active categories. They serve to observe, entertain, feed, and care for non-human creatures, and they can help to avoid animal suffering. This is the unique selling point, so to speak, of active robots that direct their focus to a specific animal or problem. Proactive machines can be easily conceived but are difficult to implement. They also require economic foundations, political decisions, and legal frameworks that still need to be addressed. They will usually also have passive and active components; just as active machines often have passive components. So, the three categories are related in certain ways. The more complex manifestations build on the less complex ones. This allows earlier stages of development to be exploited, saving development time and cost. It has already been indicated that the classification is not necessarily selective. However, it helps in sorting and classifying robots in this area and stimulates considerations about the category of proactive robots, which is hardly covered by reality.

Automatic, Partially Autonomous, and Autonomous Machines

Passive machines are mostly less complex machines that function automatically or are directly controlled or remotely controlled, or semi-autonomous systems that require regular control by a human being in addition to their autonomous functions. Active machines are often semi-autonomous or autonomous machines, especially robots. Even with given autonomy, they are typically taken to a specific area of operation, repeatedly retrieved, maintained, and recharged, and humans intervene when certain messages and warnings are issued by them. Proactive machines would typically be semi-autonomous and autonomous systems, with a quantitative and qualitative shift: they would have to be autonomous for extended periods of time, for example, with respect to energy supply. They would also have to be highly flexible and reliable—think of the example of nature reserves—at least in their special field, or as generalists they would have to be able to perform a wide range of tasks, which is admittedly technically unfeasible right now. Here and there, humans will also have to intervene, although this should partly be done remotely, and there is hope that one day machines will be able to repair each other and—for example in the event of a malfunction or total loss—transport them away.

Service Robots and Social Robots

Among the passive and active machines, classical support systems and service robots mainly came up. However, social robots were also present, if one uses this term broadly and includes observation robots for filming, which are even sometimes accepted into the social community of animals, or certain animal-friendly machines such as LADYBIRD and HAPPY HEDGEHOG, which assume a great closeness to the animal and then contribute to animal welfare and animal protection on the basis of moral rules and appropriate sensors and motor functions (Bendel, 2021a). Proactive machines could particularly benefit from social functions and capabilities and in this sense to some extent complement and replace both animals and humans. For example, if only a few individuals of a herd remained in nature reserves due to unfortunate circumstances, social robots could fill this gap, even in the appropriate function or at the appropriate hierarchical level, depending on programming and design. They could play a special role in raising young when parents have been killed—that (appropriately prepared) things are accepted as parental substitutes has been proven by some studies since Harry Harlow's experiments (Harlow, 1959). Overall, there is a trend for service robots to take on more and more social functions, including getting help from humans (think riding an elevator or climbing stairs). The animal world could also benefit from this and thus experience both practical help and emotional affection.

Tasks of Disciplines and Interdisciplinarity

Several disciplines that can play a role in this context were presented. For passive machines, insights from animal-computer interaction, animal-machine interaction, and robotics, among others, come into play. For active machines, other disciplines such as machine ethics and, as indicated earlier, social robotics help shape appearance, behavior, and interaction. Proactive machines will require all these disciplines to a great extent. This also means new requirements for interdisciplinarity: robotics must consider fields that it does not always give top priority to, or even accept their temporary or permanent leading role. However, social robotics and machine ethics must also be modestly applied because the prototypes they have produced so far are not exactly characterized by outstanding motor skills. The already aged NAO is still the most agile, but it falls far short of high-end service robotics devices such as Boston Dynamics' Atlas and Spot (though it is also only a fraction of the cost). However, highly developed motor skills will be in demand in rough terrain and the great outdoors. Social robots like Pepper, Cruzr, and Paul, despite their voice and face recognition capabilities, would be little more than a bit of junk in a nature preserve, unable to get off the ground. In addition, of course, they would have to be prepared for entirely new requirements within the limits of their capabilities, would have to recognize animal voices, and would have to recognize animal faces. In fact, initial efforts exist in both areas: some projects are trying to understand animal languages using machine learning and inventing translation systems (e.g., the Earth Species Project, https://www.earthspecies.org); others are developing algorithms and systems for facial recognition in non-human primates, big cats, bears, and wolves (Deb et al., 2018). So, artificial intelligence would have to play a major role in some systems, especially when it comes to nature reserves populated and overseen by robots, and it is classical robotics that needs to take its younger siblings like social robotics by the hand.

Machines as Parts of Systems

In many cases, passive and active machines can act as singular systems. They therefore do not necessarily require networking with other devices, machines and robots, nor additional services via a cloud. However, some already rely on additional human partners, such as the drone reporting the fawn. Proactive systems will often be a complex overall system with multiple components or an infrastructure with many elements (Mancini, 2021). The machines (especially robots) cooperate and collaborate so that they can handle tasks that are very demanding, such as moving heavy objects, numerous individual steps, or the specializations required (Bendel, 2021b). In a nature reserve, they could work together to remove obstacles and carcasses or go in search of a lost animal. Proactive machines could also benefit from a technical infrastructure, as indicated. In a nature reserve, cameras, microphones, and sensors of all kinds could be placed at feeding areas and elevated sites, and data from satellites could be incorporated, such as through the Global Positioning System (GPS) or imagery from above. All of this data could then be tapped by the machines. Ground robots could be supplemented by aerial robots, which could traverse particularly rough terrain more quickly and possibly intervene more quickly in the event of danger. Human intervention is present in both semi-autonomous and autonomous machines. A control center that sees, hears, and smells with the help of the equipment and robots can take control of them or send a strike force if needed. Another option is to add ear tags, ear notches, tattoos, branding, RFID chips, and more powerful transmitters to the animals, making them identifiable and trackable by systems (or humans). Biotelemetry devices have also been common for a long time. However, their use can cause interference and injury (Paci et al., 2020).

Animals and Humans as Interaction and Communication Partners

Passive machines can target domestic, working, farm, and wild animals. Even laboratory animals, which have been left out in this review, are possible objects. Active and proactive machines are also possible solutions for all types of animals and animal species. By no means does this include only mammals or larger animals but also, for example, insects such as caterpillars, spiders, and beetles. Admittedly, depending on the type of animal and the species, very different modes of interaction and communication are possible and necessary (Mondada et al., 2013). It may simply be a matter of recognizing an animal and then halting operations, but it may also be a matter of specifically addressing the needs and capabilities of an animal species or even an individual animal. With regard to pets and farm animals, it will also be interesting to transfer human control and communication skills to the machines. Social robots, in particular, could play a similar role here in the future as normally responsible animals or humans, for example when they keep a herd together or give appropriate commands to a trained animal. Whereas, usually a service robot or a social robot interacts and communicates with a human, and animals often only join in by chance, here it is the other way around, which means, however, that the human must also be involved and perceived as a desired or undesired entity, as a person who may and should give commands, or who must be put in his place. In this context, cooperation and collaboration with other robots can be useful, for example with security robots in relation to a poacher.

Ethical Considerations for These Types of Machines

As more and more semi-autonomous and autonomous machines that can encounter animals proliferate, it seems appropriate to convert these machines into animal-friendly ones. Of course, from an ethical perspective, one can argue that the number of machines can and should be limited. This would avoid the suffering that can be caused by them. This is true, but out of scope in this review. Another objection may be that animals and machines should not share space for ethical, social, psychological, and medical reasons. There may well be animals and species that are stressed by the sight and behavior of machines and for whom contact with things is not enough. However, there are just as many, if not more, that are less stressed through contact with humans, and above all, it may be possible to avoid transferring our scent to the creatures, causing them to be rejected by their parents or herd, or causing the animals to become directly dependent on humans. Another objection may be that one already invades the intimacy and privacy of humans by passive, but especially by active and proactive machines. This can be granted to certain animals, such as non-human primates, at least in the sense that they sometimes want to be undisturbed. However, it seems unproblematic if the machines are not perceptible at all, which was one of several proposed options in this review. In particular, an infrastructure from which robots benefit can be implemented discreetly. Still, some caution is warranted with the machines themselves, because of their cameras and sensors and their physical presence alone. Moreover, humans can be bycatch, so to speak, if they are inadvertently captured by the cameras and sensors. As has been made clear time and again, machine ethics can also contribute. Here, the moral machines it designs and implements are animal-friendly in their nature. In addition to annotated decision trees, other approaches need to be developed.

Economic Considerations for These Types of Machines

Again and again, economic aspects have become clear in the preceding chapters and sections. The use of robots of all types can save costs for persons, groups, and institutions, provided that the costs for acquisition and operation are kept within limits and sufficient application possibilities exist. Thus, typical effects of automation arise. Some economic aspects are linked to technical and social utopias. When huge nature reserves are created in response to the destruction of nature and the loss of biodiversity, they can hardly be controlled by human labor, at least not at reasonable cost. Therefore, even and especially in the newly emerging wilderness—a possible response to crises and disasters—automation presents an opportunity. It would be necessary to create an overall system that consumes as few resources as possible. In the case of robots, especially proactive ones, self-sufficient energy supplies are conceivable and have already been tested, as in the case of the Energetically Autonomous Tactical Robot (EATR), a robot that can feed on plants (in principle, also, it is alleged, on corpses on the battlefield) (Bendel, 2017a). "Consumption" of organic material can not only provide necessary energy, but also contribute to forest management and livestock control. In addition, applications of artificial intelligence should be limited, especially with regard to resource-intensive machine learning.

Robots as a Response to Crises and Disasters

As was made clear in the sketch of two proactive machines, these can be of service in the event of crises and disasters, furthermore as a preventative response to crises and disasters, such as extensive nature reserves. In both cases, existing models and operational scenarios can be built upon—but further technical developments are needed, as well as societal, political, and legal frameworks. After all, it won't just be the case that semi-autonomous or autonomous robots will rescue one animal after another without any problems or consequences. Rather, errors and accidents will occur, due to unsuitable algorithms as well as unforeseeable situations, and questions will be asked in individual cases as to why priority is given to animals and not to humans in times of need (although this need not be the case at all). Bendel (2021b) shows that also human enhancement could be a possible reaction to crises and catastrophes as well as the colonization of satellites and planets. These considerations could be transferred to animals. It must be considered that animal enhancement has so far been more to the detriment of animals (insofar as the benefit to humans was placed in the foreground) and that in the case of enhancements and implants, damage to health can also occur (Bendel, 2016b).

SUMMARY AND FUTURE DIRECTIONS

This paper has proposed a classification of machines to explore their actual and possible relationship to animals. Numerous examples of passive, active, and proactive machines have been identified. It is noticeable that these are in turn quite different, having divergent designs, tasks, and capabilities. This also depends on whether they are simple automata or (partially) autonomous robots. In the discussion, based on the systematization, considerations were given to automation status, moreover to another classification, namely that of service robots and social robots. The importance of the individual disciplines and their collaboration was emphasized, as well as that of creating overall systems, up to and including satellites. Lastly, the interaction and communication partners themselves, i.e., the animals and consequently humans, were addressed and the perspective of ethics was outlined.

Proactive machines seem to have considerable potential, at least if one takes economic considerations and technical or social utopias as a starting point. Human-centered AI could become nature-centered AI, social robotics could be understood not only as robotics for humans but also for animals (Bendel, 2021a)—in research and development, more and more attention could be paid to this blind spot, the concerns of animals in relation to machines, and in application, robots could be used to help both flora and fauna. Artificial intelligence admittedly raises difficulties, as machine learning and deep learning often require a lot of power. However, the applications outlined could be designed to conserve resources, and local applications are already sufficient for certain forms of facial recognition. Another conflict can again be identified with regard to resources: Each more complex machine and robot requires a variety of metals, rare earths, batteries or accumulators, etc., and social robots in particular, with their composite of metal and plastic, are difficult to dispose of. Overall, we are creating more and more artifacts that share space with us and that consume resources just like us.

Animal-computer interaction and animal-machine interaction need to continue to grow as disciplines, cross-fertilizing machine ethics and social robotics as much as robotics as a whole and artificial intelligence. Animal ethicists, animal protectionists, and animal rights activists should perceive technology not only as a cause of problems and an enemy of living beings, but also as a possible solution, for all the criticism that needs to be made and all the progress that needs to happen. From increased interdisciplinarity, a transdisciplinary approach could one day emerge, under whatever name it is called. Animals and technology are becoming a more and more central, pressing issue, and a focus discipline on this area offers the chance to push humans away from the center of attention in research and development as well as application, and to make room for animals and plants, which we not only need for our survival, but which also have rights or values themselves. This shift in perspective is also important when we are still exploring the use of machines first and need to include animals in the process, or when the use itself is still a critical, provisional variant (Mancini, 2021).

This paper has outlined applications of all kinds that benefit animals (and in some cases plants). In many cases, these are systems and machines that can already be used profitably and beneficially today. Particularly interesting, however, is the view of the future. Man is increasingly beset by crises and disasters, and some of these are due to industrialization, mechanization, and intensive agriculture. Mechanization, digitalization, and automation are part of the problem, but also part of the solution. They help exploit the earth on a large scale, but could, at the same time, help save animals in need and monitor and protect them in nature reserves. In the process, however, they themselves consume resources again, and they share space with humans and animals in certain areas, some of which is already heavily occupied and fragmented. Technical solutions of this kind can never be standalone but need social and political flanking measures. Ultimately, there are many methods to destroy the earth—and many to save it.

AUTHOR CONTRIBUTIONS

OB agrees to be accountable for the content of the work.

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