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Exploring cats: Their behaviors and human-cat interactions

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Exploring cats: Their behaviors and human-cat interactions

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Table of contents

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Editorial: Exploring cats: their behaviors and human-cat interactions

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Editorial on the Research Topic
Exploring cats: their behaviors and human-cat interactions

Introduction

Domestic cats are immensely popular companion animals in households around the world (1). Over 45 million US households contain at least one companion cat (2); in the European Union, the population of pet cats is estimated to be 113 million (outnumbering the estimated 92 million dogs) (1). Despite this global popularity, research into the behavior and welfare of cats living in private homes is still limited; and arguably, even less is known about the mechanisms of human-cat interactions within the home. Outside the home, cats allowed uncontrolled outdoor access alongside free-roaming cat colonies outside of human ownership (but not always without human care), still generate considerable controversy between animal advocates and conservationists concerned about cats' impact on wildlife. This Research Topic presents 12 new papers that shed light on these issues and more. The goal of this Research Topic is to improve our understanding of companion cats, with particular focus on their interactions with humans, and human attitudes toward these animals. The twelve manuscripts in this Research Topic on cat behaviors and the development of the human–cat bond cover a wide variety of themes.

The mechanics of human-cat interactions

Turner(a) presents a mini-review of the available literature on a number of topics relevant to our understanding of human-cat interactions, such as the importance of kitten socialization, how cats communicate with their humans, and the mechanics of social interactions between cats and humans (such as the influence of who initiates contact, and of symmetry in compliance, or lack of compliance, with the partner's "wishes"). Noting the importance of ensuring the animals' wellbeing during human-cat interactions (and the scarcity of research into this issue with companion cats), Haywood et al. present Human-Cat Interaction guidelines designed to improve the comfort and welfare of companion cats during such interactions. They developed and tested the efficacy of these new guidelines with 100 shelter cats, interacting with 120 novel members of the public, and report their results here. Nagasawa et al. examine physiological (urinary oxytocin and cortisol) responses to interaction with humans, by comparing these variables in cats during positive interactions with a familiar caretaker (including physical contact, play, etc.), vs. when such interactions were removed. In another study using physiological (fecal cortisol) measures of stress, along with weight and behavior, Carlisle et al. investigate stress levels of cats adopted by families of children with autism spectrum disorder (ASD). Cats in the Carlisle et al. study were specifically selected for sociability and calmness using the validated Feline Temperament Profile, and the adopters provided with education on cat behavior; the authors discuss the importance of these factors to successful adoption into these homes.

Understanding interactions between cats

Gajdoš Kmecová et al. review and seek to extend the existing research on play in cats, much of which has focused to date on object play [e.g., (3)], by looking at social play between cats. They suggest using a psychobiological approach to the study of play, which considers the motivational and emotional states of the cats; and present an ethogram (synthesized from the literature) and common terminology for use in future studies of cat social play. Khoddami et al. also seek to extend the existing literature on interactions between cats in multi-cat homes, by focusing specifically on two-cat households. They note that previous studies frequently lack focus on any particular group size, limiting our understanding of social dynamics in specific group sizes, despite the fact that most multi-cat households in the US and Canada consist of two cats (4, 5).

Free-roaming cats and wildlife

Four papers in this issue focus on free-roaming cats, with two exploring the often-contentious issue of domestic cats' impact on wildlife. Tan et al. summarize the arguments for and against allowing cats outdoor access, and identify several owner- and cat-related factors associated with allowing companion cats uncontrolled access to the outdoors. Kim et al. investigate attitudes of different demographic groups toward feral cats in Seoul, South Korea, following the establishment of government-supported cat feeding stations around that city. They report distinct and sometimes complex differences between the groups in their attitudes toward cats and their preferred management approach for feral cat populations [e.g., trap-neuter-release (TNR) vs. culling]; they also discuss the possible impact of the feeding stations on these results. Turner(b) takes a critical look at the literature on cats' impacts on wildlife, in light of recent media reports of the "alarming predation of house cats on prey populations." Turner(b) cautions that researchers should avoid bias and misinterpretation of field data, by considering what is known about predatory behavior in domestic cats and reporting estimates of total prey species population sizes. In their paper examining human-cat interactions involving free-living cats, Wandesforde-Smith et al. note the "moral pluralism" involved in the emphasis (even requirement) for humane care and protection of owned companion cats, alongside the systematic culling of large numbers of cats supported by public policy.

Use of technology in research on cats

The final two papers discuss research into new use of technology in the study of domestic cats. Xu et al. apply and advocate for machine learning techniques (in contrast to the more traditional biomechanical experiments with living cats or cat cadavers) for improving our understanding of the feline "athletic ability." Given recent work using heart rate variability (HRV) as an indicator of emotion in non-human animals [e.g., (6)], Grigg et al. compare HRV data collected using an affordable, commercially available cardiac monitoring system (Polar H10) against data from a traditional ambulatory electrocardiogram, to assess whether the Polar monitors could be used for this purpose in unrestrained cats.

In summary

This Research Topic tackles a broad range of topics relevant to domestic cats. Many of the papers add particular insight into our understanding of human-cat, and cat-cat, interactions. Others report on issues important to cat welfare, such as controversies surrounding outdoor cats and wildlife. Our understanding of domestic cat behavior and human-cat interactions continues to improve, as these papers demonstrate.

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MINI REVIEW
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The Mechanics of Social Interactions Between Cats and Their Owners

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This is a mini review that summarizes what is known from quantitative observational studies of social interactions between domestic cats and humans in both laboratory colonies and the home setting. Only results from data that have been statistically analyzed are included; hypotheses still to be tested will be declared as such. In some cases, the observational data have been combined with independently collected subjective assessments by the owners of the animals' character and owner personality traits to help interpret the data. Further some relevant experimental studies are also included. All social interactions between cats and humans that are discussed below assume that the animals were socialized to people as kittens, the first topic of this review. Such socialized cats show what might be called "friendliness to humans," which in turn affects human attachment to the cat. The visual and acoustic behavioral elements used to communicate and interact with other cats can be perceived by people and are also employed by the cats when interacting with them. The initiation, and the initiator of social interactions between cats and humans have been shown to influence both the duration of the interaction bout and total interaction time in the relationship. Compliance with the interactional "wishes" of the partner is positively correlated between the cats and the humans over all human-cat dyads examined. Cats do not spontaneously prefer one gender or age cohort of people, but the humans in those cohorts behave differently to the cats causing the latter to react differentially. The dyadic interaction structure has also been shown to differ between women and men and between older and younger adults. Nevertheless, cats—merely their presence but of course their behavior—can affect human moods and human mood differences have been shown to affect the behavior of the cats. Finally, differences have been found between interactions with purebred and non-purebred cats and between younger and older cats.

Keywords: owners, socialization, communication, mood, cats, interactions, breed

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SOCIALIZATION AND OTHER FACTORS AFFECTING ESTABLISHMENT OF A NEW RELATIONSHIP

Eileen Karsh was the first researcher to experimentally determine the sensitive phase of kittens for socialization to humans and this was supported by further data from cat colonies in Zurich and Cambridge (1–3). Kittens handled frequently by humans during their second to mid-seventh week of age become friendly and trusting of people and remain so throughout their later lives [tested to at least 3 years of age, (4)]. The duration and frequency of handling and number of handlers required for this effect have also been examined (5). Much behavior toward conspecifics is still to be learned. Schaer (6) suggested that conspecific "socialization" occurs by about 10 weeks and Hediger (2) confirmed experimentally that socialization to conspecifics and to humans can occur simultaneously. Therefore, most experts recommend not placing kittens before 10 or 12 weeks of age (7)[1].

Although original socialization status to people is of paramount importance for future cat-human relationships, other parameters have also been shown to influence the establishment of a new relationship [summarized in a model by (1, 8)]: genes of the father (9); presence and behavior of the mother (10); curiosity (exploratory behavior, see below); stroking the cat; and the act of feeding the animal (11). The model by Turner predicts differential outcomes of later positive and negative experiences with people depending on the quality of original socialization to humans. For a cat well-socialized to humans as a kitten it takes many negative experiences with other people to become wary of such contacts and very few positive experiences with a new owner to become friendly and trusting of that person. A cat poorly socialized to people as a kitten requires a great deal of positive experience to accept a new person, but very little negative experience with a person to confirm its wariness and fear of people. Most shelter employees will inform that a poorly socialized and/or mishandled cat requires a great deal of patience and understanding by the new owner after being rehomed, while a well-socialized individual will take only 1–2 weeks to adapt to the new owner and home. This has enormous welfare implications for the cats involved in that poorly socialized cats take up limited space in the shelter for longer while waiting for the personnel to find such a patient new owner, and well-socialized cats can be rehomed more easily and quickly.

FRIENDLINESS TO HUMANS

Turner et al. (9) reported a father effect on the behavioral patterns of kittens associated with what one might call "friendliness to humans." Since cat males have nothing to do with raising their kittens, this effect had to be genetic. At the time the authors cautioned that they were not talking about a "gene for friendliness" and later, McCune (3) proposed that the genetic father effect was on "boldness" of his kittens, which in turn, increased or decreased their exploratory behavior and the chances of their contact with new humans, appearing as friendliness or, if lower, shyness.

Turner and Stammbach-Geering (12) asked women living at home to subjectively assess their cats and relationships to them along 31 traits, once for their current cat and once for the "ideal" cat and relationship. The effects of civil status, housing condition (indoor or with outdoor access), and number of cats kept on the trait ratings were also examined.

Significant positive correlations were found between the ratings of "cat affection to the owner" and "owner affection for the cat." The former was positively correlated with ratings for "predictability," "proximity to the owner," "enjoyment of physical contact," "cleanliness" and "likeness to humans." The keepers of cats with outdoor access rated their animals as being less curious than those of indoor cats. The authors hypothesized that cats kept exclusively indoors were compensating for their less animate environment by initiating more contacts with objects inside than the outdoor cats did. However, it is important to remember that correlational results are not necessarily causal, and still need to be tested experimentally. Turner's (13) observational data on human contact initiation by indoor cats do however support the hypothesized interpretation.

COMMUNICATION BETWEEN CATS AND WITH HUMANS

Cat-cat visual, olfactory and auditory communication have been fairly well deciphered beginning with Leyhausen's (14) original work on the body and facial signals used [expanded by (15–17)]. Cats often use some of the same visual and vocal signals when interacting with people. When they approach another familiar cat and greet their keepers after a short absence, they raise their tails upright, presumably as a sign of friendly intentions. Only domesticated cats use this signal and it has been suggested that there was selective pressure for such a signal in the dense temple colonies of ancient Egypt (18). To get our attention, they flank-rub on our legs (which might also mark us) and head-rub—forehead to forehead—with cats they know well, presumably marking each other (and us) with a scent (1, 19). Bernstein and Friedmann [(20), also citing (21)] reported that cats preferred certain places on their bodies, particularly the head region, for being stroked, modified their postures to promote access to those preferred regions, and even led their keepers to preferred places in the home for petting episodes. Ellis et al. (22) determined that both handler familiarity and body region stroked significantly influenced negative behavioral responses. Bernstein and Friedmann (op cit.) also mentioned the cat's closing of the eyes in this relaxed situation (sometimes called the "slow blink"). This slow-blink has received more attention recently and when previously unfamiliar persons initiate such blinking, cats tend to approach them more often (23).

Auditory communication by cats has been and continues to be examined [reviewed by (17)], most recently by Schötz et al. (24) using phonetic analyses of cat-to-human vocalizations. It is generally known that cats vocalize more frequently with their human companions than with other cats (1). Yeon et al. (25) found that meows are attention-seeking vocalizations in interspecific situations and higher pitched (subjectively more pleasant) than in feral cats and wild ancestors. They also modify their purrs when actively soliciting food (more urgent and less pleasant than when just resting as perceived by the human raters) and people are capable of distinguishing these (26), both behaviors probably learned over time in interactions. Ellis et al. (27) reported that 40% of their human participants identified the correct contexts of cat vocalizations more often than by chance when the vocalizations belonged to their own cat, but did not perform

[1] www.humanesociety.org *Kitten behavior basics*.

above chance when the calls belonged to an unfamiliar cat. Interestingly, Saito et al. (28) demonstrated with the habituation-dishabituation method that privately owned cats can discriminate their own names from other words, which leads now to other studies in the area of social cognition in cats.

Recent work on social cognition in cats also has relevance to cat-human communication. Vitale Shreve and Udell (29) provided a first review of what was known and still to be discovered and a number of studies have since been published. Pongracz and his colleagues in Hungary have been particularly active this this area. Even though Miklosi et al. (30) had already shown differences between dogs and cats in their ability to use human pointing gestures, especially that cats lacked some components of attention-getting behavior compared with dogs, Pongracz et al. (31) demonstrated that cats were indeed able to read and follow human gaze for referential information. Galvan and Vonk (32) found that cats were only modestly sensitive to emotions as indicated by human postural and vocal cues, but particularly when displayed by their owner. Quaranta et al. (33) demonstrated experimentally that cats are indeed capable to cross-modally match pictures of emotional faces with their related vocalizations in both conspecifics and humans, especially for high intensity emotions. These authors concluded that cats have a general mental representation for the emotions of their social partners, both conspecific and human.

THE INITIATION OF SOCIAL INTERACTIONS AND GOAL MESHING

As mentioned above, the results from Turner and Stammbach-Geering (12) prompted a more detailed investigation of social contact initiation by household cats and their humans. Turner's (13) team observed the mechanics of social interactions in 158 cat-owning households over three consecutive days, recording which partner, the cat or the person, tried to initiate the interaction (precisely defined), the reaction of the partner (accepting or declining), the duration of each interaction as well as total interaction time observed in that cat-human relationship. The goal of the project was to determine a potential measure of relationship success or quality. Firstly, Turner looked at the proportion of "intents" to interact that were successful - separately for the cat and the person (in this study, the woman of the household) - and attempted to correlate these values with total interaction time in the relationship over all cat-human dyads observed. There was no significant correlation for the cat data, but a significant negative one for the humans. The more successful the person was in initiating interactions, the *shorter* the total interaction time with the cat. This means that it is the cat that determines how long the interaction lasts. The next measure combined the data for the cats and humans into one number, namely, the proportion of all successful attempts to interact that were due to the cat. Over all person-cat pairs, this measure was indeed positively correlated with total interaction time in a relationship. That is the higher the proportion of all successful intents to interact that were due to the cat, the more time spent overall interacting in the relationship.

In Mertens' (34) observational study in other households, she found that the human partner was generally more active than the cat in distance regulation, especially in reducing distance between the two, but that single bouts of staying close to each other were longer when initiated by the cat. Further, Mertens reported a higher degree of reciprocity in distance regulation in cat-human dyads with adults than in those with children and juveniles, indicating a better "meshing" of close contact. "Goal meshing," i.e., whether the goals of each partner are aligned with the ongoing goals of the other, is one important quality of any relationship (35).

Turner (13) continued the analysis of his data and calculated the proportion of "start interactions" (a defined and recorded element) due to the cat whenever the person had shown an intent to interact (also precisely defined), i.e., the individual cat's willingness to comply with the woman's "wish" to interact. Operationally, the "wish" to interact was defined for both the human and the cat as an approach to the partner and/or a directed vocalization. Also for each pair, whenever the cat had shown an intent to interact, he calculated the proportion of "starts" due to the woman, or, the woman's willingness to comply with the cat's "wish" to interact. These two values over all observed human-cat pairs were positively and significantly correlated. In other words, if the woman complies with the cat's wishes to interact, then the cat complies with the woman's wishes at other times; if the woman doesn't comply with the cat's wishes, then neither does the cat, with the woman's wishes. Therefore, a symmetry exists in the relationships at all levels of compliance, high to low, which might explain the popularity of cats, but also differences in the level of interactivity between relationships. In some relationships there is a high level of interactivity, in others, low, and the cat apparently accepts this, as indicated by staying on as the household pet (even when allowed outside) and lowering its own rate of initiation of interactions, when the owner shows less interactivity.

Wedl et al. (36) used a relatively new tool to analyze the structure of human-cat interactions observed in the home setting, namely Theme® (Noldus bv, The Netherlands). Strings of video recorded owner and cat behaviors were analyzed during four visits to each of 40 cat-owning households. The Theme® algorithm detects sets of events which follow each other non-randomly in the temporal sequence. Two actions that occur repeatedly and regularly in alternation form a basic "t-pattern." Hierarchically structured t-patterns emerge via the detection of relationships of these previously detected patterns by repeated use of the algorithm scanning the strings of behaviors. Wedl and her co-workers found that owner and cat personality and gender and cat age of the partners (see below) had significant effects on t-patterning of dyadic behavior. In dyads with a female owner, the number of patterns per minute tended to be higher than in dyads with a male owner. Further, cat sex did not have any effect on the temporal patterning of dyadic behavior. These results are consistent with results found by Mertens [(34), see above] and Turner (1).

DIFFERENCES RELATED TO HUMAN GENDER AND AGE

Mertens and Turner (37) reported differences found between the behavior of men, women, boys and girls in an experimental study of their colony cats. When the human volunteers were not allowed to interact in any way with the cats they were meeting for the first time in an encounter room (they had to look at an age-appropriate book during the first 5 min), the cats entering the room showed no preference for gender or age of the partner in their approach behavior. However, during the following 5 min when the persons were allowed to interact as they pleased with the cats and the authors recorded the human's behavior, the cats *reacted* to differences in behavior between men, women and children. Men tended to remain seated while women and girls moved down onto the floor, to the level of the cats. Children, especially the boys, tried to approach the cats immediately to which the cats usually reacted negatively by fleeing from them, even though they were all well-socialized. Women and girls spoke to the cats more often and the cats vocalized more often with them than with the men or boys.

These results were supported by later observations by Mertens (34) during 504 h in 51 cat-owning households with 162 persons and 72 cats. When at home, women spoke and interacted more with the cats than men did. Children were especially active with respect to motor activity, while adults spoke more often to the cats. She also found that interactions with women had a higher reciprocity and therefore probably both the person and the cat enjoyed high-quality relationships. In a more recent study, Wedl et al. (36) found that female owners entertained a more structured interaction with their cats than male owners and that extraverted owners have relatively varied interaction patterns with their animals. From a PCA analysis of answers to a questionnaire by Hungarian cat owners, Pongracz and Szapu (38) reported that women considered their cats to be more communicative and empathetic than men did and that emotional matching of the cat was more commonly reported by elderly owners than young owners.

Turner (39) compared the interactions of younger adults and elderly persons (65+) with their cats and found no difference in total interaction time between the two groups, but two differences in the structure of those interactions: Younger adults interacted significantly more often with their cats, but when older people interacted, they did so for significantly longer (Presumably the elderly waited until the cat came to them to interact, but this was not tested.). The younger owners also interacted more often from a distance and spoke more often to the cat than the elderly did.

All of the above findings have allowed recommendations to psychotherapists and pedagogues working with cats to help people in texts (40, 41) and courses in animal-assisted intervention, as well as to the general public to promote harmonious cat-human relationships.

THE EFFECTS OF CATS ON HUMAN MOODS

Rieger and Turner (42) and Turner and Rieger (43) discovered that not only the mere presence of a cat in the household, but also interactions with the cat reduce measureable negative moods in the person, e.g., anxiety, depression, and introversion. The depressive owner initiates fewer interactions with the cat, but when the cat approaches that person, s/he accepts the intent of the cat to interact, which affects the human's mood. The cat also changes its behavior in response to depressiveness of the human when close to the person (but not at a distance), vocalizing more frequently with the person and head- and flank-rubbing more often on that person. More mood subscales in women than in men are affected by the cat, and they are more strongly affected than in men. Turner et al. (44) concluded that only the partner, but not the cat, enhances positive moods, while the cats alleviate negative moods. This effect was comparable to the effect of a human partner.

EFFECTS OF CAT BREED AND AGE ON CAT BEHAVIOR AND CAT-HUMAN INTERACTIONS

Surprisingly, given the large number of popular cat breed books, there have been relatively few research studies of breed differences in behavior or behavior toward people. Turner (8, 39) reported on the only ethological study that compared the two oldest purebreds, Persian and Siamese cats, with non-pedigree cats and combined observational data with subjective trait ratings by the owners. He found few differences between the two breeds - reportedly at the extreme ends of cat personality - presumably due to convergent human selection, but those expected from the popular literature: The Persians were less active and less vocal than the Siamese, while the latter were more playful but demanding of their owners. Relative to the non-purebred cats, the purebreds were often closer to their owners and friendlier to strangers, which might be related to differences in handling (pampering) during upbringing or to artificial selection (genetic differences).

Hart and Hart (45) interviewed some 80 US-veterinarians in feline practices considered to be unbiased authorities on breed differences in cats. They ranked a random selection of five breeds and domestic short- and long-haired cats out of 15 cat breeds along 12 behavioral traits. Three traits had high predictive value to distinguish the breeds, seven traits with moderate and two traits with low predictive value. However, Turner (46) stated that confirmation of these subjective rankings is still needed from comparative ethological observations. The same criticism can be made of two more recent, but otherwise promising studies for future work, namely by Wilhelmy et al. (47) and Salonen et al. (48). Using a well-known questionnaire to generate standardized behavioral profiles, the former study found behavioral characteristics in purebred cats associated with breed, coat color and coat pattern. The latter study also gathered a large data set from a health and behavior questionnaire completed by owners and determined behavioral differences between 19 breeds and breed groups along 10 different behavior traits. A moderate level of heritability in three breeds for seven traits was found but the authors reported that substantial genetic variation exists within breed populations.

There are even fewer studies of the effect of cat age on cat-human interactions. Wedl et al. (36) employed the Theme® algorithm to their observational data and determined that the older the cat, the lower the dyadic event type complexity, meaning that the strings of cat behavior in interaction with their owners are shorter in old cats than young ones. This probably reflects decreased activity levels and playfulness with age in cats.

CONCLUDING REMARKS

This mini-review has shown that we have discovered much about the mechanics of social interactions between cats and their owners, but that more remains to be discovered when researchers apply new techniques, e.g., phonetic analysis of cat vocalizations, or by applying the Theme® algorithm to analyze such interactions. More observational studies comparing the behavior of different cat breeds and animals of different coat characteristics would be welcomed to substantiate and compliment the owners' qualitative assessments of personality traits. Further, it is hoped that an ethically acceptable method to test the prediction of Turner's (1, 8) model on the effects of later positive and negative experiences with people on friendliness to people can be found.

AUTHOR CONTRIBUTIONS

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

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REVIEW
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Coping With Human-Cat Interactions Beyond the Limits of Domesticity: Moral Pluralism in the Management of Cats and Wildlife

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Although human interactions with cats are often even typically analyzed in the context of domesticity, with a focus on what sorts of interactions might make both people and cats "happy at home," a large number of cats in the world live, for one reason or another, beyond the bounds of domesticity. Human interactions with these more or less free-living cats raise deeply controversial questions about how both the cats and the people they interact with should be sensibly managed, and about the moral imperatives that ought to guide the management of their interactions through the laws and public policies regulating both human interactions with pets and with wildlife. We review the geography of human interactions with cats living beyond the bounds of domesticity. We acknowledge the contributions made to ideas about how to manage cats by the animal protection movement. We review the tensions that have emerged over time between advocates for the eradication of free-living cats, because of the impacts they have on native wildlife species, and those who have imagined alternatives to eradication, most notably one or another variant of trap-neuter-return (TNR). The conflict over how best to deal with cats living beyond the bounds of domesticity and their wildlife impacts raises the prospect of stalemate, and we canvass and critique possibilities for moving beyond that stalemate.

Keywords: cats, feral cats, community cats, conservation, wildlife, trap-neuter-return

INTRODUCTION

The research literature on companion animals has a clear, understandable, and laudable focus on how and why it is that human interactions with domestic cats yield behavioral dynamics of attachment and affection and on how it might be reasonable and useful for both scientific and management purposes to measure those dynamics. A central even essential but all too often unexamined premise of this body of work is that it is both sensible and just, or if you prefer humane, for people to keep cats in their homes, more or less confined, as domestic pets (1).

Such domestication of cats, which has been under way for thousands of years (2), is deemed acceptable, even normal, because it does not completely prevent a cat from living a life of its own (3). This is in contrast to what happens, for example, when a recently captured exotic bird from Guatemala or Cameroon, say, is confined to a small cage in a domestic living room or kitchen and is abruptly and permanently cut off from the life it was living in the wild, from its own natural life (4, 5).

Indeed, the prevailing assumption in the literature about human interactions with domestic cats is that the cats can be and usually are, and certainly ought to be, content living in people's homes. While the owners for their part derive great happiness and satisfaction, even diversion and entertainment, from providing cats a place to live. There exists, moreover, a vast and profitable pet economy to ensure that when cats are kept in homes as pets they can be well-fed, given toys to play with, be cared for if they get sick or injured, and even have a decent interment after they die. One might be tempted to say that over the *longue durée* (6) human interactions with cats have made it seem not just possible but natural by now to think of cats only as domesticated pets.

What other life could cats conceivably lead except a life of contented domesticity?

CATS AND ENCLOSURE

The truth of the matter is, however, that cats have always been and to this day remain somewhat awkward subjects for domestication. When, despite best efforts to understand what makes them content and to provide for their needs, as well as for ours in relation to them, cats stray or are forced outside the home, to live if you will beyond the bounds of domesticity, they can and in many places do survive and prosper without direct human interaction and support.

It was not until relatively recently, in fact, thanks to the widespread availability of processed cat food, absorbent cat litter, and veterinary services for spaying and neutering that completely confining cats and preventing them from spending some time outside on a daily basis became feasible. The tale has been famously told about how President Calvin Coolidge's cat had free rein to wander to and from the White House in the 1920s. In those days, Stall observed, no-one thought of confining cats indoors (7). A great many cat owners still do not impose such confinement on their pets, although they increasingly run the risk nowadays of being seen as irresponsible pet owners in need of further education (8–10).

Despite their long-standing acculturation to living with people, then, cats have retained what some would regard as an inherent biological capacity to fend for themselves. In the case of socialized pets that are allowed outdoors, the indoor/outdoor cats, this can find expression in the taking of prey even when owners keep their pets well-fed. In the case of stray but social community cats and even more so for truly feral cats receiving no human support, however, the effects of cats fending for themselves on other species can be much more controversial.

That is why it is useful in this collection of papers not to restrict our interest in human-cat interactions and the behaviors they yield to the domesticated cats eating preprepared cat food from a can or a dry food package and leaving their litter in an absorbent clay cat box. The cats that do live outside their "homes," beyond the bounds of domesticity as we put it, and sometimes in large numbers (11, 12), raise questions about human interests in and concerns about cats that merit attention even in a set of papers primarily focused on those human-cat interactions that occur within the bounds of domesticity.

REGULATING CATS IN CONTEXT

In important ways our interest in cats and their behavior, as well as our interest in whether and why and how we want to regulate that behavior, is conditioned by the context in which cats are found. Some of them lead lives that are completely wild and free ranging and some are completely tame and confined (12). Context is related to regulation. If the context is such, for example, that cats have some freedom to move around in urban and suburban places or come to inhabit open or waste spaces, so that they are living in proximity to people but are not always in their dwellings, the behavior of cats can create nuisances, threatening property and perhaps health. Complaints about these nuisances trigger a regulatory process that tries to strike a balance between the negative externalities cat behavior can cause and the positive contributions cats make to human companionship and to vermin control, notably by barn cats on farms. The norm is that the regulatory balance should be struck locally, where the costs of abating the nuisances complained about can also be considered. In addition, since the end of the nineteenth century, initially for dogs but now also for cats, local governments around the world have evolved a variety of animal control and shelter programs to implement whatever balance between the costs and benefits of regulating the negative externalities of cat behavior seems most appropriate and acceptable, given a particular local context.

Some of these local animal control programs are complex and sophisticated, and in the best of them, at the present time, the guiding moral precept, by and large, is that killing cats to bring under control the community problems cats create is both unethical and ineffective. In the USA, the National Animal Care and Control Association adopted a policy in March 2021 stating that the "indiscriminate pick up or admission of healthy free-roaming cats, regardless of temperament, for any purpose other than [trapping, neutering and returning the cats, TNR], fails to serve commonly held goals of community animal management and protection programs and, as such, is a misuse of time and public funds and should be avoided (13)."

The way this precept works in practice for the cats can vary considerably, however, from one country to another and from one locality to another, depending on how firmly the moral precept against killing impounded cats is locally held. In the aggregate and across many urban and suburban jurisdictions, it is still the case that locally managed animal control programs euthanize large numbers of cats every year, although this now occurs less frequently than used to be the case (12).

In contexts where cats are much more remote from human settlement, where cats are living in the wild and free ranging, our interest in cats and their behavior still has to reckon with the possibility of human interactions, because the food cats eat, the prey they consume, may have been accorded a protected legal status; a situation that arises most notably where cats are deemed under international, national, and state law to be an alien and invasive species and their prey are defined as native species whose continued existence can be considered essential to the survival and proper functioning of endemic ecosystems (14), although this essentialist view has given way among conservation biologists in recent years to a view of nature as inherently chaotic and disruptive.

When they live their lives in these remote contexts, particularly on offshore islands, cats arguably become part of ecological processes that can threaten the viability of other species; a view which at the extreme fuels moral panic about extinctions and tends toward biological nativism. Cats can legally be declared in some jurisdictions to be an ecologically threatening process; an environmental pest that requires abatement. Thus, the moral precept that then comes into play is typically some variant of the same one that has been applied in the past to other species defined as pests, particularly those inimical to agricultural interests, namely that pests are to be killed, possibly in large numbers and, depending on the assessed severity of the threat, even to the point of extermination (15).

The indices of programmatic success in this case ought to be measures of the extent to which threatened species then recover, an assessment that has usually been made when cat eradication programs are conducted on islands. As a matter of everyday practice in other remote contexts, however, the index of success is almost always simply the number of cats killed, even though the relationship of that number to the viability and survival prospects of threatened species is in most cases unknown and in all cases uncertain, because of multiple confounding variables that are hard to measure and interact in ways that are difficult for even the best scientists to disentangle (12, 14, 16). The status of threatened species can also be affected, for example, by the loss and degradation of habitat and by environmental change processes related to climate change. Indeed, there are important but still open questions about whether human disturbance of natural landscapes for agriculture and human settlement are more important influences on the decline in numbers of native species than the prey behavior of cats (17, 18).

FELINE MORAL PLURALISM

Although much has been written about the different moral precepts that might guide human-cat interactions (19), the variants theoretically on offer are not easily mapped empirically across the general population or even among cat owners. What is clear, however, is that over time, the moral imperative and obligation to treat cats humanely, regardless of the context in which they live or their ownership status, has been gaining ground.

In the case of domestic cats, it has long been the case that responsibility for the way they are treated rests primarily with documented owners, although the way this is enforced has varied across time and space. However, even semiowned and unowned cats can be very well-cared for by people who do not think of themselves as owners. Such support was provided, for example, to the free-ranging domestic cats living on public lands in the Florida Keys (20) and to cats admitted to several Trap-Neuter-Return (TNR) programs in the USA (21). In Australia, the RSPCA, reflecting the assumptions built into the Commonwealth government's Threat Abatement Plan for Predation by Feral Cats, recognizes semiowned cats as cats that are fed or are provided with other care by people who do not consider they own them. Even unowned cats of varying sociability can be indirectly dependent on humans with whom they have casual and temporary interactions (14, 22). Feral cats, at least in Australia, can thus be distinguished from domestic cats, whatever their ownership status, because feral cats are unowned, unsocialized, have no dependence on humans, survive by hunting and scavenging, and live and reproduce in the wild (23).

If the human ownership bond with cats is broken, for whatever reason, public policy generally requires that reasonable efforts should be made to renew it or to find new ownership by adoption. Cats can be cared for in shelters in the interim by attending to their health needs, for example. If the ownership bond is abused, animal cruelty legislation can sanction owners and protect the cats. The moral imperative at work for domestic cats in both these circumstances entails respect and compassion; respect for the documented ownership of cats as property and compassion for each of the individual animals treated as a pet. Essentially, the same moral imperative is at work if the concept governing human-cat interactions is one of guardianship rather than ownership, although there are legal differences between the two.

A world in which individuals own cats as their property has become, then, part of a moral universe in which the deliberate and systematic killing of large numbers of cats as a matter of public policy, whether for biodiversity conservation or any other purpose, is beyond the pale of acceptable human conduct and is widely condemned by informed public opinion, most especially but not exclusively among the documented owners of cats.

In the case, however, of cats that have no owner and are living off the land in self-sustaining populations of free-living animals, different moral considerations come into play. There is a widespread belief, particularly but not exclusively in the conservation community, for example, that there can and should be no moral bar to killing cats. This is especially so if the eradication of the cats, or their complete physical removal from the landscape short of death, if that is feasible, is premised on the moral imperative of saving other species from threats to their survival, even perhaps from extinction. The consequent willingness on the part of those who are comfortable placing a privileged value on free-living species other than cats to see large numbers of cats killed can, thus, have a major impact on the life chances of cats that live outside the home.

The resulting moral conflict over whether human interactions with cats living in remote contexts should be dominated by an urge to exterminate the cats is intense; so much so it has become an unmistakable and distinguishing characteristic of much literature that deals with human-cat interactions outside the home. In the words of McCubbin and Van Patter, "The lives and deaths of cats, big and small, are sites of contestation in the world of conservation. Beginning with small cats, the management of feral domestic felines is mired in heated conflict across the globe." (24). Other observers have argued that "the scientific literature on this issue is mostly unbalanced in one direction or the other and the various protagonists commonly have difficulty engaging in a civil discussion of their [differences]" (12).

So, it is not unusual for some contributors caught up in this conflict to say, for example, that cats are killers, even serial killers, and that the time has come or is long past to declare all out "war" on such cats and to kill as many of them as possible, by whatever means can be shown to work, in order to end, as some would have it with an eye on recent headlines, the "pandemic" cats have inflicted on native wildlife (25). Others respond by saying that the determination to exterminate such cats stems from a "moral panic" that willfully overlooks clear evidence of alternative possibilities for treating the cats with respect and compassion and that blanket recommendations for the systematic extermination of cats are both scientifically indefensible and morally untenable (26).

The intensity of this feline moral pluralism is a relatively recent phenomenon.

THE PROTECTIVE PARADIGM

Until the nineteenth century, public policies for dealing with cats living beyond the bounds of domesticity rested on the assumption that such cats could and should be treated under a blunt, even primitive, and narrowly utilitarian morality. Accordingly, if they were not owned or useful, and no-one could be found to make a priority out of caring for them, cats could be quickly dispatched by any convenient means, as was true at the time for other unwanted or stray animals for which no-one had any apparent further use.

In the case of dogs, for example, Janet Davis recalls how local communities in the USA staged massive roundups in the summer, when strays were shot on sight or violently thrown into crowded wagons and later summarily dispatched at the pound (27). Other methods in use once stray pets were caught commonly included drowning, strangling, clubbing, and herding them into gas chambers, although these practices were no longer widespread by the beginning of the twentieth century. Poisoning was less common but is still in use and in some places still has its advocates for truly feral cats (28–30).

The notion that a different morality could be brought into play and that, if acted upon, would lead to different and better treatment for cats, as well as for dogs and other pets, became widespread both in Britain and the USA in the first half of the nineteenth century. It found its first major institutional expression in the USA when the New York Legislature in 1866 granted incorporation to a state animal protection society, which came to be known as the American Society for the Prevention of Cruelty to Animals (ASPCA), with police powers to prosecute abuses, and then also enacted a revised state anticruelty law. Although the initial focus was to protect from abuse horses used for haulage and transportation, it was later extended to other animals.

The account Davis provides of the subsequent evolution of the animal protection movement in the USA as a "barometer for human morality" vis-à-vis animals and as a "marker of advanced civilization" makes it clear, however, that for a long time cats were an awkward fit with the agenda for moral uplift that animal protectionists began to advance during the long nineteenth century—and for some of the reasons we have already noted. She writes, for example, that cats were conspicuously absent from the list of subjects to which early animal protectionists devoted their energies. There was certainly an interest in prosecuting individual cases of egregious cruelty to cats. Indeed, as long ago as 1641, the Massachusetts General Court had enacted a colonial statute prohibiting "any Tirranny or Crueltie toward any bruite Creature which are usuallie kept for man's use" (27).

However, when the animal protection movement came of age, most local communities did not routinely round up stray cats as they did with dogs (31). At the time, dogs were vectors for canine rabies variant, which has since been eliminated from the USA. Dogs were known killers of livestock and capable of harming people, especially children, by biting. These same considerations did not apply to cats and so cats did not become subject in the same way dogs did to local licensing, leashing, and muzzling laws. Humane groups were afraid that, if cats had to wear collars, they would strangle themselves while negotiating small and confined spaces. Muzzling and leashing requirements were thought to be impractical for "a creature that straddled the divide between wild and tame." Although some urban residents disliked cats simply because their reproductive behaviors created local nuisances (and more cats!), the real rub for many stemmed from their belief that uncontrolled cats exerted an unacceptable impact on songbirds.

In Pasadena, California, Davis reports, hostility to outdoor cats, because they arguably were villains who took too many innocent songbirds as prey, ran so high in 1903 that the local humane society called for their extermination. "Of course, I do not mean that people should not be allowed to have cats in their own houses," a representative of the Pasadena Humane Society argued, "but those which run wild should be put out of the way." The moral judgment applied to cats extended further, into the realm of how relations between people should be properly ordered. The local spokesperson for the humane treatment of cats thought that her cat extermination plan would force "cat ladies" to embrace their proper place in society. "I really believe that cats can stand in the way of many marriages (for women), and I have no use for either old maids or the cats they keep" (31).

So, it took some time for domestic cats to become a major and sustained focus of the work of animal protection organizations. Davis (27) captures Katherine Grier's explanation for this:

> The growth of a consumer culture of pet keeping, alongside the development of sulfonamides, parasite control, and antibiotics in the 1930s and 1940s, enabled people and their pets to live longer, healthier lives together in closer proximity. [As a consequence] attitudes toward cats, perhaps, changed the most. In the nineteenth century, some animal protectionists maligned the cat as a semiwild killer of cherished songbirds. Medical advances and new consumer products, such as cat litter in 1947,

> brought cats indoors. By the mid-twentieth century, dogs, cats, and sheltering dominated animal protectionism.

The social and scientific factors at work here are obviously complex (32), but the upshot of the story is clear. The moral precepts and basic operating principles according to which local communities could humanely and successfully manage cats that had strayed from home were well-established and undergoing widespread implementation by the middle of the twentieth century: respect and compassion for each animal; the impoundment of strays; sheltering and medical treatment to prevent suffering; adoption; and euthanasia as a last resort for the cats that could not be rehomed. The development and refinement of this comprehensive program is a major achievement of the animal protection movement and historians have rightly chronicled it as a story in which ideas about how people ought to treat vulnerable members of the human community have been extended to members of the animal community but without so far granting animals full moral and legal equality (31, 32).

Impressive as it was, however, this paradigm of protection still left stray cats susceptible to being killed. This was essentially because, if the cats were caught or trapped but could not be rehomed, dispatching them promptly by methods that were typically brutal was thought to be a good enough way of dealing with them, and more importantly, perhaps, because no-one had persuasively demonstrated that an alternative to killing was available.

This loophole for killing, if you will, did not sit comfortably with moral and ethical arguments that began to be made in the 1960s and 1970s that cats, as well as other animals increasingly regarded as sentient, deserved to be treated with much the same consideration as should be accorded to people (33) or that the animals had an intrinsic and individual right to be "subjects of a life" of their own (34).

Could the protectionist paradigm be extended to cats living beyond the bounds of domesticity? Could it be modified in ways that would institute programs to capture stray and unowned cats, make them healthy, remove their ability to reproduce, and then return them to their worlds to live out their own lives? Such a program would eliminate the killing loophole and reduce the need to kill stray and unowned cats to zero, or perhaps as close to zero as it is humanly possible to get.

THE ADVENT OF TNR

These are the questions that, according to Berkeley (35), began to be asked by veterinarian Jenny Remfry and other members of the Universities Federation for Animal Welfare (UFAW) in England in the 1950s and which by the 1960s had started to receive affirmative answers, albeit based on limited local experience. Just a short time later in 1980, however, it was possible for Celia Hammond, a promoter of neutering and returning to site, to tell a national symposium organized by UFAW in London that the TNR programs Remfry had pioneered on a limited local basis could be recommended for widespread adoption.

Feral cats, Hammond maintained, could be saved from killing by making it possible for them to live in what she called "neutered colonies," so much so that she had abandoned her earlier efforts to obviate the killing of cats by trapping, taming, and rehoming them. The TNR alternative was, she argued, "cheaper, more efficient, more humane, and - not least - more acceptable to the public." She had observed "many hundreds of neutered colonies" with populations and social structures that had been stabilized "without any detrimental effect whatsoever." Similar reports were made in the mid-1970s by a veterinarian in Denmark, commenting on the "reintroduction" efforts being made there by the Society for the Protection of the Cat. Thus, enthusiasm for and adoptions of TNR programs then diffused, Berkeley argues, to the USA and to many other countries (35). The earliest study of TNR done in London dates from 1978 (36).

The subsequent history of TNR is not, however, quite the unalloyed success story that Berkeley envisioned. Although a wide variety of issues surrounding the theory and practice of TNR and its impact on cat behavior has been canvassed in scholarly and professional literature (37), a literature now so large that it is difficult to track, there is no consensus over the applicability and likely success of TNR in various sorts of circumstances. This is not the place to make a comprehensive review of how divided judgments about the utility and value of TNR have evolved.

However, to make a long story short it is now reasonably clear that the success and legitimacy of TNR is not tied to its being a magic bullet that can eliminate cats living outside human sway in most contexts. Its real value lies in keeping alive cats that would otherwise be killed and in suppressing the number of outdoor cats living in and around human communities, where the vast majority of outdoor cats live. It is a way of addressing the local nuisance problems people complain about and it ameliorates some of the wildlife impacts that concern state and national policy makers. A fairly long list of preconditions has to be met to realize these benefits, and they have to be attended to with adequate resources and professionalism. However, animal protection organizations have by now distilled these requirements into manual form and have accumulated considerable experience putting them into practice (38–40). A recent analysis listed almost 40 original research papers describing and evaluating North American experience with the implementation of TNR programs (41).

Experience shows, for example, that there needs to be a welldesigned and adequately funded management program, one that is most likely to not only be implemented by a mix of voluntary individual and organizational efforts and financial contributions but can also and perhaps ideally be carried forward through at least a limited partnership with local governments and their animal control agencies. Dedicated local volunteers need to be available to trap the cats. The cats must be taken to and from a local surgery. The best TNR programs incorporate an adoption component, which has to be established and managed. Ideally, the program will monitor the status of the cats and keep good records of how the cats are faring, and this work with the cats needs to be supplemented with public education and outreach efforts, aimed primarily at helping pet owners to behave responsibly vis-à-vis their pets. TNR is best understood, then, as a methodology for managing outdoor urban and suburban cats that can and perhaps should exist side by side with other interventions more suited to remote locations.

An important key to the success TNR has been able to enjoy in the USA is that the federal government and most states classify cats as domesticated animals, which means that as a legal matter, except where federal statutes for the protection of threatened and endangered species may be implicated, the control and management of cats is primarily a local responsibility (42, 43). Given the high degree of variability in the political complexion of the several thousand general purpose governments in the USA (44), there is a strong likelihood that somewhere in the interstices of this local government system advocacy of TNR by animal protection organizations will find a foothold. If TNR is not palatable in the City of Cordova, Alabama, say, it may still find favor in the City of San Jose, California, and if not in Pecos County, Texas, then in Cook County, Illinois. Overall, a 2013 analysis showed that more than 330 local governments in the USA have acted legislatively to move forward with TNR as a preferred method for managing stray and unowned cats in their local communities (45), and a great many more jurisdictions have active TNR programs even in the absence of explicit authorizing legislation.

The structural attributes of the American federal system of government have thus combined with the vigorous exercise of animal protection advocacy to give variable political expression across the country to feline moral pluralism. In some localities, the majority of public sentiment might support a policy to kill cats that stray beyond the bounds of domesticity and cannot be accommodated by animal control and shelters. In other places, elected officials and shelter directors might respond to public opinion by avoiding killing as much as possible and may aim for a zero tally. Most localities strike a balance that is somewhere in between.

AUSTRALIA: THE EFFECTIVE PROSCRIPTION OF TNR

Federalism has yielded a very different outcome in Australia, however, where there are lots of cats, six states, two mainland territories, and some 550 local governments with various responsibilities for managing cats, as well as a good number of vigorous animal protection organizations.

Standard histories of cat management in Australia show that the impacts of cats on other species began to be observed and commented on as early as 1863 (46–48). Between that date and 1992, however, when the Commonwealth government became a signatory to the Convention on Biological Diversity and listed cats in Australia as a key threat to the conservation of native species, the realization that cats had biodiversity impacts and that they might be substantial made only halting progress. This can be traced through perhaps a dozen key publications that Denny and Dickman usefully listed (49–60). Some of this work was rudimentary, and it took some time for initial observations about the impacts of cats on birds to extend to other animals. But perhaps the most remarkable part of the story, as Denny and Dickman and others tell it (46, 47), is that even after Rolls (54) dramatically publicized the issue in 1969 (54), there was not much in the way of response. Interest in cats and their negative biodiversity impacts did not quicken noticeably in the scientific community until after 1992, eventually centering in the work of the Threatened Species Recovery Hub, a project of the National Environmental Science Program (61).

Two things are clear from this history of interest, concern and research.

The first is that, despite their apparent proclamations to the contrary, governments at all levels in Australia have never taken cat management very seriously, except to see it as an opportunity to kill pests, either by using cats as instruments for killing animals inimical to agriculture or more recently by treating cats themselves as pests and killing them in the interest of saving native species (14).

In its submission to the parliamentary cat inquiry undertaken in 2020 by the Australian House of Representatives, the Threatened Species Recovery Hub described feral cats as being "largely unmanaged," almost 30 years after cats were formally declared to be a biodiversity threat and after plans to abate the threat they posed were supposed to be developed, funded, and at work (62). In a separate publication in the same year, the Hub scientists described domestic pet cats as "ill-governed" (28). Nothing much had apparently changed since a landmark review, published a decade earlier by some of the same principals, said that cat management in Australia, despite a long record of apparent interest and concern, was "in its infancy" (46).

On the face of it, this long-term insouciance about the environmental impacts of cats should have created a scientific and political environment in which TNR could thrive as a potentially viable alternative to killing. Animal protection organizations for their part have long taken an interest in TNR and have been anxious to learn from and apply lessons learned from TNR experiences in other countries, particularly the USA. They have been most especially interested in trying to use TNR to manage human interactions with the outdoor cats that live on the peripheries and in the interstices of the major urban and suburban population centers where the great majority of Australians, and thus the great majority of Australian pet owners, reside. The community cat program developed and advocated by the Australian Pet Welfare Foundation is a paradigmatic exemplar (40).

The second thing that is clear, however, from the history of cat management in Australia is that since a national commitment was made to implement the Biodiversity Convention in 1992, and since subordinate Commonwealth and state legislation was then enacted to give effect to that international legal commitment, TNR has for all intents and purposes been legally proscribed in Australia (14). It is an offense in at least one jurisdiction, namely Queensland, to give sustenance to animals formally declared to be a biodiversity threat. And under long-standing animal control legislation in some other Australian states, returning cats to live their lives after they have been treated through a TNR program could be prosecuted as illegal abandonment.

Animal protection organizations, most notably the Australian Pet Welfare Foundation, have nevertheless taken the risk of launching a handful of TNR programs in these legal shadowlands, while also pleading for permission to practice TNR more openly. However, they have not so far prevailed for the most part against what appear to be increasingly entrenched perceptions about cats in Australia.

The view persists in the community of conservation biologists in Australia that TNR is simply unsuited to the environmental conditions that Australians, who save for the aborigines are themselves immigrants, have created on the continent. The descendants of the cats the first settlers brought with them in 1788 are, so the argument goes, so numerous by now, so widespread across the continent (63), and so successful at reproducing and competing with native species that the prospect of releasing them after they have been captured as part of a TNR program is unconscionable. It would also cut against the grain of the perception that Australia has made solemn commitments under international law to make the conservation of its remaining native species a top policy priority at all levels of government (14).

So, it has become, in effect, an article of faith among people outside the animal protection movement in Australia that TNR is, if you will, insufficiently Australian to be good policy and practice for Australia. This is a view that the recent parliamentary inquiry on cats in Australia summarily endorses in its report (25). The report does this without any apparent regret that an opportunity to explore TNR as a viable, locally adapted alternative to a crude blanket policy of trap and kill might be missed. This conclusion is reached notwithstanding the fact that by all accounts, both those published more than a decade ago (46) and those appearing just within the last year (28), a predominant reliance on killing cats has not so far produced much in the way of positive results for Australia's native wildlife, save in the unusually controlled conditions that can be created on some islands and behind fences (12, 64). That has been the experience in New Zealand, too (65).

A breakthrough might occur with the invention and deployment of new poison delivery systems, although that appears to be at best a fraught proposition (28, 29, 66), because of public opposition and difficulties with targeting, or with an advance in genetic engineering, but that has major problems of its own (67).

THE AVOIDANCE OF STALEMATE: REIMAGINING RESIDENT SPECIES?

An objective observer might be forgiven for concluding that in Australia at least the contest between advocates for and opponents of TNR has reached a stalemate.

An effort has recently been made to set out as a hypothetical exercise the terms and conditions under which questions about whether TNR might work in Australia could be resolved through cooperation and goodwill and a research program endorsed and participated in by all sides (19). However, the new parliamentary inquiry report on cats and wildlife in Australia (25) does not embrace this idea. The people associated with the Threatened Species Recovery Hub reject it, because they continue to insist that, given Australian conditions and declared policy ambitions for native species, TNR is biologically, environmentally, ethically, and economically flawed (68). Animal protectionists are unlikely to find it attractive because it gives too little credence to good research work that they have already done on TNR, and it sanctions, unnecessarily and inappropriately so in their view, too much killing of cats.

Unless, then, there is a fundamental shift in the grounds on which both scientific and political disagreements about how to manage human interactions with cats living outside the home in Australia might be mitigated, it is hard to see how parties contending over the practice and promise of TNR can avoid a future in which they continue to throw occasional grenades at each other in the pages of academic journals and in legislative lobbies, and the winner will turn out to be whichever side can best withstand and afford the resulting political attrition.

One alternative way forward was sketched by environmental scientists in Australia and New Zealand about 50 years ago. In 1973, two ecologists studying the Maori rat (kiore), which was brought to New Zealand in the canoes of Polynesian immigrants, long before the advent of European settlers, observed that the animal was being referred to as native, even though it was introduced. It had, they wrote, "even crept into the ranks of desirable native wildlife, vying with such elite as the tuatara and saddleback for protection on select island refuges." Could an introduced rat "with but squatter's rights aspire [to native status], and how much longer must later introductions await similar recognition?" This country, to paraphrase what they wrote, "will [not] come of age ecologically [until] Western man and his animal introductions are regarded as part of the natural environment" (69).

This prompted Carolyn King, a world-renowned student of the ecology of pest management, to say in 1990 that "It is time that the native and introduced mammals [in New Zealand] were treated in practice as *resident species* of equal status in the scientific sense (emphasis added)." This would recognize, she argued, that Europeans now live in the country but that they have become, along with the animals they brought with them, including the cat, part of "a working, evolving community.…[that] will continue to evolve according to natural processes largely beyond our control" (70).

Essentially, the same point was made by Arthur Bentley who in 1978 published an analysis of the consequences flowing from the introduction of deer into south-east Australia. Being un-Australian in origin, he wrote, the deer "are considered not quite right for the country." On the other hand, the deer living in the south-east Australian bush represented, in the late 1970s, "a valuable and irreplaceable asset," and treating them as exotics that should be eliminated was "sheer humbug." How could a "white exotic human," conjuring up a "Dreamtime environment" that needed to be preserved, condemn to elimination a species he or she was never likely to see (71).

There is, in other words, some malleability to the notion of what constitutes a native species and a good deal of leverage to be had from reimagining both native and introduced animals simply as currently resident species, living alongside the immigrant settlers whose descendants are now also residents of Australia. When Carolyn King went to New Zealand from Oxford in the early 1980s to study the impacts of introduced stoats on native wildlife, she did not, however, find much interest in seeing stoats as residents, which prompted her to observe that the desire to protect the animals the stoats were eating did not adequately take account of the fact that but for human bungling and mismanagement the stoats would not be a problem in New Zealand at all (72).

THE AVOIDANCE OF STALEMATE: TURNING TO ENCLOSURE?

Given the zealousness with which conservation biologists strive to protect what they choose to regard as native species, and given that they have vigorously advanced a political agenda to recreate a biodiversity ideal their ancestors in the antipodes long ago abandoned, for what they thought at the time were good and sufficient reasons, the idea of now reimagining cats as residents, equal in status for scientific and policy purposes to the animals that were living in Australia in 1788, when the first white settlers arrived and brought various animals with them, may not prove attractive to conservation biologists any time soon (73).

Meanwhile, the native species they care most about remain under threat, and three decades after it began in earnest the effort to manage the contribution outdoor cats make to that threat continues, by their own admission, to languish, with bright spots only here and there. The analysis and recommendations offered up by the recent parliamentary inquiry to correct this situation have already been declared to be interesting and perhaps even in some ways promising, but in a fundamental sense inadequate (74).

The principal spur to a more determined and sustained campaign against cats was supposed to be an unimpeachable calculation, or ultra-sophisticated statistical estimation at least, of exactly how many cats exist beyond the bounds of domesticity in Australia, where they live, what they eat, and what proportion of their diet consists of native species (28). The strategic gamble on the part of researchers chasing these numbers was that the impacts of cats on native species, once they were properly quantified, would prove to be so large and so pervasive across the country that the wisdom of killing cats in large numbers—perhaps as many as two million dead cats from a vigorously prosecuted eradication conducted in accordance with the official Threatened Species Strategy (14)—would be self-evident. There is not much doubt that Australia now has better numbers about the cats who live there in various contexts, and about what the outdoor cats eat, than any other country in the world. However, as the report of the parliamentary cat inquiry reveals, there is a lot more to making socially licensed policies for cat management than the imaginative generation of good numbers about cats and their impacts. In this context, there is a quickening interest in enclosure.

There are at present, for example, only a limited number of reserves on the continental mainland of Australia in which native species are favored and from which cats are excluded, whether by fencing or some other means (64). The report of the parliamentary cat inquiry (25) endorses a Project Noah to create more such reserves, although the details of how and where that policy would be carried out, particularly in mainland Australia, what it would cost, and what relevance it might have for urban and suburban rather than bush and outback landscapes on the continent remain to be determined.

Whatever the details turn out to be, this strategic turn to make the tighter enclosure of threatened native species a featured addition to the toolbox used to manage the impacts cats have on those species is an important acknowledgment that killing cats cannot be relied upon to get the job done. The argument a decade ago was that "in the absence of any other long-term eradication programs for cats on the mainland, exclusion fencing has proved to be effective for the protection of many vulnerable and endangered species" (46). However, the evidence adduced for this at the time was anecdotal, the methodologies for effectively excluding cats and other predators, such as foxes, from fenced enclosures were unsettled, and the preference for eradication as a first resort was undiminished (46).

A decade ago, in other words, reserves where threatened species would be protected behind fences were an exceptional remedy for the cat problem and no more than a fallback from killing cats. It is hard to see the turn to featuring protected reserves as a mainstream public policy for managing human-cat interactions in Australia as anything other than a strategic retreat from cat eradication, and at the very least, it signals a growing awareness that the dividends from paying closer management attention to species at risk are probably greater than a single-minded focus on killing cats. The best numbers show that "over 300,000 feral cats are killed (in Australia) annually, with much of that effort happening outside the traditional conservation sector" (75). That is not a rate of kill sufficient to control, let alone eradicate, the "1.4 to 5.6 million feral cats in the Australian bush (depending on recent rainfall patterns through the arid zone)," to which must be added the 0.7 million living in towns and cities (28).

A second and perhaps even more radical exploration of enclosure as a way out of the stalemate that now seems to mark cat management appears in work on the management of Australian pet cats that was published just as the recent parliamentary cat inquiry was getting under way (28):

> For pet cats, given enough political and public support, the available technical solutions for reducing impacts are simple; responsible cat ownership includes actions such as early age desexing, keeping pets indoors or in a securely contained outdoor area, and designating suburbs adjacent to high conservation-value areas as cat-free. Reducing the numbers of feral cats living in towns and cities is more challenging, but tighter management of

> refuse and sites of high food subsidy should reduce cat numbers substantially. As well as reducing cat impacts on 'urban' wildlife, reducing the numbers of pet and feral cats wandering at large will also reduce transmission rates of cat-dependent pathogens.

Although there is much to be said for responsible cat ownership, which has been central to the agenda of animal protection organizations for decades, it is not by any stretch of the imagination a straightforward "technical solution" to the problem of managing pet cats. Nor is it "simple." The veterinary costs alone of fully implementing responsible cat ownership can be substantial and the ability to pay them is unevenly distributed amongst documented cat owners, which is why many of them do not incur such costs, even if they can be persuaded that it is the right thing for cat owners to do, and even if local legislation requires it.

Moreover, in Australia, as elsewhere, only a limited number of people who are the documented owners of cats live in homes capable of providing "securely contained outdoor areas" for the enclosure of their pets. One might even say that for people who live in apartments and other multifamily dwellings that is an insensitive recommendation. Tightening up the rules of enclosure for cats living "at home," and dealing more aggressively with outdoor cats living near towns and cities, or adjacent to high value conservation areas and refuse sites, will also have substantial enforcement costs. The exact magnitude of these remains to be estimated but whatever they are they will cut against the likelihood that managing cats through more rigorous enclosure will find "enough political and public support" to achieve social license.

A decade ago, the prospect of tighter rules of enclosure for cats kept as domestic pets was barely a blip on the radar screen of conservation biologists looking for ways to protect native species. Denny and Dickman, for example, briefly observed that "the control of owned, domestic cats is an important aspect for the control of all cats on the Australian mainland," (46) and literally left it at that.

The very much more pointed recommendation now from the principals associated with the Threatened Species Recovery Hub is that for all intents and purposes long-standing and socially accepted understandings of what it means to own a cat as a domestic pet, both for the owner and for the pet, need to be redefined or renegotiated so that all documented owners are required to sign up for, finance, and in the first instance enforce a full array of regulatory measures, the sum and substance of which is that no matter the circumstances in which they live their lives pet cats will no longer be able to roam.

The likelihood is, however, that this will be a step too far for most of the people who are the documented owners of the 3.8 million cats now estimated to live in Australian homes (28), including the farmers who still rely on them for pest control. It is not, on its face, a policy that is consistent with the welfare of the animals to be enclosed (4, 76). Also, it is an imposition on pet cats and their owners that could almost certainly be avoided if proper steps were taken, with the help of TNR, to reduce the number of cats who pose a threat to biodiversity because they do not live at home.

Between the total incarceration and the total non-confinement of cats, one imagines that there is a middle ground, so far largely unexplored in any systematic way, in which it becomes clear, much clearer than it is now, what Australian and American landscapes, and other landscapes too, would look like if the presumption that cats only belong indoors under strict human ownership and control was abandoned.

CONCLUSION

We have made great strides, particularly since the 1950s, in examining carefully and coping more effectively with those human-cat interactions that occur beyond the bounds of domesticity. We know more than ever about the dynamics that shape such interactions and what their wider impacts are, especially on other species. However, this greater knowledge has not yet yielded any settled reconciliation of the different moral imperatives people think should govern our relationships with the cats that do not live at home.

Clearly, the ones that do get away, for whatever reason, and then live off the land, as they can do, exact a toll on other species, and that may cascade into ecosystem effects. What moral judgment should we make about that price, which would not have been exacted at all if settler societies had not introduced cats to new worlds, in an effort let it be said to make the settlers feel comfortable in worlds to which they were also new? Is it a price worth paying if both some of the cats and some of their prey remain alive, and continue to coevolve? Or are we morally obliged to restore the *status quo ante*: to worship, as David Lowenthal has it, at the altar of a biological purity which is to be saved at almost any cost from contamination by introduced aliens. We are still struggling to find the answers to these questions, although Lowenthal himself was quite clear that indigenous purity is neither possible nor desirable (77):

> Nature and culture alike generally benefit from creative intermingling. Ex-colonial Jamaica, for example, readily domesticates what is alien. Since the seventeenth century, trees, grasses, crops and flowers brought in from the East Indies, Africa, North America and Europe have spread throughout the island. Do Jamaicans resent this riotous medley for displacing native flora? Quite the contrary; they rejoice in it as intrinsically Jamaican. They celebrate the commingled fragments of manifold ecologies enhanced by exotica from every land.

It is reasonable to infer that Lowenthal would have wished Australians could feel about their cats the same way that Jamaicans feel about their plants: that the cats have become intrinsically Australian. Years ago, he retold a story about a playwright who in the 1930s had converted a scruffy patch of New England land into a fine country estate. The playwright was visited by a preacher who congratulated his host on the beautiful place he had built, him and God together. "Yes," the host replied, "and you should have seen it when God had it all to Himself" (77). We cannot go back, either in Australia or in any other country, to days when God had it all to himself. If we want to find places where all cats can live lives of their own in the different worlds people have made for them in different places around the globe, it will do no good to pretend that by completely enclosing cats, whether in homes or in fenced enclosures, we will have found ways to solve the cat problem that are acceptable, enduring and consistent with the nature of cats as animals.

AUTHOR CONTRIBUTIONS

GW-S drafted the article. JL, WL, JR, SR, JS, and PW listed have made a substantial, direct and intellectual contribution to reviewing and revising the work, and have approved it for publication.

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Providing Humans With Practical, Best Practice Handling Guidelines During Human-Cat Interactions Increases Cats' Affiliative Behaviour and Reduces Aggression and Signs of Conflict

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The importance of animals' experiences and associated comfort during Human-Animal Interactions (HAI), and particularly Animal Assisted Interventions (AAI), are increasingly recognised. However, there remains a paucity of published research, particularly concerning less formal but frequent HAIs to which companion animals are typically exposed, such as stroking or petting. Additionally, few practical evidence-based guides to facilitate humans' optimal animal handling and interaction in these contexts exist. A simple set of Human-Cat Interaction (HCI) guidelines were therefore created, with the aim to enhance domestic cats' comfort during generic HCI contexts. Based around a "CAT" acronym, guidelines focused on providing the cat with choice and control ("C"), paying attention ("A") to the cats' behaviour and body language and limiting touch ("T"), primarily to their temporal regions. Guidelines were presented to human participants during a brief training intervention, and guideline efficacy was subsequently assessed. Domestic cats available for rehoming at Battersea Dogs and Cats Home, UK ($n = 100$) were filmed during interactions with novel members of the public ($n = 120$). Cats were exposed to a maximum of six, 5-min interaction sessions, balanced across "control" (interactions with humans pre-training) and "intervention" conditions (interactions with humans post-training). For each observation, cat behaviour and posture were coded and humans' cat-directed behaviour rated on the degree to which it reflected best practice principles. Data were extracted from a total of 535 observations and average human interaction ratings and cat behaviour values compared between control and intervention conditions via paired Wilcoxon tests. Compared to the control, humans' interaction styles were rated as significantly more closely aligned with best practice principles in the intervention condition. Cats also displayed significantly greater frequencies and/or durations of affiliative and positively-valenced behaviours in the intervention. In contrast, cats in the control displayed significantly greater frequencies of human-directed aggression, in addition to greater frequencies and/or durations of behaviours associated with conflict and negative valence. Results demonstrate the positive impact of practical interaction guidelines on cats' social behaviour and comfort during HCI, with the potential to improve cats' general experiences during interactions, reduce human-directed aggression and ultimately improve cat-human relationships.

Keywords: human animal interactions, animal assisted interventions, cattery management, petting, gentling, felis silvestris

INTRODUCTION

As scientific interest in the value of Human Animal Interactions (HAIs) grows, our understanding of their dynamics and associated impacts to both human and animal parties increases. Over the past several decades, pet ownership and various forms of HAI, including Animal Assisted Interventions (AAIs), have been investigated for their potential benefits to humans' physical and mental health, in addition to their support of children's learning, literacy and the development of prosocial behaviour [see reviews by Barker and Wolen (1), Brelsford et al. (2)]. In this regard, however, the general body of literature remains largely anthropocentric, with considerations for animals' perspectives in HAI contexts gaining traction comparatively recently [e.g., (3, 4)]. Historically, investigation into the impacts of HAIs on animals has been limited to agricultural contexts, with a heavy emphasis on animal productivity and predominantly negative aspects of wellbeing, such as stress, fear and anxiety [e.g., (5–7)]. Few studies have sought to investigate the benefits of HAIs for animals or explored the impact of HAIs on companion populations.

Despite their limited representation within welfare-based HAI literature, companion animals' social significance within human society [e.g., (8, 9)] means their interactions with humans likely represent a substantial portion of all HAIs taking place. For species such as domestic cats, the majority of these HAIs likely occur with their caregivers in the domestic home or animal rescue/rehoming environment. During HCIs, cats can be observed displaying a range of affiliative behaviours (e.g., a vertically raised tail on approach, purring, kneading and rubbing against the person), which are generally assumed to be indications of their enjoyment of, and willingness to participate in, HCI (10–12). In both home and rehoming centre contexts, cats may also show preferences for human interaction over food and toys (13), suggesting the potential value of HCI to individuals.

However, it is not appropriate to assume that HCIs are always of mutual benefit to both parties. For example, the relatively high occurrence of cat human-directed aggression amongst cat-owning households (14–16) is potentially indicative of cats' discomfort during HCI. In a large survey of Brazilian cat owners (15), cat aggression was reported by almost 50% of respondents and was most likely to occur in situations where owners were directly interacting with their cats in a social context (such as during petting or play). Aggressive responses were also more likely to occur amongst cats described as "disliking" petting. At the same time, a lack of aggressive response does not necessarily imply enjoyment, or an absence of negative experience for the cat, as significantly higher faecal cortisol metabolite levels were found amongst cats that were described as "tolerating" rather than actively "liking" or "disliking" being stroked (17).

Cats' desire for, and experiences during HCI are likely to be context dependent and moderated by their individual characteristics (such as temperament), in addition to the behaviour and characteristics of the human. For example, in novel environments or stressful situations, cats tend to seek out physical places of safety and security (18), and even otherwise friendly cats may prioritise these resources over social interactions with humans, particularly during periods of habituation. In a shelter environment, both fearful and frustrated cats may benefit from regular HCI, but only if humans are perceived as a positive (non-threatening) stimulus [e.g., (19, 20)]. Otherwise, human proximity and associated HCI may have negative, or at the least less positive, impacts on well-being [e.g., (19, 21)], particularly if the cat does not have the option to effectively "opt in" or "opt out" of the HCI [e.g., (19)].

Cats are also likely to value choice and control during HCI and to prefer humans that are sensitive to their behavioural responses and associated needs. Amongst well-socialised cats, individuals tend to prefer to interact with humans that do not approach them when they are resting, nor follow them when they are attempting to retreat, but instead adopt a lowered (cat height) position and vocalise to them [e.g., (22)]. Cats also tend to prefer HCI that they themselves initiate, and will respond more positively to humans that are generally more responsive to their requests for interaction (23). Finally, cats appear to have preferences for the regions of their bodies that are touched during HCI. Stimulation of cats' temporal regions is likely to induce more positive responses, whilst stimulation of the caudal region may have the opposite effect (11, 24). In contrast, stimulation to the cats' perioral, flank, stomach, and back areas may show more varied responses, depending on the their individual preference (11). The provision of sufficient autonomy and the importance of observing animals' reactions during HAI are thus fundamental to ensuring relationships with humans have a positive impact on animals (25).

With the growing popularity of cats being included in HAI outside of the domestic home, cats are being exposed to HCI across increasingly diverse landscapes, in novel environments, with novel people. For example, the involvement of cats within both educational and therapeutic forms of AAI appears to be on the rise. These range from cats being placed with families to provide social and emotional support to children diagnosed with Autism Spectrum Disorder (26), to cats housed in shelters being visited and read to by children [e.g., (27)], and cats visiting care facilities to provide emotional and physical health benefits to the ill and elderly (28, 29). Initially a Japanese phenomenon (30), the growing international popularity of Cat Cafés present an additional (non-interventional) context, where cats are exposed to HCI for humans' benefit. Concerns over the negative impacts of Cat Cafés to cats (e.g., due to their being constantly handled by unfamiliar humans) have been raised (31, 32). Similar sentiments are also increasingly echoed in relation to the broader welfare implications of the inclusion of both companion and non-companion animals in HAIs such as AAI (33, 34), but also animal-based tourism (32).

To ensure HCI are enjoyable for cats, an understanding of their desire for, and preferences during, HCI are crucial. Evidence-based guidelines that translate these preferences into practical, species-specific and easy to implement actions are however missing, particularly outside of formal veterinary handling contexts [e.g., (35, 36)]. The development of simple, generic cat-interaction guidelines could therefore be extremely useful in supporting cats' well-being and enjoyment during all forms of HCI, including those that occur in the domestic home and rehoming centres, but also those taking place in interventional (i.e., AAI) and other tourism based contexts (e.g., Cat Cafes).

The purpose of the current study was to therefore test the efficacy of a set of "best practice" informed human cat-interaction guidelines, when introduced to humans during a brief training intervention. Efficacy was primarily determined via the objective quantification of cats' behavioural responses during HCI, focusing on their human-directed social behaviour (both agonistic and affiliative), as well as more general indicators of comfort (e.g., behaviours linked to positive and negative affect and/or conflict). To maximise general efficacy, the guidelines were designed to be sufficiently generic to enable cross-context application and to be usable by individuals without professional knowledge of cat behaviour. For this study, we therefore assessed guideline efficacy when applied by general members of the public within a rehoming centre context. This provided the additional benefit of easily controlling for human-familiarity and environmental effects during HCI. Given that cats' temperament can differentially mediate the well-being impact of HCI in shelter settings (19), we also sought to determine whether individuals might benefit more or less from humans' implementation of the guidelines, depending on the cats' temperament. For example, cats with emotional predispositions toward anxiety and/or frustration during HCI, might be predicted to respond relatively more positively (or at least less negatively) when humans followed the guidelines. In contrast, highly gregarious cats might be less sensitive to differences in humans' handling styles and therefore show little difference between conditions.

Overall, the guidelines encouraged a more hands-off or restrictive approach than most people might prefer when petting cats. In the rehoming context, the initial HCI between prospective adopters and cats are likely crucial to peoples' decision making. Therefore, to ensure that the guidelines could be effectively applied in this context without negatively affecting rehoming rates, we also sought to assess their effect on peoples' perceptions of individual cats during HCIs.

Specifically, our aims were to:

i) Determine whether the training intervention had a positive impact on the general handling styles cats were exposed to (i.e., did intervention handling align more closely to best practice principles, compared to the control?)
ii) Determine whether the training intervention had a positive impact on the behavioural responses of cats during HCI (i.e., did cats respond more positively and less negatively toward participants in the intervention condition?)
iii) Determine whether the temperament of the cat moderated the impact of the intervention on their behavioural responses (i.e., depending on their temperament, did some cats display relatively more positive and less negative behaviours in the intervention condition?)
iv) Determine whether adherence to a potentially more restrictive form of HCI might negatively impact humans' impressions of cats (i.e., did participants rate cats less positively during the intervention condition?).

METHODS

All supplementary materials are available via https://doi.org//10.6084/m9.figshare.14828397.

Development of the "CAT" Interaction Guidelines

The interaction guidelines were developed by author LF and aimed to reflect current best practice methods of interactions with cats, informed by a combination of expert opinion (e.g., LF and colleagues) and the (limited) published evidence on this topic [e.g., (11, 22–24)]. Based around a "CAT" acronym, the guidelines aimed to provide a memorable and easy to implement set of instructions for people to follow during all HCI contexts, with the exception of situations requiring specific handling for formal veterinary procedures or specific husbandry activities. The "C" represented providing the cat with Choice and Control during the HCI, enabling them to both "opt in" and "opt out." The "A" encouraged people to pay attention to the cats' behavioural and postural responses during interactions, and to moderate their behaviour accordingly. The "T" encouraged people to restrict their touching of cats primarily to the cats' temporal regions (see **Table 1**).

Data Collection

Data collection took place at Battersea Dogs and Cats Home, Battersea, London, UK between 20th January and 13th March 2020 and was carried out by authors LF, RFW, CH and JP. Participants were recruited on a voluntary basis via an online advert circulated on social media, with a similar version also sent directly to Battersea's LinkedIn contacts. Participant contact details were collected for the purposes of arranging testing slots only. Upon arrival, each person was allocated a reference number so that the subsequent study data collected could be fully anonymised. Participants were given a short verbal introduction to the study but were not told of the

TABLE 1 | A summary of the key principles of the "CAT" interaction guidelines explained to participants during the training intervention.

C choice and control	**Provide the cat with choice and control during the interaction** • While remaining in your seated position, gently offer your hand to the cat, allow the cat to approach you, and let them choose if they want to interact with you or not • If the cat wants to be touched, he or she will rub against you. If they don't make contact, avoid stroking the cat • Allow the cat to move away from you if they choose, and don't be tempted to follow after them • Allow the cat to control how much you stroke them. If stroking the cat, briefly pause every 3–5 s to "check in" with the cat–when you stop stroking them, do they rub against you to ask for more? If not, they may be ready for a break
A attention	**Pay attention to the cat's behaviour and body language** The following are signs that the cat may need a little break: • The cat turns it head or moves away from you • Their ears become flattened or rotate backwards • They shake their head • The fur on their back appears to ripple • They lick their nose • They go a bit still, and stop purring or rubbing against you • They sharply turn their head to face you or your hand • They suddenly start grooming themselves, lasting only a few seconds • Their tail twitches or 'swishes' vigorously, usually when held horizontally or close to the ground
T touch	**Think about where you're touching the cat** • Most friendly cats will prefer being touched at the base of their ears, around their cheeks, and some also under their chin, so try to stick mainly to these areas • Avoid the base of their tail and tummy, and be cautious then touching the cat's back, flank, legs, and tail–pay close attention to their body language to see if they appear comfortable

specific study aims (i.e., to investigate the impact of the training intervention on cats' behaviour). Participants were asked to complete a short survey that included very basic demographic questions (i.e., age and gender), in addition to several questions about cat ownership and experiences with cats. The second part of the questionnaire included the 44-item Big Five Inventory (BFI) to assess human personality (37) (see **Supplementary File 1** for a copy of participant questionnaire). Data extracted from this questionnaire is currently being analysed for inclusion in further publications. Participants visited six different cats, three prior to and three after receiving training on the "CAT" guidelines. These conditions reflected the "control," and the "intervention" conditions, respectively.

Cat and Human Demographics

A total of 114 cats were initially included in the study. Almost all cats (93%) were neutered at the time of testing. Forty two percentage were male and 58% were female, with an average age of 6.1 years (sd 4.3 years). With the exception of 4 cats (a British short hair, Somali, Burmese, and Ragdoll) all study cats were domestic short or semi-long haired (see **Supplementary Data 2** for full details).

A total of 120 participants took part in the study, the vast majority of which were female (90%). Ages spanned the following ranges, 18–25 (9%), 26–35 (30%), 36–45 (25%), 46–55 (21%), 56–65 (12%), and 66–75 (3%), and 57% of participants currently lived with at least one cat. To reduce the collection of unnecessary sensitive data, no further demographic information were collected from participants.

Test Protocol

Control Condition

Participants visited three different cats for 5 min each. They were initially presented with a brief instruction sheet explaining the protocol (**Supplementary File 3**) before being instructed to quietly enter the cats' pen and to then sit in the corner nearest to the door, facing diagonally toward the back corner. Optimal camera placement and participant positioning was determined during piloting. Two GoPro HERO7 cameras were subsequently mounted on flexible mini tripods and attached (roughly 1–1.5 m from the ground) to the front and back sections of each cats' pen, facing inwards and angled downwards, in order to capture the whole area of the pen. The control condition was designed to encourage relatively "naturalistic" interactions between humans and cats, whilst ensuring the cat was protected from handling that might cause them distress or lead to participant injury. Participants were therefore instructed to interact with the cat as they usually would, without picking the cat up or restraining them, and to remain in their seated position for the duration of the test. This ensured that if the cat chose to retreat or hide during the HCI, they could do so without the risk of being disturbed. To reduce external visual and acoustic disturbance during tests, sessions predominantly took place on the cattery floors that were off-access to the general public. In the rare cases where cats located on the public floor were used, this occurred during quieter periods of the day. Once the test began, a dark curtain was placed over the door of the cats' pen to reduce the impact of external disturbance. For infection control purposes and to remove the scent of previous cats, participants were instructed to sanitise their hands with Anigene (Medimark Scientific) hand sanitiser in between cats.

Intervention Condition

Following the control condition, participants were exposed to a short training intervention. This consisted of a 5-min educational video created by LF (**Supplementary Video 4**), explaining and visually demonstrating the CAT guidelines (**Table 1**) whilst a cat was present. Participants were then presented with an instruction sheet (**Supplementary File 5**) that further highlighted key points of the CAT guidelines. Following the training, participants visited three additional cats using a similar test protocol to the control condition, with the expectation that they were requested to follow the CAT guidelines. As a further prompt, and to encourage compliance during HCI, a laminated poster containing the CAT acronym was attached to the wall in the cats' pen during each test (**Supplementary File 6**).

Experimental Set Up

Each cat was housed singly in a pen measuring approximately 2 × 3 × 1.5 m. All cats were provided with a litter tray, several concealed areas (one elevated and another at ground level, located in the back section of their pen), blankets, toys, a scratching post, and water. Cats were fed and provided with a clean litter tray twice daily. Cleaning, feeding and opportunities for human interaction followed a predictable daily schedule. On test days, cats were not provided with opportunities for human interaction outside of those occurring during feeding and cleaning. This was to standardise the amount of social interaction to which test cats were exposed and to avoid possible carry over effects from interactions with staff or volunteers prior to testing.

Participant Inclusion Criteria

Participants were required to be aged 18 or over, comfortable interacting with cats whilst sitting or kneeling on the floor for short periods of time and also willing to travel to Battersea on an agreed date and time.

Cat Inclusion/Exclusion Criteria

Cats were required to be >6 months of age and physically healthy (i.e., not currently in pain or experiencing any acute health complaints). At the time of testing, cats needed to have been occupying their respective pen in the cattery for a minimum of 48 h to support initial habituation/acclimatisation to the cattery environment [e.g., (38, 39)]. Cats deemed notably stressed, unsettled or uncomfortable were not enrolled in the study on welfare grounds, and to ensure sufficient HCI data could be collected (given such cats would likely remain hiding for the duration of the test, irrespective of human interaction style). For inclusion, cats had to be deemed well-socialised to humans and considered suitable to be rehomed to live with humans as a companion (i.e., rather than requiring a "non-pet" outlet such as a farm).

Cat Testing Order

All cats were tested between 9 a.m. and 3 p.m. to avoid feeding and cleaning times. Cats were tested in blocks of 12, over the course of two consecutive days, receiving 6 tests in total and 3 per day, each time with a novel participant. As time of day could potentially impact on the cats' behavioural responses during HCI, and the number of previous cats a person had visited (i.e., 0 compared to 5) might impact on the participants' behaviour toward a cat, these factors were controlled via a complete balanced block design [e.g., (40)]. Additionally, condition order always alternated between a "control" and an "intervention" with a minimum break of 1.5 h between each test per cat to control for potential carry over effects between tests. To provide sufficient numbers of cats for each block of testing, 17 cats were exposed to a second set of 6 tests, with a minimum break of 1 week in between testing blocks.

Cat Ratings

After visiting each cat, participants were asked to complete a form (see **Supplementary File 7**) where they rated each cat on a 5-point Likert scale for (i) how friendly and (ii) how comfortable they found the cat, in addition to (iii) how likely they would be to choose that cat if they were considering rehoming one.

Cat Temperament Assessment

To determine whether cat temperament might mitigate or mediate any impact of the CAT intervention on cats' behavioural responses, cattery staff filled out an L-CAT questionnaire for each cat enrolled in the study (**Supplementary File 8**). The L-CAT is a validated (i.e., demonstrated convergent, discriminant, and predictive validity), reliable (i.e., demonstrated inter, intra-rater and temporal stability) and practical tool which provides cats with three scores based on their perceived level of friendliness, fearfulness, and tendency toward frustration in the context of HCI (41).

Behaviour Coding

Human Behaviour

To ensure that participants' interactions with cats changed in line with the "CAT" guidelines following the training intervention, a simple human handling score was assigned to each participant for each observation. The score reflected the degree to which the participant was judged to be interacting with the cat in a way that aligned with the best practice principles of the "CAT" guidelines (3 = closely, 2= somewhat, 1 = not at all).

Cat Behaviour

Videos were divided between authors CH and LR. Forty seven aspects of cats' behaviour were coded across all videos in BORIS coding software v. 7.9.8. (42), using a specially developed and thoroughly piloted ethogram (see **Supplementary Data 2** for the full list of behaviours and their operational definitions). The ethogram was informed by previously published work and was designed to capture a range of practically codeable and easily standardised measures, typically associated with either positive or negative valence in domestic cats in social contexts [e.g., (11, 24, 36, 43–45)]. These included human-directed social behaviours (both affiliative and agonistic), in addition to relevant postural and behavioural indicators of comfort (e.g., behaviours associated with negative arousal, relaxation and positive arousal). The ethogram also included two codes (Zones 1 and 2) that were used to quantify the position of the cat relative to the human. Zone 1 represented the first third of the pen where the cat was mostly within touching distance of the participant. Zone 2 represented the rest of the pen, furthest away from the participant where the cats' main hiding and sleeping areas were located. Zones could be easily visually discriminated for standardisation, due to three equally sized glass panels positioned along the length of the pens. Duration of time the cats' head, tail, and body could not be coded (due to limited visibility) were also measured and later used to transform relevant behaviour measures into proportion data (see further). Depending on the specific nature of the behaviour, behaviours were coded as frequencies (e.g., approaches person), durations (e.g., crouch/tense posture) or as both frequencies and durations (e.g., tail wave) (see **Supplementary Data 2** for ethogram details). Video eligibility for coding required the cat to be visible for a total of at least 2 min out of the 5-min test duration and to have at least one observation for both the control and intervention conditions. With the exception of the videos coded by a second coder for inter observer reliability (see further), the majority of videos could not be blind coded for several reasons. The primary coder (CH) was involved in the data collection process and was therefore aware of cat testing orders. Additionally, the CAT guidelines attached to the wall during the intervention condition (to act as a "prompt" for participants) were clearly visible within most videos, and therefore this condition was easily identifiable to those familiar with the test protocol (e.g., CH).

Inter-rater Reliability Coding

A sample of 20 videos coded by CH were pseudo-randomly selected for inter-rater reliability coding, ensuring an equal number of "control" and "intervention" conditions were included, and that each video was of a different cat. Selected videos were blind coded by LR (who was unfamiliar with the test protocol).

Data Preparation

Collapsing of Measures With Low Occurrences

To provide a more detailed, exploratory picture of potential differences in cats' behavioural responses between conditions, we opted to avoid the collapsing/grouping of behaviour variables prior to analysis where possible. However, due to the relatively low individual occurrence of frequency-based behaviours linked to conflict/negative affect ($n = 6$, see ethogram in **Supplementary Data 2**) within both conditions, it was necessary to collapse these variables into a "conflict" composite score, so that their values could be analysed statistically. For the same reasons, this process was also undertaken for frequency-based measures relevant to agonistic behaviour ($n = 3$), creating an "agonistic" composite score (see **Supplementary Data 2** for further details of measures). A total of 40 cat behavioural measures were therefore assessed, including their inter-rater reliability, in addition to the human-handling ratings.

Creation of Averaged Measures for Each Condition

To account for potential inter-individual variation in human handling and human perceptions of cats within conditions, single averaged scores were generated for each cat for human-handling and human cat-ratings, in both the control and intervention conditions.

Behaviour measures retained post-reliability analysis (see further), were transformed into proportion data based on the duration of time each measure could be coded within each video due to the cats' visibility. Average proportion values were then generated for each cat for both the control and intervention conditions (see **Supplementary Data 2** for full dataset).

Cats With Missing Data

Excluded Cats

Of the 114 cats initially included in the study, 14 were subsequently excluded from the dataset due to (i) being visible for <120 s for each of their observations ($n = 6$), or (ii) not having at least one observation from both the control and intervention condition. The latter occurred due to early removal from the study for health and welfare reasons ($n = 4$), the cat being rehomed ($n = 2$) and concerns for participants' safety ($n = 2$).

Included Cats

From the remaining cats ($n = 100$), a total of 586 videos were coded. Of these 100 cats, 30 did not have a full set of 6 observations, due to video camera malfunction ($n = 5$), early removal from the study due to rehoming ($n = 5$), health or welfare reasons ($n = 3$), or the cat being visible for <120 s during some of their observations ($n = 22$). To retain as large a dataset as possible, in these instances, averaged values for the control and intervention conditions were created from 2 rather than 3 observations ($n = 19$ for control, $n = 19$ for intervention), or a single non-averaged value was used ($n = 10$ for control, $n = 7$ for intervention). In the cases where cats had been exposed to two blocks of tests (i.e., 2×6 observations, $n = 17$), observations from their first block of 6 tests were extracted. If there were any missing observations from the first block, data were supplemented from their second block, in order to create a full set of 6 observations. Of the initial total of 586 observations coded, data were extracted from 535.

Statistical Analysis

All statistical analyses were undertaken in R version 4.0.2 (46) using functions within the "psych" package (47), "base" and "stats" packages (46). Boxplots were generated via "ggplot2" (48).

Inter-rater Reliability

Inter-rater reliability for both the behaviour measures and human-handling scores were assessed via Intraclass Correlation Coefficients (ICC2), a measure of absolute agreement between raters (49), with an ICC2 threshold of <0.5 used to identify measures with poor agreement (50). Measures with poor agreement ($n = 3$, see **Supplementary Data 2**) were excluded from subsequent analyses.

Differences Between the Control and Post-intervention Condition

Differences in average control and intervention scores for all the behaviour measures as well as "human-interaction" and "cat ratings" were non-normally distributed (Shapiro-Wilk tests, $p < 0.05$) and thus analysed via paired Wilcoxon signed rank tests. All behaviour measures with acceptable levels of inter-rater reliability were analysed ($n = 31$), with the exception of the frequency and duration values ($n = 6$) that were used to calculate relative proportions for the other measures (i.e., head/body/tail not visible).

Due to the exploratory nature of this study and the lack of "gold standard" measures of behaviour when testing the effect of an intervention of this nature on cats' behavioural responses, we opted to test differences in behavioural outcomes across a range of individual measures that were considered context appropriate and of high biological relevance. To avoid the risk of type 2 errors, we opted against performing any power reducing corrections (e.g., Bonferroni) and instead chose an alpha value of $p < 0.05$ to determine significance and also calculated the effect size for each measure [as recommended by Nakagawa (51)], using the standard formula for non-parametric data ($r = Z/\sqrt{N}$). The r value varies from 0 to close to 1, with values of 0.10 to <0.3 considered indicative of small effects, 0.30 to <0.5 moderate effects and >0.5 large effects (52).

Data Visualisation

Data were plotted via a series of boxplots in order to visualise the relative difference in values between the pre and post-intervention conditions.

Interactions Between Cat Temperament and Relative Difference in Behaviour Between Conditions

Outcomes of the Wilcoxon tests highlighted several measures associated with affiliative behaviour and/or positive affect that were significantly greater in the intervention condition ($n = 5$, see results for full details), as well several measures associated with social discomfort/negative affect ($n = 4$) that were significantly greater in the control. These respective "positive" and "negative" affect linked measures were subsequently summed to create "positive" and "negative" composite scores for each cat for both the control and intervention conditions. Both frequency and duration values were included in each composite score, thus all measures were scaled (using the "scale" function in r) prior to summing. Relative differences in "positive" and "negative" scores between the two conditions were then calculated by subtracting the respective intervention score from the control. Separate Generalised Linear Models (GLM) were performed, with either the "relative positive" or "relative negative" composite score included as the response variable and the three temperament scores and their interaction as the explanatory variables (i.e., frustration*friendliness*fearfulness). A summary of the full model was called to identify potential effects of the explanatory variables. In both cases, all explanatory variables and their interactions were non-significant, thus a lack of effect was then confirmed by comparing each full model to the null model via ANOVA chi-square tests. Five cats were missing L-CAT scores, therefore data used in the GLMs was n = 95.

RESULTS

Inter-rater Reliability

With the exception of three measures relating to treading frequency, crouching duration and tail parallel duration, reliability coefficients for the behaviour measures and human handling score were generally well-above the acceptability threshold of 0.5. ICC values ranged from 0.64 to 1 (see **Supplementary Data 2**).

Differences Between the Pre and Post-intervention Conditions

Human-Interaction Scores

Average human-handling scores were significantly higher (indicating greater compliance with best practice) in the intervention compared to control condition [$p < 0.001$, $\nu = 8.5$, $r = 0.866$, mean (control) score = 1.7189, mean (intervention) score =2.803], see **Table 2** and **Figure 1**.

Human Cat-Behaviour Ratings

Average "friendly," "comfortable," and "rehomeable" ratings given to cats by participants did not differ significantly between the control and intervention conditions (all $p > 0.05$, **Table 2**).

Cat Behaviour Measures

Various frequency and duration-based measures differed significantly (p-values ranged from $p < 0.001$ to $p < 0.05$) between the control and intervention conditions (for full results, see **Table 2** and **Figures 2**, **3**). Associated effect sizes were generally moderate (i.e., 0.30 to <0.5). The exceptions included small effects (i.e., 0.10 to <0.3) for frequency of entering zone 1, frequency of ears rotated and/or flattened, and durations of sniff person and tail swish, and large effects (i.e., >0.5) for duration of ears rotated and/or flattened, frequency of rub/paw person, and also human-handling score.

Summary of Differences in Affiliative and Positive Affect-Linked Behaviours

Compared to the control, on average, cats in the intervention condition waved their tails for significantly longer and more frequently, had their ears in a neutral or forwards position for longer, "treaded" or "kneaded" with their front paws for longer, sniffed the participant for longer and also rubbed against them more frequently.

There were no significant differences in the average frequencies with which cats approached and made contact with the participants between conditions, although cats were in physical contact with participants for significantly longer average durations in the control.

Summary of Differences in Agonistic and Negative Affect-Linked Behaviours

Agonistic events occurred amongst 27% of cats in at least one of their observations for the control and amongst 16% of cats in at least one of their observations in the intervention condition. Average agonistic scores (i.e., composite of hiss/growl, cuff/swipe, bite) were significantly higher in the control condition, compared to the intervention.

TABLE 2 | Paired Wilcox test outputs and descriptive statistics of all behaviour measures coded across the control and intervention conditions for $n = 100$ cats.

Measures	**Paired wilcox test values**			**Descriptive statistics–control**				**Descriptive statistics–intervention**			
	***P*-value**	***V*-value**	**Effect size (r)**	**Mean**	**sd**	**Median**	**se**	**Mean**	**sd**	**Median**	**se**
Zone1_dur	0.8004	2,252	0.0120	0.8688	0.1602	0.9395	0.0160	0.8486	0.2064	0.9505	0.0206
Zone1_freq	**0.005102**	**3,340**	**0.280**	**0.0068**	**0.0049**	**0.0051**	**0.005**	**0.0056**	**0.0035**	**0.0044**	**0.0003**
Zone2_dur	0.7768	2,111	0.0148	0.1307	0.1605	0.0588	0.0161	0.1514	0.2064	0.0495	0.0206
Zone2_freq	**0.002631**	**2,971**	**0.307**	**0.0067**	**0.0067**	**0.0051**	**0.0007**	**0.0051**	**0.0050**	**0.0033**	**0.0005**
Tail_s_dur	**0.0142**	**3,118**	**0.245**	**0.1752**	**0.1778**	**0.1188**	**0.0178**	**0.1487**	**0.1601**	**0.0860**	**0.0160**
Tail_s_freq	0.2188	2,773	0.126	0.0257	0.0349	0.0178	0.0035	0.0223	0.0193	0.0167	0.0019
Tail_w_dur	**0.0001388**	**775**	**0.379**	**0.0117**	**0.0359**	**0.0021**	**0.0036**	**0.0160**	**0.0215**	**0.0089**	**0.0022**
Tail_w_freq	**3.564e-05**	710	**0.416**	**0.0017**	**0.0025**	**0.0011**	**0.0003**	**0.0032**	**0.0036**	**0.0022**	**0.0004**
Ears_f_dur	**4.256e-06**	1,157	**0.459**	**0.7297**	**0.2207**	**0.7877**	**0.0221**	**0.8120**	**0.1599**	**0.8440**	**0.0160**
Ears_f_freq	0.3162	2,817	0.100	0.0191	0.0096	0.0182	0.0010	0.0186	0.0091	0.0178	0.0009
Ears_r_dur	**1.264e-08**	**4,106**	**0.569**	**0.2636**	**0.2184**	**0.2085**	**0.0218**	**0.1713**	**0.1435**	**0.1267**	**0.0144**
Ears_r_freq	**0.02019**	**3,141**	**0.233**	**0.0166**	**0.0097**	**0.0156**	**0.0010**	**0.0151**	**0.0090**	**0.0145**	**0.0009**
Roll_dur	0.9527	1,129	0.00929	0.0813	0.1202	0.0172	0.0120	0.0900	0.1557	0.0050	0.0156
Roll_freq	0.3131	1,301	0.0625	0.0037	0.0056	0.0011	0.0006	0.0031	0.0053	0.0011	0.0005
Sniff_dur	**0.04881**	**1,869**	**0.196**	**0.0405**	**0.0636**	**0.0140**	**0.0064**	**0.0467**	**0.6072**	**0.0231**	**0.0067**
Sniff_freq	0.1232	1,990	0.153	0.0098	0.0096	0.0068	0.0010	0.0113	0.0094	0.0091	0.0009
Approach	0.6786	2,404	0.0416	0.0109	0.0077	0.0090	0.0008	0.0110	0.0069	0.0089	0.0007
Meow	0.9146	507	0.0556	0.0040	0.0143	0.0000	0.0014	0.0034	0.0104	0.0000	0.0010
Tread_dur	**3.394e-06**	**255**	**0.470**	**0.0963**	**0.2325**	**0.0000**	**0.0232**	**0.1394**	**0.2654**	**0.0082**	**0.0265**
Phys_cont_dur	**0.001684**	**3,439**	**0.314**	**0.6795**	**0.2244**	**0.7098**	**0.0224**	**0.6057**	**0.2516**	**0.6167**	**0.0252**
Phys_cont_freq	0.3453	2,800	0.0946	0.0371	0.0386	0.0318	0.0039	0.0335	0.0215	0.0300	0.0022
Rub	**1.396e-14**	**286**	**0.770**	**0.0450**	**0.0334**	**0.0385**	**0.0033**	**0.0801**	**0.0464**	**0.0782**	**0.0046**
Confl_disc	**0.0006854**	**3,513**	**0.340**	**0.0189**	**0.0189**	**0.0156**	**0.0018**	**0.0138**	**0.0087**	**0.0121**	**0.0009**
Agonistic	**9.111e-05**	**500**	**0.380**	**0.0017**	**0.0041**	**0.0000**	**0.0004**	**0.0005**	**0.0014**	**0.0000**	**0.0001**
Tail_u_dur	0.2935	2,831	0.105	0.4333	0.2500	0.4191	0.0250	0.4223	0.2365	0.4187	0.0236
Tail_u_freq	0.8784	2,570	0.0155	0.0194	0.0106	0.0179	0.0011	0.0194	0.0108	0.0189	0.0011
Tail_p_freq	0.137	2,092	0.149	0.0136	0.0111	0.0111	0.0011	0.0146	0.0110	0.0122	0.0011
Tail_d_dur	0.488	1,551	0.0705	0.0470	0.0866	0.0118	0.0089	0.0550	0.0936	0.0144	0.0094
Tail_d_freq	0.9547	1,756	0.0102	0.0063	0.0110	0.0022	0.0011	0.0054	0.0084	0.0022	0.0008
Tail_o_dur	0.2832	2,783	0.107	0.3713	0.2528	0.3648	0.0253	0.3554	0.2406	0.3177	0.0241
Tail_o_freq	0.5017	2,282	0.0683	0.0139	0.0099	0.0111	0.0010	0.0140	0.0100	0.0122	0.0010
Human handling (scale = 1–3)	**<2.2e-16**	**8.5**	**0.866**	**1.7189**	**0.4108**	**1.6667**	**0.0413**	**2.803**	**0.2987**	**3**	**0.0300**
Human cat rating (scale = 1–5) "Friendly"	0.2386	1,606	0.0817	4.3201	0.7461	4.6667	0.0702	4.2832	0.7292	4.3333	0.0686
"Comfortable"	0.7425	1,590.5	0.0235	4.3201	0.6543	4.3333	0.0616	4.3422	0.6751	4.5000	0.0635
"Rehomable"	0.2678	1,536.5	0.0913	4.1504	0.7539	4.3333	0.0709	4.1976	0.7597	4.3333	0.0715
L-cat personality	Maximum	Minimum	Mode	Mean	sd	Median					
"Friendliness" (scale = 4–20)	20	11	19	16.21296296	2.467028	17					
"Fearfulness" (scale = 3–15)	13	3	9	7.486238532	2.730607	8					
"Frustration" (scale = 3–15)	9	3	3	3.42201835	1.450801	3					

Measures with significant differences ($p < 0.05$) between conditions are indicated in bold.

Average conflict/negative affect scores (i.e., composite of paw lift, rapid groom, head/body shake, freeze/crouch, sharp turn of head toward participant, avoid/move/turn away from participant) were significantly higher in the control condition, compared to the intervention. On average, cats also swished their tails for significantly longer durations and rotated and/or flattened their ears more frequently and for longer durations in the control.

Differences in Pen Location

On average, cats changed their position between zone 1 (nearest the participant) and zone 2 (furthest away from the participant) significantly more frequently in the control condition, but

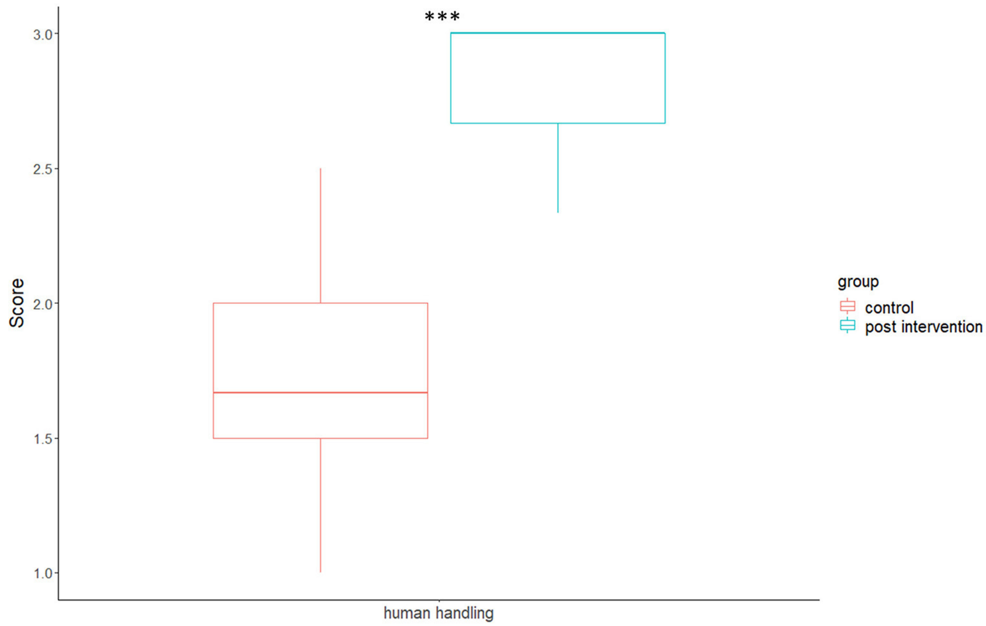

FIGURE 1 | Boxplots of humans' handling scores for control and intervention conditions (*p < 0.05, **p < 0.01, ***p < 0.001).

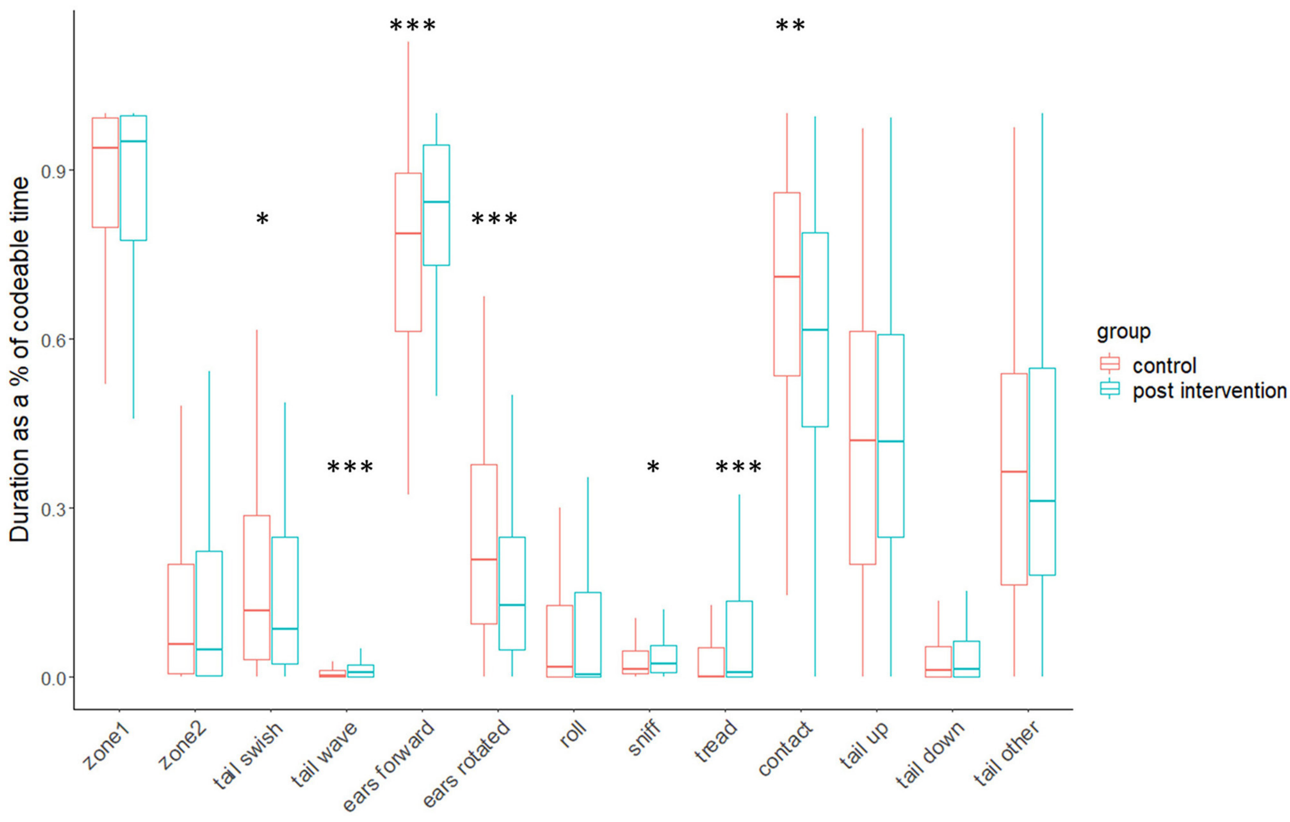

FIGURE 2 | Boxplots of cats' average (duration based) behavioural responses for control and intervention conditions (*p < 0.05, **p < 0.01, ***p < 0.001).

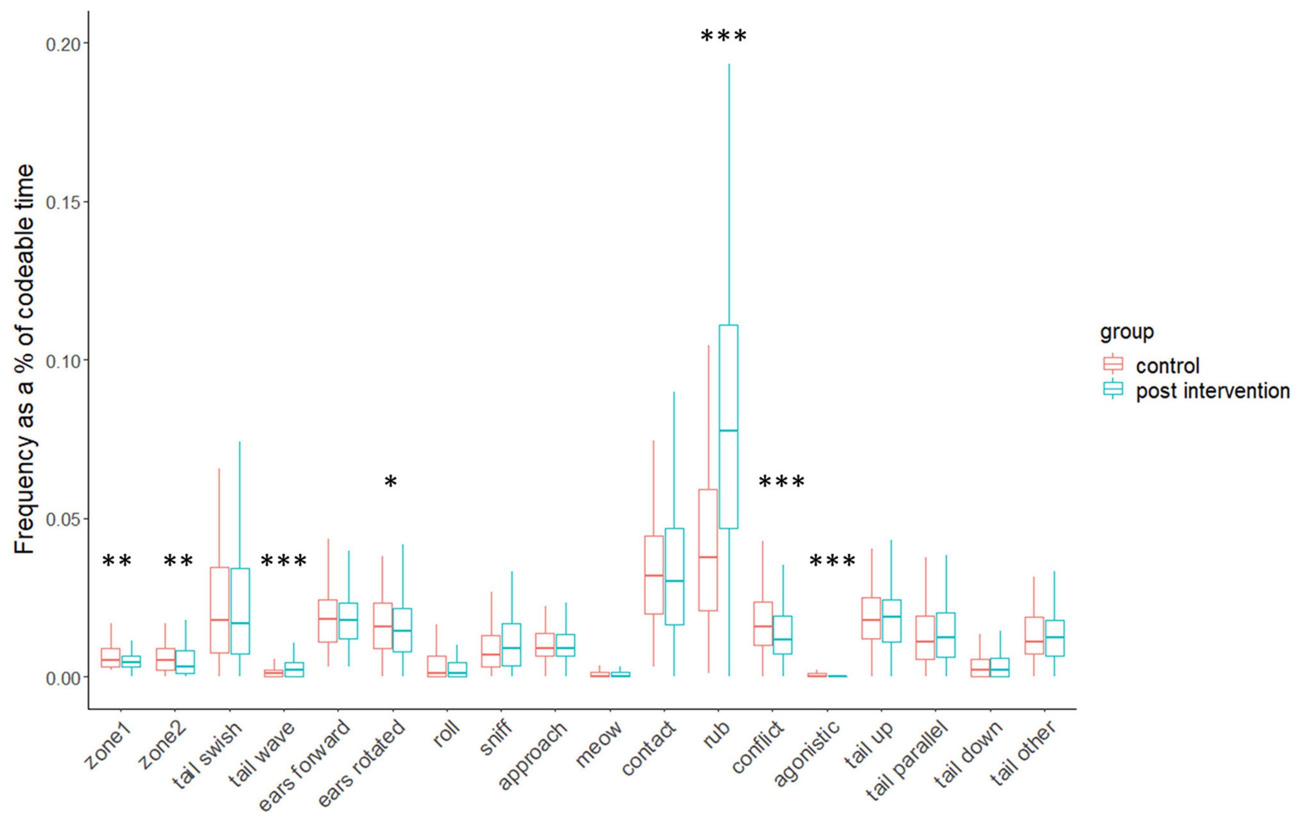

FIGURE 3 | Boxplots of cats' average (frequency based) behavioural responses for control and intervention conditions (*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$).

did not spend significantly longer durations in either zone between conditions.

Interactions Between Cat Temperament and Relative Differences in Control and Intervention Behaviour

Results of the GLMs indicated a lack of significant relationship between cats' temperament scores (and their interactions) and the relative difference in their "positive" and "negative" behaviour composite scores between conditions. In both cases, outputs of the model summary and subsequent comparisons of the full and null models yielded non-significant (both $p > 0.05$) values, with the null models producing the lowest Akaike information criterion (AIC) values in both cases.

DISCUSSION

The results of this study demonstrate the beneficial impact of a simple set of cat-interaction guidelines on cats' real time responses to humans during HCI. Humans' general interaction style was significantly more closely aligned to "best practice" principles following the training intervention. Additionally, not only did cats behave less aggressively during the intervention condition, but they also performed fewer behaviours associated with conflict or negative affect, as well as more human-directed affiliative behaviours and those associated with positive affect. Collectively, these results suggested that the guidelines are easy for non-experts to understand and implement, and may facilitate safer and more beneficial HCIs for both cats and humans.

Perhaps counterintuitively, cats were in physical contact with humans for significantly longer average durations in the control compared to the intervention condition. However, as this measure did not differentiate between whether the contact was initiated by the cat or the human, it is likely that the direction of differences in this measure are reflective of participants adopting a more "hands-off" approach following training (as encouraged by the CAT guidelines). As cats otherwise reacted more positively and less negatively in the intervention condition (where physical contact occurred for shorter periods), a "less is more" approach is likely relevant when it comes to cats' preferences for physical contact during HCIs, even though cats rubbed against participants more frequently in this condition. Durations of time spent in either Zone 1 or 2 were not significantly different between conditions, however cats entered in (and out) of both Zones significantly more frequently in the control. As both zones represented the cats' relative proximity to the participant (i.e., Zone 1 was nearest to the person and Zone 2 furthest away), such behaviours are potentially indicative of greater participant-directed distance increasing/decreasing behaviour in the control, and therefore the cat possibly experiencing greater anxiety or perceived conflict [e.g., (53)] in this condition. This interpretation is plausible, given the higher frequency of other, more direct, cat conflict-linked measures identified in this condition. Interestingly, frequencies of the cat directly approaching and making contact with the person did not differ significantly between conditions. This potentially suggests that whilst the cat's comfort was negatively impacted by the participants' style of handling in the control (perhaps motivating them to periodically put more distance between themselves and the person), these potentially negative experiences did not affect the cats' general intent to physically/socially engage with the person overall.

Interestingly, applying the guidelines did not significantly positively impact participants' impressions of cats or their "desirability." This is surprising, given that human-directed affiliative behaviours (54, 55) and aggression (14, 16) are typically considered desirable and undesirable respectively. However, the guidelines had no significant *negative* impact on participants' impressions of cats either. This would suggest that prioritising cats' comfort and human safety, by encouraging "best practice" approaches during HCI, can potentially be achieved without limiting humans' ability to form positive associations with cats. As such, it is unlikely that applying the CAT guidelines would negatively impact upon rehoming rates, and might actually lead to increased adoption [e.g., (54, 55)], although this hypothesis requires further testing.

What is potentially concerning, is that whilst participants' ratings of cats' level of friendliness and degree of comfort did not differ between conditions, objective measures of cats' behaviour suggested their comfort during the control condition was compromised. This may indicate that participants were not sensitive to the degrees to which behaviours associated with positive/negative valence were present/absent in the cats they interacted with, or that they were at least unaware of the relevance of these behaviours to the cats' comfort. Such interpretations would appear congruent with other findings suggesting humans tend to struggle to correctly differentiate between positive and negative affective states in cats, based on their behavioural expressions (56), and do not focus on these cues when making adoption decisions (55). However, absolute occurrences of conflict and agonistic behaviours were relatively low across both conditions (meaning they could be easily missed by participants), and affiliative behaviours comparatively more frequent. Additionally, cats' control and intervention ratings were completed by different people, rather than by the same person making a comparative between-condition judgement of the same cat. Both of these factors could equally explain the lack of significant between-condition differences concerning the "friendliness" and "comfort" ratings given to cats. Future educational interventions aimed at increasing humans' awareness of the important (but less overt) behavioural signs of cat comfort/discomfort during HCI would be beneficial none-the-less.

Effect sizes for the differences in cats' behaviour between the control and intervention were generally moderate. However, the protocols put in place to protect cats' well-being and humans' safety during the study are likely to have mitigated the negative impact of the control condition on cats' experiences during HCI to a degree. For example, whilst the "control" condition was intended to encourage more "naturalistic" styles of HCI, the reality of instructing participants to remain seated and to not follow the cat, pick them up, or disturb them whilst hiding, meant the control already incorporated several key elements of "best practice" handling. Additionally, by only including cats considered well-socialised toward people, and subsequently removing any cats that showed more intense aggressive responses during the study (i.e., potential to cause real harm to participants), it is very likely that we selected against the cats that might actually have benefitted most from the CAT approach to HCI. This likely explains the relatively low levels of human-directed aggression and conflict-based behaviours across all observations, as well as the lack of effect of cats' temperament on relative differences in the occurrence of "positive" and "negative" behavioural responses between conditions. Indeed, mode L-CAT scores for the traits "Friendliness" and "Frustration" were near the maximum and minimum end of the scale, respectively, suggesting this was a relatively homogenous population of well-socialised cats, with minimal tendencies toward human-directed aggression. It is therefore anticipated that application of the CAT guidelines within more typical cat shelter populations (i.e., those that are less friendly but more anxious or easily frustrated), and when contrasted against more usual baseline styles of human handling, would produce even greater positive effects on cats' behaviour.

In addition to their application amongst members of the public visiting the cattery, the CAT guidelines may be particularly useful when incorporated into the standard HCI practices occurring between cats and their caretakers. As residing within the cattery environment is typically a stressful experience for cats, handling and husbandry protocols that promote positive cat well-being are essential (57). Several studies have investigated the potential benefits of exposing cats within a rehoming environment to "gentling" programmes (i.e., a human stroking and vocalising to a cat) in order to promote relaxation and improve well-being (19, 58). However, specific methods of "gentling," as described in these studies, were mostly unclear and/or implied that for at least some cats (i.e., those behaving aggressively), individuals were not provided with choice and control over the nature of the HCI (19). Indeed, within this latter study, certain individuals responded fearfully and/or defensively to "gentling" and did not appear to benefit from this form of HCI in the same way as did cats that responded in a positive, affiliative manner (19). These approaches to HCIs may therefore be beneficial for some, but not all cats, and in certain cases may induce (or at least exacerbate) negative affective states. Adopting HCI methods (such as the "CAT") which allow cats to either "opt in" or "opt out" of HCIs, as well as dictate their nature, are likely to ensure HCIs have positive impacts on cats. Such approaches may also ensure that HCIs do not inadvertently induce experiences of stimulus flooding or subsequent "learned helplessness" (59, 60) that could otherwise arise due to the cats' lack of perceived control or ability to remove themselves from the (potentially) aversive situation they are being exposed to [e.g., (61)].

Human-directed aggression is typically considered a "problem behavior" requiring professional intervention (62). Its presence may negatively impact cats' well-being, in addition to the cat-owner relationship (63), potentially influencing cat relinquishment decisions (64, 65). Application of the CAT approach to HCIs within the home may therefore help to promote more positive cat well-being and cat-human relationships, and reduce the likelihood of owners surrendering their cats. Whilst little information exists to enable accurate quantification of the numbers of cats involved in AAIs, the current popularity of AAIs within both educational and therapeutic settings [e.g., (1, 2, 34)] suggests this may be considerable. With greater inclusion of cats within AAI programmes, and increased popularity of Cat Cafes (31), comes a greater risk of cats exposed to suboptimal HCI, leading to human injury and cat discomfort. As the principles of the "CAT" are suitably generic for broad application, and associated training materials (see **Supplementary Files 3–6**) easily modifiable, effective application of the CAT guidelines within both the domestic home and a range of other HAI contexts are anticipated. Further studies to test "CAT" efficacy within such situations are therefore recommended.

Inter-reliability for the measures analysed within this study were established via coding contributions from a second coder that was blind to the conditions within observations. However, due to practical limitations, the majority of data used in the main analysis were coded by a (technically) un-blind individual, potential creating a source of coder bias. Therefore, where CAT efficacy testing is undertaken in further studies, suitable experimental protocols should be utilised to ensure that all video observations can be coded in a fully blind manner. Additionally, while highly reliable between coders, ratings of participants' handling styles were relatively subjective. Thus, further, more objective investigations of the impact of the CAT intervention on humans' behavioural styles during HCI are recommended. These may help to better understand the specific differences in humans' behaviour that underpin the more positive behavioural responses observed in cats following the intervention.

DATA AVAILABILITY STATEMENT

The data presented in the study are deposited in the Figshare repository as '**Supplementary Data S2**' and can be accessed here: https://figshare.com/articles/dataset/Suplememntary_data_S1-8/14828397.

ETHICS STATEMENT

Ethical approval for the study was granted by the delegated authority of Nottingham Trent University, Research Ethics Committee ref: ARE192011. All aspects of experiments were performed in accordance with relevant guidelines and regulations. All personal data provided by participants for the purposes of the study were stored in line with current GDPR guidelines. All cats were periodically monitored during data collection by cat welfare experts LF, RF-W, CH and JP, in addition to the wider cattery team. Any cats observed showing signs of distress, illness or the potential to injure the participant were immediately removed from the study and human participants were free to leave the experiments at any time.

AUTHOR CONTRIBUTIONS

LF conceived and designed the project, collected data, performed the data analysis, and wrote the manuscript. LR coded the videos and performed the data extraction and analysis. RF-W, CH, and JP collected the data. CH also coded the videos. All authors approved the submitted version of the article.

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SUPPLEMENTARY MATERIAL

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REVIEW
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Are These Cats Playing? A Closer Look at Social Play in Cats and Proposal for a Psychobiological Approach and Standard Terminology

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Play in domestic cats has been largely studied using a contextual approach, i.e., with a focus on what the cat is playing with, such as an object, itself or another cat. Such classification may be superficially attractive scientifically but it limits the ability to investigate function. We propose consideration of a psychobiological approach, which increases attention on hypotheses about the motivational and emotional state of the actors, may be more valuable. This may be particularly important in the case of intercat exchanges that might involve play, for example when one cat may chase another which does not want to be chased, the general interaction should not be considered playful. Key to improving the scientific study of such interactions is the need to adopt a common terminology, thus we synthesise a common ethogram from the published literature. Secondly at the heart of a psychobiological approach is a consideration of both the affective state and motivational goal of each actor in an interaction, since they may not be congruent, and recognition of the hypothetical nature of any such functional classification. However, this bottom up approach provides valuable insights that can be tested. We argue that when one cat treats another as an object or prey, such activity relates to the former cat seeking to learn about its own skills in relation to manipulating its physical environment (prey are not considered part of the complex social relationships and thus social environment of an individual). However, when interaction between cats is reciprocal it may function to facilitate social learning and may be best described as mutual social play. It needs to be recognised that interactions are dynamic and thus our classification of a situation needs to be flexible. So mutual social play may turn into a form of non-reciprocal interaction. We conclude by outlining priorities for future research to help us improve our ability to answer the question "Are these cats playing?" in a wider range of contexts.

Keywords: cat, intercat, interaction, play, psychobiological approach, social, taxonomy

INTRODUCTION

Play varies greatly between species but also individuals, and has been examined from a variety of scientific perspectives, so it is not surprising that it has been variously defined. The first comprehensive text on animal play (1) divided it into nine categories: Experimentation, Movement play, Hunting play, Fighting play, Love play, Constructive arts, Nursing play, Imitative play, and Curiosity. Within the "Fighting play" category it was stated that "tussling among animals" could function to practise predatory instincts. Broadly speaking it is widely acknowledged that play can function for motor training, cognitive training and socialisation (2). Focusing on possible proximate functions of play, i.e., the consequences of the behaviour patterns which are of immediate (proximate) benefit to an individual (3), play was considered a "*behaviour that functions to develop, practice, or maintain physical or cognitive abilities and social relationships, including both tactics and strategies by varying, repeating, and/or recombining already functional subsequences of behaviour outside their primary context. It is a matter of taste whether behaviours that do not simultaneously satisfy the structural, causal, contextual, functional, and developmental criteria of this definition are to be called play*" (4).

By contrast, an ethological perspective might emphasise structural aspects suggesting the ultimate function of play. For example, Martin and Caro (3) modified the definition of play by Bekoff and Byers (2) to "*all motor activity performed postnatally that appears to an observer to have no obvious immediate benefits for the player, in which motor patterns resembling those used in serious functional contexts may be used in modified form. The motor acts constituting play may have some or all of the following structural characteristics: exaggeration of movements, repetition of motor acts, and fragmentation, or disordering of sequences of motor acts.*"

Burghardt (5) in his extensive review of the history of attempts to define play instead of trying to create a new definition, proposed a list of five criteria which need to be satisfied in "*at least one respect, in order to identify a behaviour as play in whatever context or species being studied.*" Using this approach, he suggests (5) that play can be recognised as behaviour which is

(1) not fully functional in the form or context in which it is expressed;
(2) spontaneous, voluntary, intentional, pleasurable, rewarding, reinforcing, or autotelic (for its own sake);
(3) structurally or temporally different from strictly functional behaviour expressions;
(4) repeated in similar but not rigidly stereotyped form during a portion of the animal's ontogeny;
(5) initiated when the animal is in a "relaxed field"—fed, healthy and free from stress or intense competing systems.

This approach has been used to potentially recognise play behaviour in lizards, turtles, bony fishes, stingrays, octopus (6) and even wasps (7). Burghardt's fifth criterion suggests play can be a good welfare indicator, and this has been supported in several welfare related reviews (8, 9).

However, confirming Burghardt's five criteria from field observations can be difficult, especially in a species like the cat. This is evident from the attempted operationalisation of cat play behaviours in a recent review (10) on the development and functions of cat play. Their overview ethogram demonstrates the diversity of descriptions used in cat play studies including contextual, functional but also circular definitions (where "play" is defined as "play"). Therefore, in this review we critically evaluate the classifications used to describe play involving cats, with a particular focus on play *between* cats; on this basis we propose a framework to aid the differentiation of psychobiologically meaningful categories of play and the associated evidence for this.

CLASSIFICATION OF CAT PLAY

Challenges From Contextual Classifications

Contextual classifications focus on the circumstances in which play occur in order to define different forms. These are perhaps most widely used with division into locomotor, object and social play (3, 6, 11, 12); however, the distinction between these can be deceptively difficult to define. Martin and Bateson (13) defined locomotor play in cats as activity distinct from manipulation with objects and not directed to other individuals, but rather directed toward the external environment. However, terms such as "self play," including bouts of a cat chasing its own tail (14) and behaviour that does not appear to be social or directed to an object (15) have also been used to describe play where there is no obvious environmental target. Thus, most definitions seem to agree that locomotor play is usually a solitary activity (6), but not what the target of the action is, nor whether the individual may employ others as "objects" within play. Indeed, the proposed standardised ethogram for *Felidae* delineates this activity as solitary in situations where cat is alone but behaviour patterns such as chasing, pawing, pouncing can be directed to an object or tail of a cat (16).

Object play is typically recognised when an animal manipulates an object and this activity seems to provide no immediate benefit for an individual (6). It has also been referred to using the term "object contact" [pats and paws directed to an object and bites of these objects (17)]. Moreover in cats, play with live prey has been referred as predatory play and differentiated from predation involving non-hurtful manipulation of prey (18). Despite similarity of behaviour patterns in both object and predatory play, there is no consensus on how they should be categorised; for example Mendoza and Ramirez (19) differentiated predatory play from two other subcategories, which they referred to as social and non-social play (which included object and self-directed play).

Whether or not a classification is actually *contextual*, may also be confusing. For example, the term "social play" can merely describe playful activity directed toward a conspecific (19), but in other contexts it may be applied to describe behaviour that has a particular emotional-motivational basis (20). In this latter context a cat who "plays" with another and treats it like a prey object is not engaged in social play but rather a "SEEKING" [*sensu* (20)] type of activity.

Contextual classifications may be superficially attractive but they appear to be often arbitrary and do not inform about motivation, having little biological relevance. Thus, they are not very useful clinically when considering how to manage these responses if they are seen as problematic. Managing a cat who is perhaps more predatory in its playful actions toward another cat requires quite different intervention to one who is engaged in rough and tumble play. In the latter the both might be in a positive affective state, but in the former the one being chased (if the behaviour is not reciprocated) could be in a very negative affective state.

Functional Classification

Operationalised definition of cat play (10) highlights that "social play" is probably one of the most frequently used but also most variedly defined terms. It may be simply defined as play directed to conspecifics (6) but might also include play with a human (21, 22); it might also be associated with activity directed toward a toy by more than one individual at a time: "*activity of two cats playing with same toy simultaneously or within 3s*" (23). Beyond the aforementioned definitions, it has been argued that "common sense" be used to recognise social play in cats. In one of the earliest studies of play in kittens, the authors admit that the observer usually has an intuitive sense for recognising playful behaviour and they used working definition criteria only in occasions where the playful character of interactions was not obvious (17). However, this obviously poses challenges when we consider the scientific quality of the work (such as its potential replicability). Indeed in this latter study, (17) authors admit that despite applying these criteria and excluding harmful interactions, in older animals they may have scored as playful some interactions that might have been "serious." The risk of recording "serious" interaction as play becomes even greater when very broad definitions are used, e.g., all social encounters between cats are considered to involve social play (24, 25).

Likewise, referring to a playful activity in terms of specific behaviour patterns (e.g., chasing or biting) supplemented by adjectives such as "friendly" and thus relying on subjective assumption that they are not agonistic (26, 27) may be similarly problematic. This highlights the difficulty of distinguishing play from agonistic interaction, especially in a species such as the cat. Relying on descriptions based on circumstances, combined with common sense or subjective beliefs is not sufficiently scientifically robust for recognising play. An alternative approach is to begin by acknowledging that the labelling of something as play involves making an inference about it, which inherently implies there is some uncertainty about the accuracy of this. Thus, the description of play is a postulate that needs to be supported by several lines of evidence, but can still be subject to potential scientific falsification as new evidence comes to light.

Within the field setting, it has been argued (28) that it is useful to differentiate three elements to a behaviour, its contextual, motivational, and emotional basis. Context (the circumstances surrounding expression of the behaviour), can be defined objectively, however both its motivational (biological goal) and emotional (personal significance) basis cannot be measured directly (28) but can be inferred with varying degree of confidence by triangulating the evidence available from careful and systematic observation of the antecedents to the behaviour and its consequences (motivation) and the stimulus contingencies, signs of arousal, behavioural tendencies, and communicative signals (emotion). With this approach, it is recognised that the description of an action as playful remains a hypothesis that can be tested (and potentially falsified in line with scientific methodological requirements), for which the evidence can be gathered objectively. This approach has the potential to link the behaviour with a meaningful psychobiological basis. For example, when the term social play is used purely in relation to context, i.e., it is play occurring between two individuals (6, 11), this tells us nothing about underlying mechanism in terms of neurobiology or psychological state. Panksepp (20) argues that from an affective neurobiological perspective what he describes as social play (PLAY) is a pleasurable reciprocal interaction (rough and tumble play) that affords both individuals the opportunity to obtain important social skills which can be used later on in life. We propose below, that the term "*mutual social play*" is a preferable term as it emphasises not only the context (a mutual interaction) but also the motivation (social play) and potentially its emotional quality (the social pleasure associated with PLAY).

From this perspective, what is described as object play, locomotor, and self-play are also pleasurable activities but lack the social dimension; they have the potential function for the individual to not only learn about the physics of their environment, including both animate and inanimate objects, and potentially awareness of their own body; but also to facilitate the development of future behavioural skills.

Behavioural similarities between object and predatory play suggest common motivational elements; clearly there is also a close relationship between these motivational systems and those involving feeding including its natural precursor: predatory behaviour. For example, hunger motivates cats to interact with larger toys which are otherwise neglected (29), but it also leads to the performance of apparently playful behaviours with large prey such as rats (18). It might be that these associations are the product of related, but separate, functional motivational systems regulated by a common affective system [SEEKING *sensu* (20)]. However, an alternative psychobiological perspective might suggest that the functional relationship between these activities is even closer, than outlined. It has long been argued, that what is often called "predatory play" may be a misperception of inhibited predatory behaviour and not related to a separate play motivational system (30). It is suggested (30) that the perception of "play" comes from a failure to consummate the predatory action with a kill, and the seemingly exaggerated actions directed at the prey; however this might instead reflect an emotional tension between a desire to attack and an anxiety to avoid potential harm from the prey (30), within a single functional predatory system. The seemingly exaggerated playful behaviours, might be functionally important in avoiding harmful contact from the prey (30).

The psychobiological perspective may thus help address Burghardt's argument (6) that play is not fully functional and

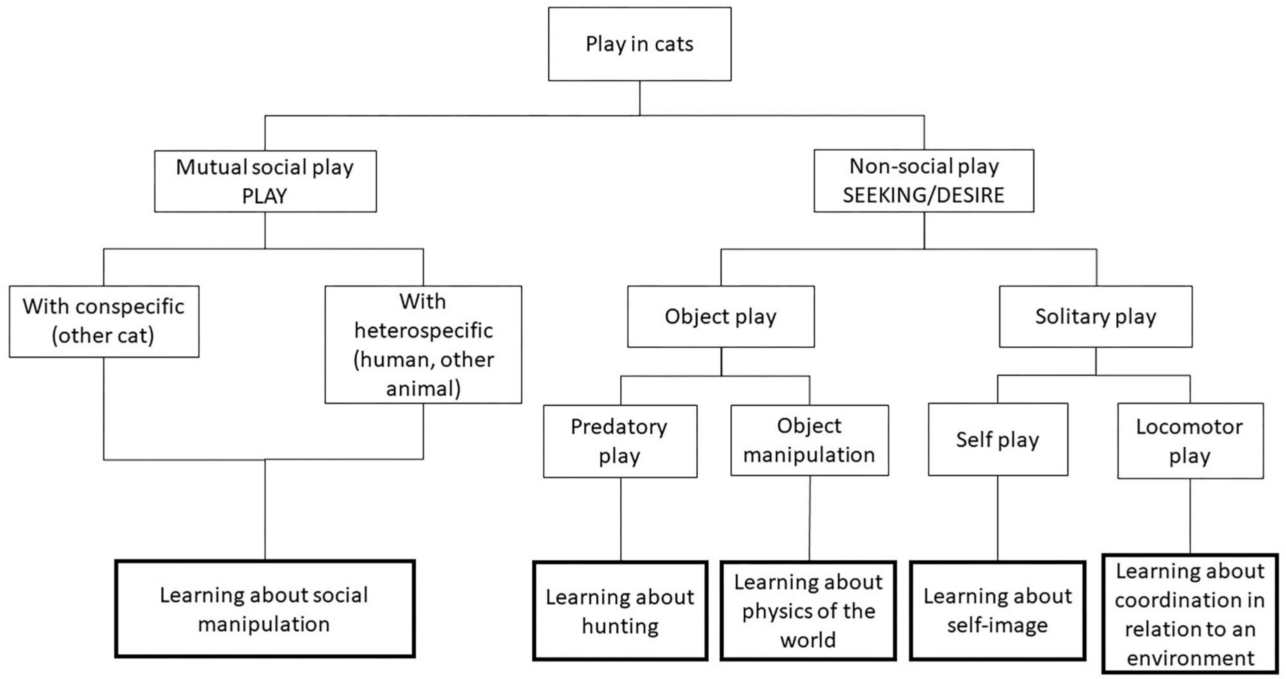


FIGURE 1 | Proposed psychobiological classification of play in cats. At the first level the affective (psychological) basis to the type of behaviour involving play is distinguished using the terminology of Panksepp (20). The lowest level represents the specific functional (biological motivational) goals of specific types of action, several of which may be related to a given affective system.

the classification of play should not focus solely on function. We suggest that a primary focus on the underlying qualitative emotional state of the individual engaged in apparently playful behaviour, alongside consideration of the functional behavioural systems that might be involved and how they develop, provides valuable insight into the problem of the classification of play in cats (and other species). This is particularly useful when considering the factors influencing the different forms of play described in the literature and how they might be most effectively managed (31).

This psychobiological framework (**Figure 1**) places affect at the top of the mechanistic considerations and is able to embrace the diversity of play seen both with and without another individual in a rationally consistent way. For example, when one cat is playfully hunting or manipulating the tail of another, we would argue this cat is not engaged in mutual social play, but rather some form of object play, which is related to the affective system described by Panksepp (20) as SEEKING. Likewise, when interaction is not reciprocal and one cat is treated by another cat as if it was a prey or object, the necessary criteria for social play (from a psychobiological perspective) are not met as it is not a *reciprocal* pleasurable or mutual activity, and so it should be classed as a separate type of activity.

This approach also helps to highlight a number of important practical considerations. For example, as cats differ greatly in their social requirements, e.g., contact with conspecifics may be beneficial for one cat but might be stressful for another (32): social interaction, including apparently playful activity, does not necessarily support good welfare (33); instead we need to consider the specific emotional predispositions of the individuals involved and thus what is important to them as individuals. This focus on underlying affect, also highlights the potential for meaningful change within a given interaction. Thus, an interaction between cats may start off as a form of mutual social play but develop into something quite different. If the play stops being reciprocal and/or one cat wants to terminate the interaction, e.g., by trying to escape after a bout of mutual chasing (34), the response of the other cat is critical to how what follows should be viewed psychobiologically. It may accept this and stop interaction (will not approach the cat which left after the chase), or it may entice the individual to play again by pouncing on the cat that left the interaction (for the definitions of the behaviours see **Table 1**) (34), which might result in withdrawal (the cat walks away again), aggressive behaviour (bite) (41) or a reciprocal response in this cat (pounce) leading to the resumption of mutual social play. We illustrate these potential sequences within the context of intercat exchanges and their interpretation below in **Figure 2**.

Given the psychobiological mechanistic complexity of these scenarios, it is not surprising that besides the scientific confusion that has existed, there is often considerable uncertainty among cat owners concerning the behaviour of their cats' interactions. Consistent terminology and the processes described here for classifying the activity can help determine what is probably happening, but there is undoubtedly a need for greater research and objective data to reduce the uncertainty concerning whether

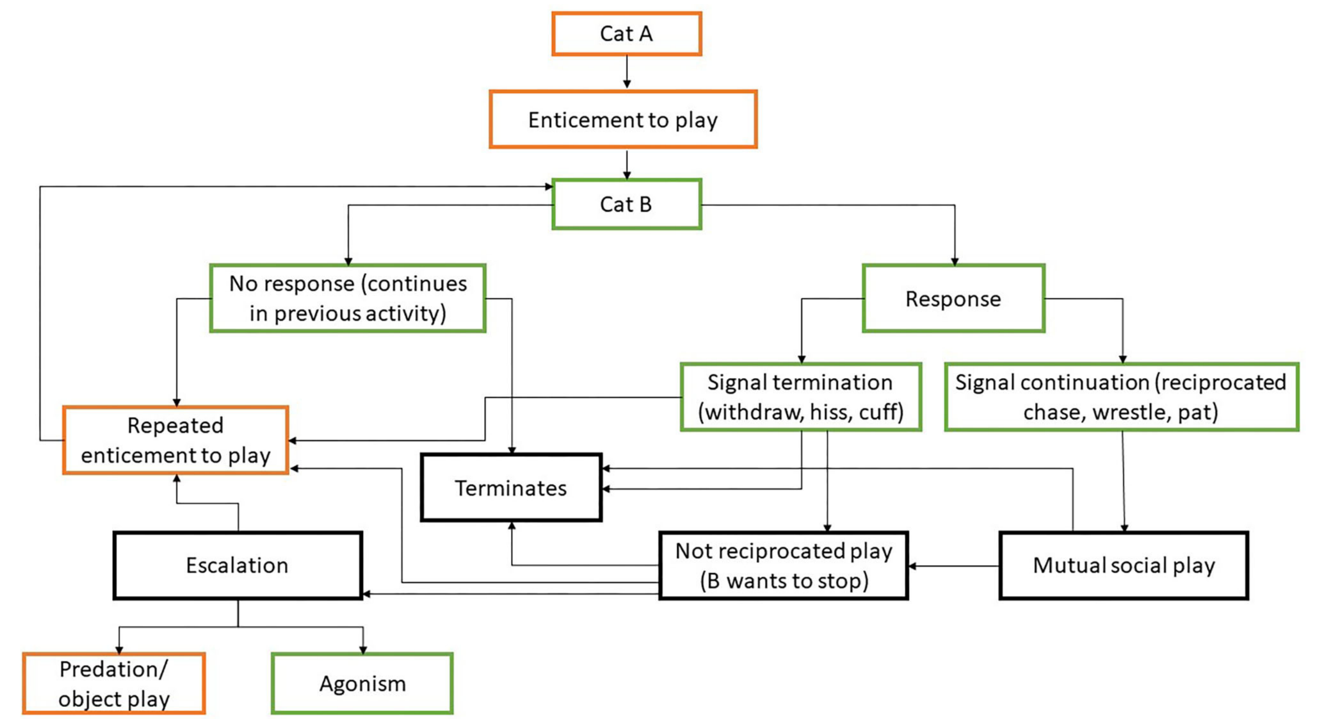


FIGURE 2 | The elements intricately linked with intercat play (including elements of mutual intercat play). Any element could be considered part of play, due to context but motivationally may involve other systems [inspired by diagram of the sequence of interactions in black bear social play (6)].

two cats are playing, and the implications of this for their well-being. To this end, we suggest that the term "*intercat play*" be used purely as a contextual description of an interaction which appears playful at some level, with no implication concerning underlying emotion or motivation, nor mutuality. In order to build the necessary evidence base to make the inferences we suggest, it is necessary to have an agreed terminology for the structural behavioural elements of play in the cat. Accordingly, in the next section, we review the ethograms used to describe intercat play and propose a standard terminology for future use.

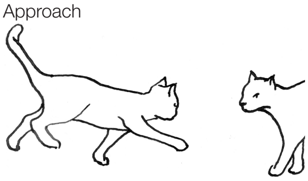
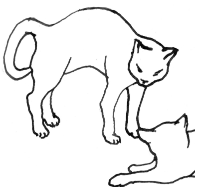
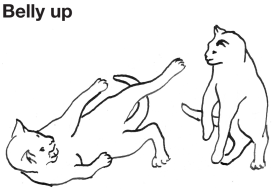
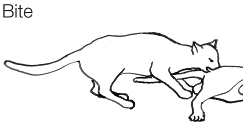
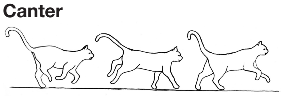
THE STRUCTURE OF INTERCAT PLAY—A REVISED ETHOGRAM

The work of Stanton et al. (16) provides a useful framework for a standard ethogram of intercat play, but we suggest it is incomplete. Therefore, **Table 1** is a more comprehensive ethogram based on the available observational studies of intercat play in domestic cats. In order to highlight where there might be confusion, **Table 1** also highlights when the same or similar terms are used by other authors but with potentially different definitions.

On the basis of the study by West (34), who offered a description (rather than true sequence analysis) of behaviours that appear to be potentially part of what we term "mutual social play," we suggest that this activity is often initiated by one cat pouncing on another who often responds with a belly-up posture. However, a combination of belly up and stand-off posture can also be seen as an initiation pattern for mutual social play. These two patterns—belly-up and stand-off, together with face-off behaviour are regular parts of the continuation of mutual social play, while it is most commonly terminated by chasing and arching. Reciprocity is demonstrated by a combination of certain behaviours such as pouncing with belly-up or rearing and a stand-off posture as a response to the belly-up posture (**Figure 3**). Alternation of these two behaviours has also been suggested to serve as a signals of playful intent (34). Interestingly, rolling on the back with the abdomen exposed (which is similar to the belly-up posture) has been observed within intercat play by various authors in a range of contexts: in association with "wrestling" behaviour (25, 34, 36, 38); but also within affiliative (26) and agonistic contexts, where it may be interpreted as a potentially deferential, appeasement or submissive gesture (42, 43). Further research is required to establish if it plays a role in the proximate regulation of social play in cats.

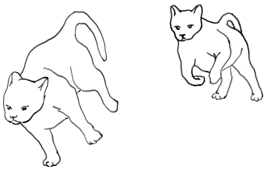
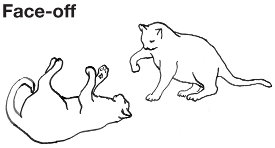
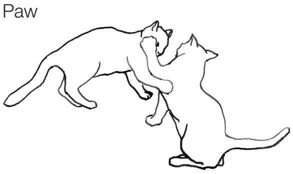
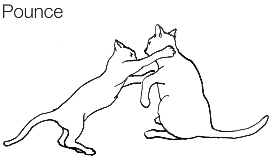
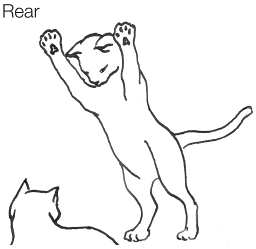
The structure of intercat play changes with age, and this may reflect shifts in behavioural maturation and the associated motivational and emotional systems or stimuli influencing the occurrence of the behaviour at any given time (17, 24). Examining the temporal relationships between certain behaviours which have both a specific function and which are

TABLE 1 | Overview ethogram of intercat play behaviours with suggested common terms of the variables.

Ethogram element as per Stanton et al. (16) unless otherwise indicated (highlighted in bold)	Description	Equivalent term used by other authors	Equivalent definition used by other authors	References
Approach 	Cat moves toward cat while looking at it.	Approach	Locomotion of any sort toward prey/sibling.	(24, 35)
		Approach	Movement of any sort (excluding canter) toward another cat.	(25)
		Approach	Each occurrence of movement by an individual from at least two kitten body lengths away from another individual to less than two kitten body lengths away from that individual.	(14)
Arch back 	Cat curves back upwards and stands rigidly.	Horizontal leap	The kitten assumes a lateral position, with respect to another kitten, arches back slightly and curves its tail upwards and toward its body then leaps off the ground.	(34)
		Side-step	The kitten arches its back, curls its tail upwards and walks sideways toward or around another kitten or object.	(34)
		Arch	Each occurrence of a marked upward curving of the spine while standing still, leaping upwards, or moving sideways. The orientation is usually side-on in relation to another cat or object.	(17, 36)
		Neck Flex	Each occurrence of a marked downward flexion of the neck. The head is also turned to face another cat if the body is side-on. It can occur simultaneously with the Arch and can be given while standing still or moving sideways.	(17)
		Arch	A marked upward bending of the spine while standing still, leaping upwards or moving sideways.	(24, 35)
		Arch	A marked upward bending of the spine while standing still, leaping upwards or moving sideways, with or without piloerection.	(25)
Belly up 	The cat lies on its back with front or all limbs held up but not touching another cat. Back legs may be alternating between flexion and extension and front legs reaching toward another cat which may be standing over the subject cat. The tail is typically straight back and may be moved back and forth. Mouth is held open and teeth are exposed.	Belly-up	The kitten lies on its back, its belly up, with all four limbs held in a semivertical position. The tail is straight back and may be moved back and forth. Typical paw movements associated with the belly-up posture are to move the back legs in a treading motion and to make reaching or pawing movements with the front legs. The mouth is held open and the teeth are exposed. In a social encounter, one kitten assumes the belly-up position and another kitten stands over it. Thus, the treading and pawing movements bring the kitten into contact with parts of the body of the standing kitten. Usually, these areas are the head, neck and ventral area.	(34)
		Mouth open	Gaping at another cat while in a rolled position.	(25)
		Paws up	Front paws, and sometimes back paws as well, held up to but not touching another cat, while subject is in a rolled position.	(25)
Bite 	Cat snaps teeth at and is successful in making contact with another cat.	Bite	Bringing jaws into contact with the prey/sibling and closing them.	(24, 35)
		Bite	Bringing jaws into contact with a cat and closing them.	(25)
Canter 	Asymmetrical running gait during which all paws repeatedly and simultaneously leave the ground and limb movements patterns are different on the right and left side; head and tail may be held high.	Canter	Jerky running gait during which all paws repeatedly and simultaneously leave the ground; head and tail often held high.	(25)

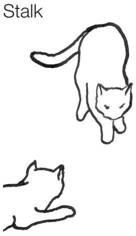
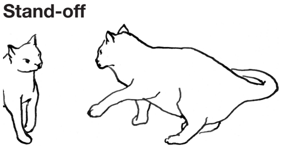
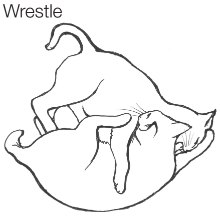
(Continued)

TABLE 1 | Continued

Ethogram element as per Stanton et al. (16) unless otherwise indicated (highlighted in bold)	Description	Equivalent term used by other authors	Equivalent definition used by other authors	References
Chase 	Cat runs rapidly in pursuit of cat.	Chase	A chase involves a kitten running after or from another kitten. It could, perhaps, be differentiated into pursuit and flight.	(34)
		Chase	Running after a moving kitten.	(24)
		Chase	Running after a moving cat.	(25)
		Chase	Each bout of running after another individual/mobile object with the chased individual running away from the chaser for at least a distance of 1m.	(14)
		Flee	Cat runs away from cat.	(16)
		Flee	Running while being followed by a moving cat.	(25)
Face-off 	Cat is sitting near to another cat with head and neck oriented toward it and body hunching forward. Cat is moving its tail back and forth and may lift a front paw and move it in direction of another cat. The other cat may be in a similar face-off position or may be in belly-up position (as shown here).	Face-off	A kitten sits near another kitten and hunches its body forward, moving its tail back and forth, and lifts a front paw and moves it in the direction of the other kitten. The kitten's head and eyes are also oriented toward the other kitten. Two kittens may face-off simultaneously and direct their front paw movements at one another's face.	(34)
		Face off	Sitting next to another cat, often with tail lashing and head twisting; recipient in a rolled position or similar face off stance).	(25)
Paw 	Cat pats cat with its forepaw(s). Claws are usually retracted.	Paw	Bringing the forepaw into contact with the prey/sibling.	(24, 35)
		Paw	Bringing the forepaw into contact with a cat.	(25)
		Cat contact	Includes pats and bites: Each pat with a paw making contact with another cat and each bite of another cat.	(17, 36)
		Cat Contact	Each pat with a forepaw, and each bite, making contact with another cat (mother or sibling).	(37)
		Paw/pat	Each occurrence of a pawing/patting… movement directed at another individual/mobile object which lasts no longer than 1 s and also involves no grasping or holding of the individual/mobile object.	(14)
Pounce 	Cat leaps onto cat.	Pounce	The kitten crouches with its head held low or touching the ground and its back legs tucked in and its tail straight back. The tail may be moved back and forth. The kitten moves its hindquarters back and forth and moves forward, the thrust coming from the extension of its back legs.	(34)
		Attack	Jump onto a cat and grasp it with forepaws or forelegs.	(25)
Rear 	Cat stands up on its hind legs with forelegs toward or against cat.	Vertical stance	A kitten assumes a sitting position and then rocks back on its hindquarters, lifts its front paws off the ground and stretches them out perpendicular to its body. The kitten also extends its back legs so that it is in a stationary bipedal position.	(34)
		Rear	Each occurrence of sitting, standing or vertical leaping on the hindlegs with forelegs raised and splayed. It was performed beside another cat or object.	(17)
		Rear	Standing or vertical leaping on the hindlegs, with forelegs raised and splayed.	(35)
		Rear	Each occurrence of sitting, standing or vertical leaping on the hindlegs with forelegs raised and splayed.	(36)
		Rear	Standing or vertical leaping on hindlegs, with forelegs raised and splayed.	(24, 25)

(Continued)

TABLE 1 | Continued

Ethogram element as per Stanton et al. (16) unless otherwise indicated (highlighted in bold)	Description	Equivalent term used by other authors	Equivalent definition used by other authors	References
Stalk 	Slow, forward locomotion in a crouched position directed toward cat, with head kept low and eyes focused on cat.	Stalk	Each bout of crouching with hindlegs treading, or creeping (or running briefly) with belly close to the ground and head low toward another cat or object.	(17)
		Stalk	Each bout of low crouching with hindlegs. Treading or creeping (or running briefly) with belly close to the ground and head low toward another cat or object.	(36)
		Crouch	Belly on the ground with all limbs by the side of the body, oriented and attentive to a conspecific; backlegs often treading.	(25)
		Stalk	Each bout of low crouching with hindlegs treading, or creeping (or running briefly) with belly close to the ground and head low toward another individual/mobile object (17).	(14)
Stand-off 	The cat stands near or over another cat with its head oriented toward the head and neck region of the other cat. The subject's mouth can be open and it may raise one of its front paw and paw at other cat.	Stand-up	The kitten stands near or over another kitten with its head oriented toward the head and neck region of the other kitten. The stand-up kitten's mouth is open and it may direct "bites" toward the other kitten. The kitten may also raise one of its front paws and paw at the other kitten.	(34)
		Stand off	Standing next to another cat, often with head twisting; recipient usually in a rolled position.	(25)
Wrestle 	Cat engages in physical contact with cat, whereby the cat struggles with cat. Can include pulling cat toward itself with its forelegs and perform raking movements with the hind legs.	Wrestle	Each bout of lying while clasping with forelegs and kicking with the hind legs another cat or object. This pattern formed part of West's (34) "Belly-up."	(17)
		Rolled contact	Lying on dorsal or lateral surface and employing any of the above contact patterns. (Contact patterns refer to the combined paw, hold, bite and carry scores).	(35)
		Hold	Bringing the forepaw or forearms simultaneously into contact with the prey/sibling.	(24, 35)
		Hold cat	Each occurrence of grasping another cat between the lower part of the forelimbs.	(36)
		Hold	Bringing forepaws or forearms simultaneously into contact with a cat.	(25)
		Rolled contact	Lying on dorsal or lateral surface and employing any contact pattern (Paw, Hold, Bite); (a similar pattern to Barrett and Bateson's "wrestle").	(24, 25)
		Four paw contact	All four paws in contact with another cat while subject is in a rolled position.	(25)
		Foot contact	Contacting another cat with one or two back paws or backlegs, e.g., stepping on, kicking once or repeatedly kicking with backlegs in unison.	(25)
		Rake	Each bout of kicking movements at another cat or at an object with one or both hind legs. A component of Barrett and Bateson's (17) "Wrestling."	(36)
		Roll	Each occurrence of rolling on the side or back [see (38)]. Overlaps with Barrett and Bateson's (17) "Wrestling"	(36)
		Wrestle	Time spent by an individual holding/grabbing another individual/mobile object, sometimes kicking at it with the back legs [incorporates Hold Cat, Hold Object and Rake (36)].	(14)
		Wrestle	One cat struggles with another cat, raking with its hind legs and pulling the "opponent" toward its body with its forelegs. It is mainly a play behaviour, and is distinct from FIGHT (being much less intense and lacking the additional elements of FIGHT).	(39)

Caption 1 Terms highlighted in bold—No equivalent found in standardised ethogram for the felidae by Stanton et al. (16), therefore term by original authors is used and proposed inclusive definition (2nd column). Pictures are redrawn from (17, 35, 40) or drawn according to the descriptions.

Note the ethogram does not include behaviours used to terminate play, since these are generally forms of non-reciprocation or escape by one of the cats. For visualisation purposes, we have used a convention of showing both cats in full, where the behaviour of both actors is important, where it is not, then the cat whose behaviour is not relevant is shown as a partial image.

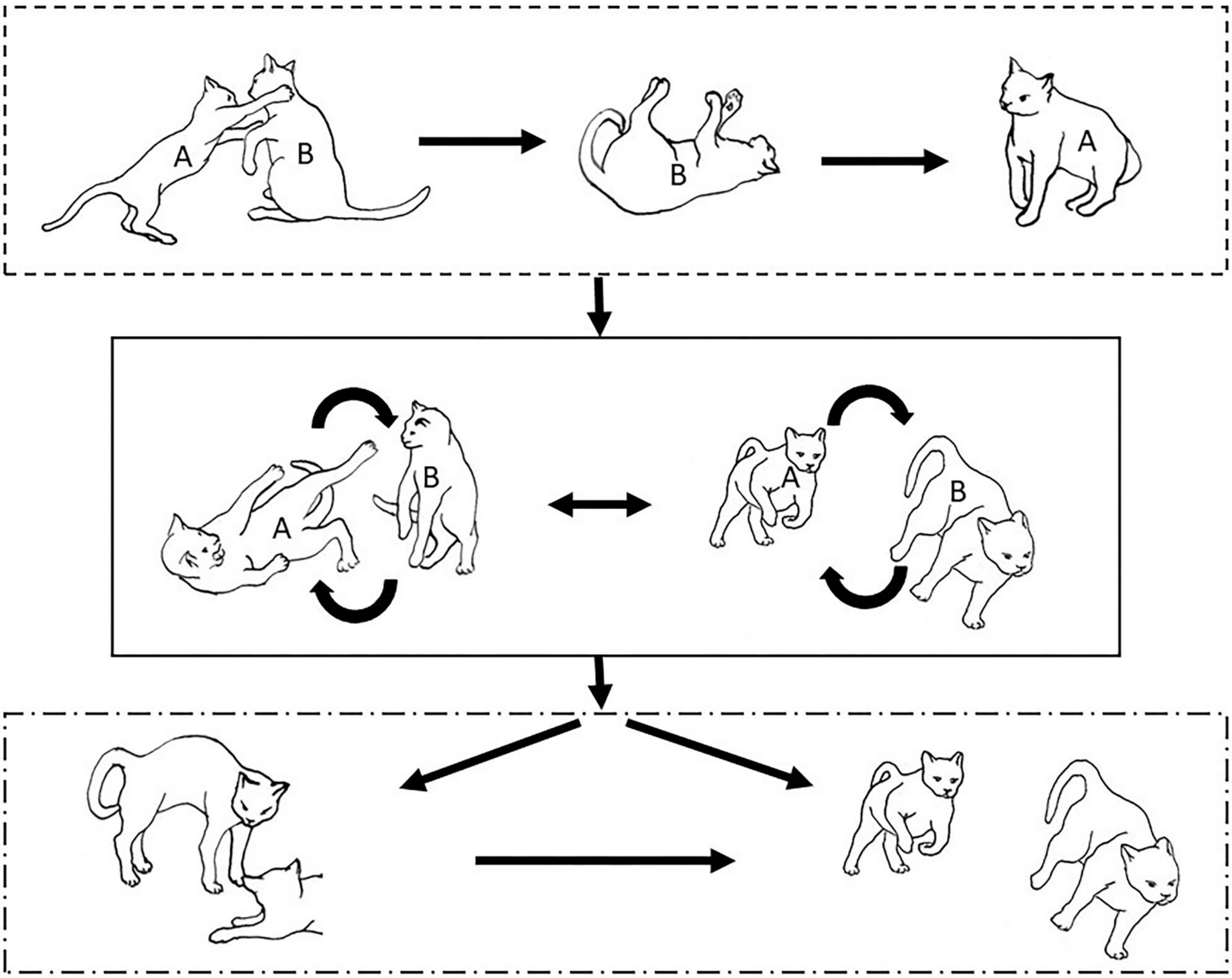


FIGURE 3 | Sequences involved in mutual social play [inspired by (34)]. Top box represents sequences which often form part of initiation of the play, middle box includes those which are seen in continuation of the play and in the bottom box, behaviours which can terminate mutual social play bout without aggressive interaction, are depicted.

also expressed in play may provide important insights into how the importance of certain forms of play may vary with age. For example, side stepping (34) declines as a feature from 12 weeks and this may be because of its resemblance to the defensive arched back posture seen in the agonistic encounters of adult cats. Similarly, the related term "arch" measured in other studies (17, 24) decreases in frequency from the 7th to 12th week of age and occurs much less frequently when intercat play is apparently peaking around 10–14 weeks of age (19). This is consistent with the suggestion that the expression of behaviours in play may help to refine their later functional expression, at which time their appearance in play may need to decline to avoid ambiguity. For example, Caro (24, 35) in his studies of different forms of play in kittens have suggested that arching and chasing are under the control of the same factors that control later agonistic behaviour and separate to those associated with future predatory behaviour, given the negative relationship in their frequency between 8 and 12 weeks of age.

Cat contact appears to decrease while object contact increases from 7th to 8th week of age (17) supporting the separation of related forms of play. It seems that cats continue to play regularly with conspecifics until about 4 months of their age but their attention is gradually drawn to objects, as their need to obtain food by themselves increases (34). Indeed the presence of prey appears to have an inhibitory effect on intercat play (24), while the provision of meat and object play might reduce predatory behaviour, as indicated by the number of prey carried home (44), further reinforcing the function relationships already described.

This is supported by the observation that some behaviour patterns associated with manipulation with prey such as "paw" and "bite" (24) are similar to those used in manipulation with an object (17). The potential for cats to treat other cats as predatory objects is also supported by the observation that observations of cat approaching, pawing, and biting of another cat show positive correlations with respect to other predatory measures from 8th to 12th week of age alongside holding of another cat (24, 35). Thus predation, predatory play and object play appear to be related and this is consistent with the view of Panksepp (20) that they are all expressions of a SEEKING rather than PLAY system even when used within the context of interaction with another cat. However, striking another cat with a paw and biting may also be seen within the functional context of agonistic behaviour in adult cats (24) which is an expression of RAGE [*sensu* (20)] and so it should not be assumed that any given behaviour is specific to a given motivational or affective system. These observations further support the suggestion that there is no single motivational system controlling play.

Clearly, the dynamics of cat play change over time and intercat play can be used to refine express skills associated with predation and agonistic behaviour. Mutual social play appears to be rarer as the kitten matures and this raises concern over the labelling of adult exchanges as playful on the basis of "common sense." The older the cats are, the more cautious we need to be about interpreting their social behaviour.

METASIGNALS AND INTERCAT PLAY

Metasignals are used to help clarify how a piece of information (such as a deliberate action) should be understood. Within the context of play, metacommunication concerns the exchange of signals to indicate that what follows is play (45), rather than what should happen within play. Metacommunicative signals from a sender must be unambiguous and reduce distance between interacting animals (46). Potential metasignals indicating a social play context have been studied in dogs (47–49), while there is some debate about their specific meaning and function (40, 50, 51).

It has been suggested that cats, like dogs, can use a play face (mouth slightly open without showing teeth with ears and eyes relaxed or fairly alert) to communicate a distinction between playful and "serious" encounters (10, 11, 16, 34) but this is a somewhat subjective description and to our knowledge this has never been established by scientific observation of domestic cats. The vertical position of a tail during social encounters (tail-up posture) signals affiliative intent of the cat-sender and thus reduces the risk of aggressive behaviour within an intercat interaction (52, 53). It has been suggested that "tail-up" is also used during social and object play (54) together with other tail movements (11) but the significance of tail postures as metasignals during the mutual social play lacks scientific evaluation. Further observational studies should explore this potentially important contribution to intercat communication. Moreover, as lateralisation of the tail might affect willingness to approach in dogs (55), this aspect should be examined in cats as well, as it might further clarify the tail-signalling function in this species.

Although as mentioned above, certain behaviours such as arching and chasing, whose miscommunication could have serious consequences, tend to decline as features of play, they do not disappear and so it is predicted that there should be some metasignal to qualify these actions for the context of mutual social play. Nonetheless, there appears to be a general lack of research on metasignalling in relation to play in cats, despite its potential importance, especially in adult cats (another understudied area of play in cats). As discussed further below, recognising play in adult cats is also an area of practical concern for owners and those seeking to support the welfare of pets.

FELINE SOCIALITY

The study of social play in domestic cats is complicated by the suggestion that they, unlike their ancestral species, are potentially much more social animals, capable of forming social groups (56, 57). The core of the group is typically formed by related individuals (56) but also non-related cats may live amicably when they are familiar with each other for a longer period (58). Cats that belong to the same social group usually express affiliative behaviours such as holding their tails up when approaching each other, rubbing against each other, allogrooming, sleeping in close contact together and it widely believed that such individuals are capable of playing together as well (57, 59).

Suggestions have also been made about the nature of aggressive acts when they form part of intercat play. Such displays should include minimal or no vocalisation such as growling, hissing or screaming, in addition scratching and biting is inhibited (59) and play fighting should include plenty of pauses (60). When rough-and-tumble play gets too rough one cat may terminate it by simply walking away from the interaction (41), however escalation into harmful interaction is a commonly mentioned scenario in the clinical feline behaviour literature (41, 59, 61). However, many of these points remain speculative and untested in the scientific literature, perhaps because of the problem of reliably identifying cat play without creating circular arguments.

PROBLEMS ARISING FROM RESEARCH METHODOLOGY AIMED AT INCREASING OUR UNDERSTANDING OF INTERCAT PLAY

Observational Studies

The majority of observational research on intercat play has focused on developmental studies in kittens; monitoring spontaneous behaviours of play, from birth until 24th week of age, in the presence of at least one other cat (mother or sibling). This has been conducted in stable (17, 19, 24, 25, 34) or dynamic environmental conditions. These include assessment of the impact of social isolation (62), separation from mother (36), interruption of lactation (37, 63), food rationing (64), and litter size (14) (See **Table 2** for an overview of the main findings of these observational studies). Time of day designated for observation, duration of observation and sampling techniques differed among studies. In nearly all studies [the single exception being (34)], laboratory cats were observed and

TABLE 2 | Overview of main findings from observational studies of intercat play.

Reference	Context in which intercat play has been studied	Main findings related to intercat play
West (34)	Development of intercat play	Eight behaviours of intercat play and their sequences were identified. Intercat play was most frequent in period from 4 weeks to 4 months of cat's age.
Barrett and Bateson (17)	Development of play	Object contact, Wrestle, and Stalk increased and Cat contact and Arch decreased from 4–7 week period to 8–12 week period, suggesting existence of few controlling systems of play behaviour category.
Caro (35)	Relationship between kitten behaviour and adult predation	Approaching, pawing, holding, and biting were positively correlated with adult predatory behaviour and attention to prey, while rearing, arching, and chasing showed negative correlation in this relationship.
Guyot et al. (62)	Effects of social isolation on behaviour of young cats	Kittens deprived of littermates since birth or 2 days of age were less successful in maintaining non-hurtful character of intercat play when tested socially from 8th week to 20th week of age.
Bateson et al. (63)	Effects of lactation interruption (in 5th week after birth) on play in kittens	Interrupted lactation in 6th week after the birth, and thus earlier weaning, resulted in higher frequency of object play but have not influenced intercat play.
Bateson and Young (36)	Effect of separation from mother on development of play in cats	Separation from mother in 5th week after birth resulted in higher frequency of intercat play in period from 5th to 7th week of age of kittens.
Caro (24)	Relationship between intercat play and development of predatory behaviour	All measures of intercat play, with exception of arching, increased in frequency from 5th to 8th week. In the period from 8th to 12th week approaching, pawing and biting were more closely associated with predatory behaviour and rearing arching and chasing became less associated with predation.
Caro (25)	Influence of sex on termination of intercat play	Males from all-male groups played together more than females from all-male groups in period from 12 to 16 weeks of age, while frequencies of females' play behaviours declined with decreasing number of males in group.
Martin and Bateson (37)	Effects of lactation interruption (in 4th week after birth) on play in kittens	Early weaned kittens showed higher frequencies of intercat play than kittens from control group.
Mendoza and Ramirez (19)	Relationship between play and cohesion and aggression in cats	Occurrence of intercat play peaked between 9th and 14th week, period during which cohesion behaviours (approach, physical contact, interindividual closeness, nose-nose contact) were observed.
Mendl (14)	Effects of litter-size variation on development of play in cats	Single kittens experienced less intercat play than kittens with siblings but directed play behaviour more on their mothers, which did not always reciprocate this activity.
Bateson et al. (64)	Effect of lactating mother's food rationing on play in kittens	Frequency of intercat play did not differ between kittens from rationed families and those from *ad libitum* families.

so how this relates to what emerges in the more complex home environment of most cats is questionable. The studies show what can affect play behaviour not what necessarily does in the typical world setting.

Another group of observational studies concern simple descriptions of intercat play in adult cats (65–67), which often lack useful controls and may define social play very loosely. This can lead to confusion about the meaningful characteristics of social play. For example, one study, supposedly on social play, focused only on play between a cat and human in domestic settings and did not consider who initiated the action and how this might affect the behaviours observed (21). Another considered two cats playing with the same toy simultaneously as a form of social play (23). With poor definition of "social play," the assumption that it is an indicator of good welfare may be challenged and the validity of the conclusions drawn, especially the absence of an effect of an intervention, may be questionable.

Questionnaire Based Studies

To our knowledge, somewhat surprisingly, the structure of intercat play as a specific entity has not been studied using questionnaire based studies. However, "Playfulness" in the form of a single item on play with other household cat(s) together with 13 other items on playful behaviour related to object and self play, does form part of the Feline Behavioural Assessment and Research Questionnaire (Fe-BARQ) (68, 69). This appears to be the only validated questionnaire of relevance developed to date. Fe-BARQ consists of 101 items relating to the behaviour of cats which group into 23 factors; each item is scored using a 5-point Likert scale referring to the frequency of behavioural item (0 = never to 4 = always). In relation to intercat play, Fe-BARQ combines this item with other play contexts (e.g., play with object or people) into a common "Playfulness factor," because the former is more closely related to the latter than any other aspect of behaviour assessed. This does not mean that it shares a common mechanistic basis and the concept of "playfulness" as a common factor may be misleading, as demonstrated by some of the specific relationships identified in section on the structure of intercat play, above. Mindful of this limitation, Fe-BARQ has been used in a recent study (70) to evaluate the relationship between aggression toward other cats and playfulness with objects or people and the item relating to "social play" (cat plays with other household cat/s). This found a negative relationship between "social play" and intraspecific aggressivity and a positive relationship with other forms of playfulness, but neither relationship was strong. This supports our suggestion that there is a fair degree of independence between social play and these other factors.

CONCLUDING COMMENTS

Burghardt's five criteria for recognising play are difficult to apply scientifically when two cats are playing together, and there is a danger that circular reasoning is applied when analysing play behaviour in cats. Accordingly, the descriptive value of observational field and contextual data needs to be clearly separated from the functional inferences which it may be used to support. The latter are hypotheses about the likely emotional-motivational state of the two interacting cats, and should be considered tentative until we can apply more definitive tests. Appealing to common sense is inadequate. In order to make progress, it is important that a standard terminology is adopted and the distinction between the observed and the inferred is clearly acknowledged and articulated. A functional classification is important from a clinical behavioural context, where the humane management of the behaviour, and thus hypothesised internal state, is important. Indeed, it might be that through careful analysis of intervention programmes and the gathering of detailed ethological data, in line with the recommendations above, that we can test our hypotheses and advance our understanding of whether "these two cats are playing" in a scientifically more rigorous way.

We propose here adoption of a standard terminology and functional affective classification to play between cats considering emotion and motivation. Thus, a cat may be playing by itself, or be with another and perceiving it as an object (including prey), in which case the activity relates to the desire to learn about an individual's own capacity in relation to the physical environment; this should not be considered from a functional perspective to be social play, even if another cat is involved (i.e., it is a form of intercat play). At other times interaction with another cat may facilitate learning about the individual's capacity in relation to the social environment (including both social skills and social role), and in these circumstances we would argue that the interaction is from a functional perspective social play, which may or may not be mutual. Further it needs to be recognised that bouts of intercat interaction can start as mutual social play but can turn into intercat play, when reciprocity is lost or the interaction becomes truly agonistic. Such alternation between emotional-motivational states is not uncommon in cats and adds a layer of complexity not evident in some other species, such as the dog.

AUTHOR CONTRIBUTIONS

NGK and DM conceptualised and designed the manuscript. NGK reviewed the literature. All authors contributed to the article and approved the submitted version.

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The Urinary Hormonal State of Cats Associated With Social Interaction With Humans

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Research to assess the relationship between cats and humans is in a nascent stage. Some studies have assessed the stress status in cats using physiological indicators, such as the cortisol hormone, but have not focused on the social interaction with humans. Moreover, the role of oxytocin secretion in the relationship between cats and humans remains unclear. In this study, we determined the possibility of quantifying the urinary concentration of oxytocin in cats and assessed the effects of social contact with humans on the levels of urinary oxytocin and cortisol metabolite. Four cats were subjected to two conditions, namely, social (control), and non-social (no social contact with humans) conditions. The levels of cortisol and oxytocin metabolite in urine samples from the cats in both conditions were determined using enzyme-linked immunosorbent assays. The urinary concentrations of cortisol and oxytocin under the non-social condition were significantly higher than those under the social condition. In addition, the concentration of oxytocin significantly correlated with that of cortisol in cats under the non-social condition. In this study, it was possible to quantify the concentration of oxytocin in the urine of cats, and the obtained results suggest that cats recognize the social interaction with humans as important. This information might contribute to the establishment of an assessment method for the welfare of cats and might help in clarifying the relationship between cats and humans.

Keywords: cats, humans, social interaction, cortisol, oxytocin, urinary

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INTRODUCTION

The number of cats exceeds that of dogs in Japan (1), and this trend is common worldwide (2). The life expectancy of cats (3, 4) as well as of humans (5) has increased. To enhance the relationship between cats and humans, more information related to the human–cat interaction is needed.

There is a large and increasing number of questionnaires related to the human–animal interaction (HAI) (6). A questionnaire is an essential subjective indicator to assess the relationships between cats and humans. However, Rodriguez et al. (7) has highlighted the need to incorporate methodologically rigorous designs, combining both subjective and objective outcome measures, for developing the field of HAI. Thus, objective measurements, such as behavioral observation and physiological assessment, are also fundamental indicators in the field of HAI research.

Behavioral observation, for example, the development of an ethogram (8, 9), is frequently used to assess the relationships between humans and cats. The cat stress score is a well-known observational assessment scale for evaluating the stress status in cats (10). Several studies on shelter cats used this assessment scale (11, 12); however, these studies have focused on the welfare of the cats, and not their relationship with humans.

Several physiological indicators, such as the heart rate variability and blood pressure, are mainly used in the field of veterinary research to assess the clinical conditions of cats (13, 14). Cortisol is a steroid hormone released to help cope with an acute stressor (15); it is, therefore, a useful indicator of the stress status in cats. Blood is a valid sample for quantifying the concentration of cortisol (16). However, procurement of this sample type is accompanied by physical confirmation (e.g., holding of the body) and an invasive procedure; thus, researchers should have confirmation sample types that can be collected non-invasively. For example, feces (17, 18) and hair (18) samples have been used to measure the concentration of cortisol. Especially in the field of HAI research, urine samples are useful because of the ease of collection. These studies have been conducted under various conditions, for example, in shelter (19, 20), laboratory (21), and house (22). Nevertheless, these studies were focused on the welfare of cats, not on their social interaction and relationship with humans.

Recently, oxytocin has received much attention in the field of HAI research. Oxytocin has variable functions, for example, in stress reduction, such as in decreasing the cortisol concentration and blood pressure (23), promoting well-being (24), and increasing social behavior (25). Rault et al. (26) mentioned that oxytocin is an essential indicator of psychological and social well-being in domesticated animals. Furthermore, oxytocin has a function related to pregnancy and uterine contractions (27), and is related to the construction of attachment relationships between infants and mothers (28). Some studies have shown relationships between dogs and humans, similar to those of infants and mothers (29).

Mutual interaction between dogs and their owners causes the secretion of oxytocin from their bodies (30, 31). Pet owners develop attachment not only with their dogs but also with cats (32). Therefore, oxytocin secretion may be a key factor in creating a bond between cats and humans. However, Potter and Mills (33) suggested that the attachment between cats and their owners is not transparent. Additionally, it is unclear whether oxytocin secretion is associated with the construction of a bond between cats and humans. To understand the genuine relationships between cats and humans, it is necessary to conduct a study focused on oxytocin. Blood oxytocin concentration in cats has been assessed by enzyme-linked immunosorbent assay (ELISA) (34). However, blood sampling can be quite stressful for the animals, and the evaluation of the correct physiological values is difficult. The content of urine is filtered from the blood, accumulated in a certain amount, and then naturally expelled. Therefore, urinary analysis may be an optimal non-invasive method for assessing these physiological conditions.

The purpose of this study was to determine whether the feline urinary cortisol and oxytocin metabolite concentrations could be quantified by ELISA. In addition, to clarify the relationship between cats and humans, we examined whether social contact with humans affects the concentration of these hormones in cats.

METHOD

Ethics Statement

The experiments performed in this study were approved by the Animal Experiment Ethics Committee (approval number: 1301312) at the Tokyo University of Agriculture in accordance with the World Medical Association's Declaration of Helsinki.

Test Animals

The experiment was performed on four cats (A: 3-year-old, male, mix; B: 6-year-old, male; C: 10-year-old, female, Ragdoll; D: 3-year-old, female, mix). All the cats had always lived in a laboratory room (7 × 7 m) like a house cat. The cats freely spent time in the same room and were individually kept in a three-tier cage (93 × 63 × 178 cm) during the nighttime. Additionally, a caretaker looked after the cats as a house cat every day, ensuring proper feeding, physical care, playing, clicker training, physical contact (touching, petting, and grooming), and oral communication (calling and talking).

Assay Methods

Collection of Urine Samples

To ensure the welfare of the cats, we adopted a non-invasive method of urine collection by natural urination. Additionally, we collected spot urine samples, instead of pooled samples, each time from the tray in litter boxes and transferred them directly to plastic 2-ml centrifuge tubes. The samples were kept frozen at −80°C until analysis. For quantification, the supernatant obtained after centrifugation of the urine samples at 1,661 × *g* for 15 min at 4°C was used.

Quantification of Cortisol in Urine Samples

Urinary cortisol metabolite concentration was determined using the DetectX® Cortisol Enzyme Immunoassay Kit (K003—H5W, Arbor Assays LLC, USA; goat anti-mouse IgG) used in previous studies (35, 36). The assay standard curve ranged from 50 to 3,200 pg/ml, and the assay sensitivity was 27.6 pg/ml. The urine samples were diluted 10-fold with the assay buffer. The intra-assay coefficient of variation (CV) for the cortisol assay was 4.10%, and the inter-assay CV was 5.25%.

Quantification of Oxytocin in Urine Samples

The urine samples were extracted with a Hyper Sep C18 column (3 ml/200 g, Thermo Fisher Scientific, Tokyo), as described by Finkenwirth et al. (37). Previous studies successfully quantified the urinary metabolite concentrations in dogs, wolves, and humans (38, 39). The C18 column was conditioned by washing three times with 3 ml of 100% methanol and then three times with 3 ml of distilled water. A mixture of 1 ml of urine sample and 10 μl of phosphoric acid was transferred to the column. The columns were washed with 3 ml of 10% acetonitrile and 0.1% trifluoroacetic acid. Samples were then eluted with 1 ml of 80% acetonitrile. The eluted samples were dried using an evaporator. The dried samples were reconstituted in 1 ml of assay buffer provided with the kit and used for determining the metabolite concentration of oxytocin. Urinary oxytocin metabolite concentration was determined using the DetectX® oxytocin Enzyme Immunoassay Kit (K048 - H5, Arbor Assays LLC; goat anti-rabbit IgG) used in previous studies (40, 41). The assay standard curve ranged from 16.38 to 10,000 pg/ml, the assay sensitivity was 17.0 pg/ml, the intra-assay CV for the oxytocin assay was 4.25%, and the inter-assay CV was 4.59%.

Quantification of Creatinine in Urine Samples

Throughout the experiments, the four cats had free access to drinking water; thus, the water intake of individual cats varied daily. Therefore, the urinary hormone concentrations need to be corrected by urinary creatinine to account for the quantity of water in the sample. All oxytocin and cortisol levels were described as pg/mg creatinine (Cre). The concentration of creatinine was measured by the Jaffe reaction using 96-well microplates (3881–096, Iwaki, Japan). After the reaction, the optical density was read at 490 nm using a microplate reader.

Experimental Protocol

The experiment was performed under two conditions: social condition (SC) and non-social condition (NSC). In SC, urine samples were continuously collected for 3 days. In NSC, arrangements were made such that the caretaker engaged in minimum necessary care (e.g., feeding and managing the environment), excluding social contact (e.g., physical care, playing, clicker training, physical contact, and oral communication) for 3 days. The interval between the experiments under the two conditions was 2 weeks. All cats were fed a constant amount of food throughout the experiment to negate its effects on urinary hormone metabolite concentrations.

Statistical Analyses

We excluded outliers, defined as 1.5 × interquartile range (IQR), from the analysis. The difference in the mean hormone concentration during SC and NSC was determined using the Welch's *t*-test or Mann–Whitney *U*-test. The effect sizes were calculated by Cohen's d. Using Spearman's rank correlation coefficient, we assessed the correlation between cortisol and oxytocin concentrations. Statistical significance was set at $p < 0.05$. All statistical analyses were performed using BellCurve for Excel (Social Survey Research Information Co., Ltd., Japan). There was no outliner in the cortisol assay, whereas there were three outliers in both SC and NSC in the oxytocin assay.

RESULTS

We collected 54 urine samples and performed the different quantification assays. The mean cortisol metabolite concentrations in SC and NSC were 5,433.40 ± 1,805.02 ($n = 25$, range 1,843.53–9,528.73) and 6,339.98 ± 1,908.95 ($n = 29$, range 3,531.81–11,048.50) pg/mg•Cre, respectively (**Figure 1A**). The mean oxytocin metabolite concentrations in SC and NSC were 115.72 ± 9.28 ($n = 22$, range 31.62–203.48) and 193.06 ± 82.57 ($n = 26$, range 61.63–383.91) pg/mg•Cre, respectively (**Figure 1B**).

There was a significant difference in the cortisol concentration between SC and NSC conditions in all 54 samples (**Figure 2A**, $p < 0.05$; Cohen's d: 0.49). However, no differences were found when analyzing the samples collected from each individual: A ($p > 0.05$; Cohen's d: 0.98), B ($p > 0.05$; Cohen's d: 0.44), C ($p > 0.05$; Cohen's d: 0.02), and D ($p > 0.05$; Cohen's d: 0.96).

The concentration of oxytocin in NSC significantly increased relative to that in SC for all the samples (**Figure 2B**, $p < 0.01$; Cohen's d: 1.39), and samples belonging to cats B ($p < 0.01$; Cohen's d: 1.98), C ($p < 0.05$; Cohen's d: 1.14), and D ($p < 0.05$; Cohen's d: 1.54); however, there was no difference for cat A ($p > 0.05$; Cohen's d: 1.13).

In all the samples, there was a significant correlation between cortisol and oxytocin concentrations (**Figure 3A**, $r = 0.40$, $p < 0.01$). In SC, the concentration of cortisol did not correlate with that of oxytocin (**Figure 3B**, $r = 0.07$); however, in NSC, cortisol concentration significantly correlated with that of oxytocin (**Figure 3C**, $r = 0.45$, $p < 0.01$).

DISCUSSION

We showed that it is possible to quantify the urinary metabolite concentrations of hormones in cats using ELISA; hitherto, there has only been one report (34) on the quantification of the blood oxytocin concentration in cats. Measurement of both cortisol and oxytocin might help in accurately assessing the physiological status of cats because oxytocin influences the activities of the hypothalamic–pituitary–adrenal axis and autonomic nervous system, as does cortisol (23). Measurement of not only cortisol but also of oxytocin is a useful method to accurately understand the physical status of house cats; therefore, our results are of great importance in the field of HAI.

It is notable that we used the natural spot of urination of cats. Because urine sampling through an invasive method using catheters might have negative effects on the welfare of cats, we adopted a non-invasive method. Thus, methods for collection of samples for physiological assessment of cats under different situations (e.g., laboratory cats, shelter cats, stray cats, and household cats) should be expanded. Additionally, in this study, we focused on urinary metabolite concentration, and not locally produced and circulating hormones. Urine metabolites accumulate in the bladder for a long time; thus, urinary metabolite concentration reflects the long-term physiological condition. Urinary metabolite hormone concentrations correlate with circulating hormone concentration (42). This is an advantage in assessing the basal and long-term physiological states, and not just temporary and short-term states. The purpose of this study was to determine the physiological state of cats for 3 days; therefore, metabolite concentrations served as reasonable indicators. Future studies should focus on developing quantification methods for urinary hormone metabolites as assessment tools for the welfare of cats.

There is controversy regarding the immune-reactivity of urinary oxytocin metabolite in ELISA. Previous studies in

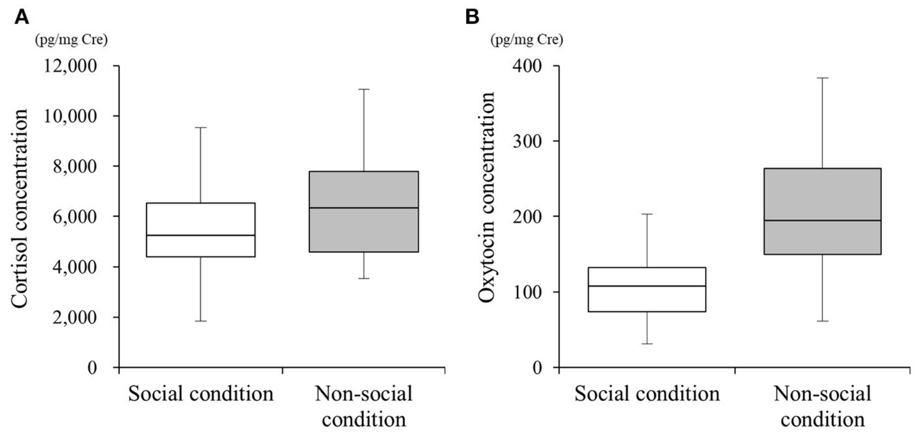

FIGURE 1 | Differences in urinary cortisol **(A)** and oxytocin **(B)** concentrations under social (SC) and non-social (NSC) conditions. Box plots show the interquartile range (IQR) for each condition, with whiskers extending to 1.5× the IQR.

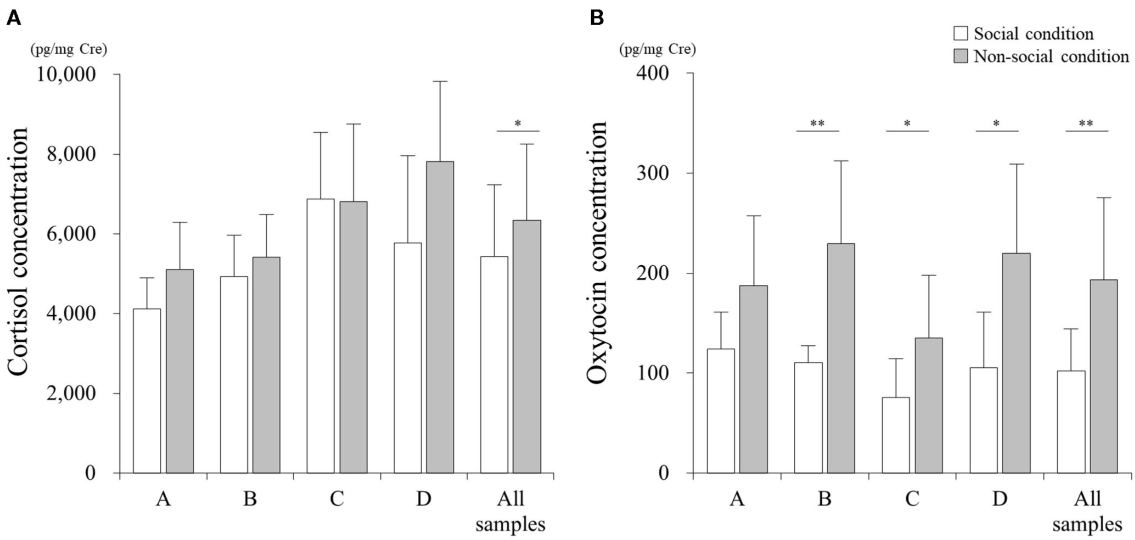

FIGURE 2 | Comparisons of cortisol **(A)** and oxytocin **(B)** concentrations between social (SC) and non-social (NSC) conditions. $^{*}p < 0.05$, $^{**}p < 0.01$.

dogs, wolves, and humans reported that urinary oxytocin metabolite has two peaks of immune-reactivity although the oxytocin metabolite concentration can be quantified (38, 39, 42). Moreover, a previous study reported no relationship between OT in the plasma and urinary samples in humans (43). The findings of this study should be interpreted carefully. In the future, it is necessary to verify the immune reactivity of urinary oxytocin in cats.

In the present study, the metabolite concentrations of both cortisol and oxytocin under NSC were higher than those under SC. Acute stressors induce the secretion of cortisol; thus, cats might perceive the interception of social communication with humans as a stressful event. In previous studies, interaction with humans has positive physiological and behavioral effects on shelter cats (44, 45). Our results possibly support the results of these studies from the perspective of hormonal change. Additionally, oxytocin concentrations in three out of four cats were different between SC and NSC conditions, although the difference for cortisol concentrations was not confirmed. Oxytocin has the functions not only to inhibit and reduce stress (46, 47) but also to promotes social behavior (48–50). Oxytocin might have been secreted in cats seeking social interaction with humans; therefore, we believe that cats recognize interactions with humans as important. Moreover, in NSC, but not in SC, urinary cortisol concentration was significantly correlated with oxytocin. The basal plasma concentrations of oxytocin and cortisol have a positive correlation only when the experimental situation causes anticipation of stress or a novel situation (51). Our results show that cats might have perceived NSC as a stressful event, and as such, the concentration of urinary oxytocin would

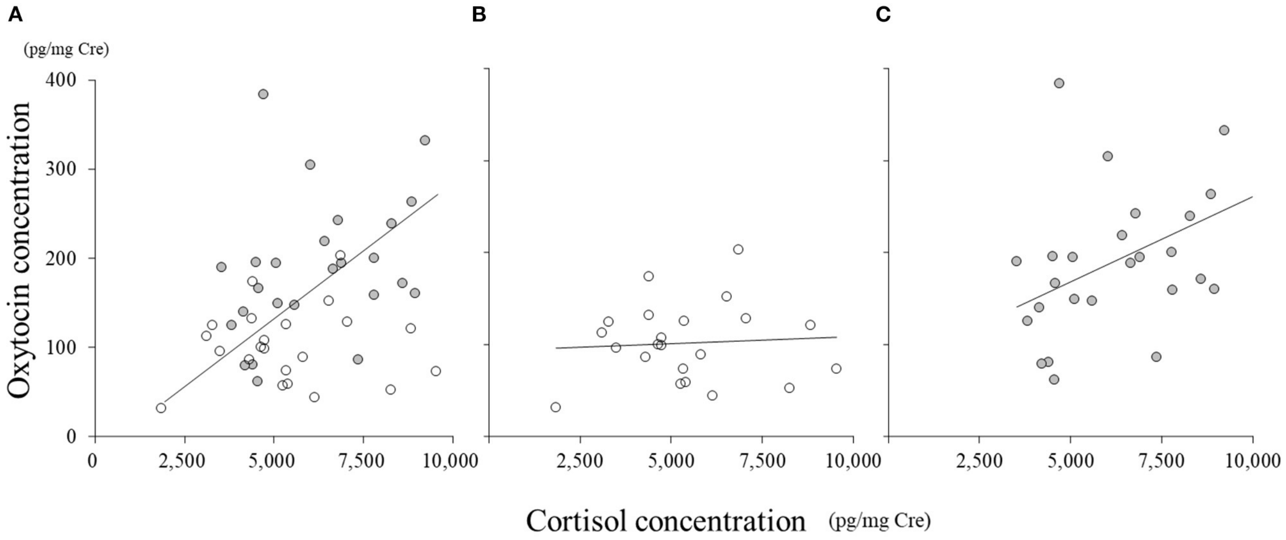

FIGURE 3 | Correlations between oxytocin and cortisol concentrations. **(A)** All samples; **(B)** social condition (SC); **(C)** non-social condition (NSC).

be correlated with that of urinary cortisol under social stress conditions, but not under normal conditions.

It is not easy to interpret the results of this study. At first, oxytocin has variable physiological functions; thus, the rigorous causal relationship for consequence is still unclear. Second, there is evidence showing the negative correlation between circulating oxytocin and cortisol (52), namely, oxytocin has the function to inhibit the activity of cortisol. The reverse consequence of this study may be explained as a difference in the period of interest. The phenomenon that oxytocin decreases the cortisol concentration might occur following both cortisol and oxytocin temporal increase. In the case of the result of the above whole phenomenon, both the urinary oxytocin and cortisol metabolite concentration might be high levels; therefore, it is a possible explanation that both urinary oxytocin and cortisol of cats showed high levels in the social stress condition. However, it is very difficult to judge the conclusion by only this study. This study had a potential limitation, as only four cats were included in this study, and the number of urinary samples collected was small. Moreover, the cats were only kept for 3 days under NSC considering the welfare of the cats. In the future, it is required that more cats and urine samples are analyzed, and deeply discuss the relationship between cortisol and oxytocin.

Herein, we demonstrated the possibility of quantifying the urinary metabolite concentration of oxytocin in cats. Moreover, the urinary metabolite concentrations of oxytocin and cortisol in cats were found to be influenced by social interaction with humans. The results of the present study should contribute to the development of strategies for the welfare of cats and should provide a new perspective on the social relationship between cats and humans.

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 authors.

ETHICS STATEMENT

The animal study was reviewed and approved by Animal Experiment Ethics Committee at the Tokyo University of Agriculture.

AUTHOR CONTRIBUTIONS

TN performed the experiments and analyzed the data. All authors planned the experiments and wrote the manuscript.

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Exploratory Study of Fecal Cortisol, Weight, and Behavior as Measures of Stress and Welfare in Shelter Cats During Assimilation Into Families of Children With Autism Spectrum Disorder

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Background: Cats are a common companion animal (CA) in US households, and many live in families of children with autism spectrum disorder (ASD). The prevalence of ASD is one in 54, and many children have behavior challenges as well as their diagnostic communication disorders.

Objective: Benefits of CAs for children with ASD have been identified, but little is known about the welfare of CAs in these homes. This study explored the welfare of cats ($N = 10$) screened for ideal social and calm temperament using the Feline Temperament Profile (FTP) and adopted by families of children with ASD.

Methods: Cat stress was measured using fecal cortisol, weight, and a behavior stress measure (cat stress score). Measures were taken at baseline in the shelter, 2–3 days after adoption, and at weeks 6, 12, and 18.

Result: Outcome measures suggested the adopted cats' stress levels did not increase postadoption; however, the small sample size limited analytical power and generalizability.

Conclusion: This study provides preliminary evidence for the success of cat adoption by families of children with ASD, when cats have been temperament screened and cat behavior educational information is provided. Further research is warranted to confirm these findings.

Keywords: cat stress, autism spectrum disorder, children, shelter cats, cat adoption

INTRODUCTION

The most common companion animal in US homes is the housecat with over 86 million living in American homes (1). Among these homes are many families of children with autism spectrum disorder (ASD). One in 54 children are identified as having ASD, and symptoms for these children include social, communication, and other behavior challenges (2). These behavior problems could pose potential challenges for the well-being of cats. Children with ASD are shown to benefit from the presence of companion animals (CAs) (3–5). However, to our knowledge, no specific studies have been conducted on the welfare of cats residing in homes of children with ASD.

Cats adapt to and respond positively to consistent, safe predictable environments. Cats may exhibit problem behaviors when placed in stressful situations, such as, entering a new family (6). Households with children can be stressful; families of children with ASD may represent an especially stressful home environment. Approximately 70% of children with ASD are reported by their parents to have had severe temper tantrums at some point and 60% of those within the severe tantrum group were reported to continue to have tantrums on a daily basis (7). Loud sounds accompanying tantrums could present a challenge for cats exposed to this noise. Amat et al. (8) reported cats with noise-related phobias are more likely to respond with redirected aggression toward humans. Cats routinely subjected to unpredictable child behavior and noise may have increased stress. The behavior changes observed, secondary to stress, may mimic medical conditions such as anorexia, vomiting, and diarrhea (9) with resultant weight loss indicating a decline in health (10).

Screening cats for calm and social temperament for adoption by families of children with ASD and identifying cat stressors may be key to promoting cat welfare in home introductions. The Feline Temperament Profile (FTP) has been validated as an objective measure of cat temperament. Increased stress, which may result in undesirable behavior, leads to a physiological response of increased cortisol in cats (11, 12). Cortisol can be measured in cat feces, providing a non-stressful and reliable method of sample collection (13). Cats often need a minimum of a 12-week time period to adjust to a new environment (6). Therefore, assessing both behavioral and physiological measures (13) for at least 12 weeks should be adequate to identify welfare issues within new home environments.

The aim of this study was to explore the stress and welfare of cats in families of children with ASD. The following hypothesis was posited: After a transition period, shelter cats screened for social and calm temperaments introduced into the families of children with ASD will not demonstrate significant signs of stress (i.e., increased fecal cortisol levels, weight loss, or stress behaviors).

MATERIALS AND METHODS

The Experiment

This study was approved by the Animal Care and Use Committee of the University (protocol #9583). This study was nested into a randomized controlled trial with families of children with ASD adopting shelter cats (14). A repeated measures design with data collection at baseline, 2–3 days after cat adoption, and weeks 6, 12, and 18 was conducted. Parents in the adopting families were also contacted by study staff 3 weeks after adoption to inquire about cat acclimation and to offer educational support, if needed. Results on the child arm of the study, including child-cat interaction and bonding go beyond the aim of this study and were published separately (14). Findings in the child arm indicated that cat adoption might be beneficial for some children with ASD.

Animals

Cats were screened from two participating animal shelters and required to reach a score of 20 or greater on the FTP to be eligible for adoption. Any cat attempting to bite during the FTP assessment was excluded, regardless of the FTP score. Cats were required to be between the ages of 10 months to 4 years old (based on estimated ages by shelter staff). All cats were spayed or neutered, current on vaccinations, and without health-related issues at the time of adoption.

Participants (hereafter referred to as families) included parents and their child with ASD aged 6–14 years old and not currently living with a cat in their home. Families were excluded if anyone living in their home had cat allergies or acknowledged a history of aggression toward an animal. Families were required to obtain approval to adopt a cat through the standard adoption protocol of the animal shelter where they chose their cat. The study staff provided written and verbal cat care information to the families, including, specific techniques regarding the introduction of a cat into a new environment and how to help cats with life stressors, litter box training, and engaging cats in play, based on recommendations and guidelines developed by The Ohio State Indoor Pet Initiative (15). Each animal shelter also provided verbal instructions on cat adoption.

Once adopted, families were required to maintain their cat indoors only throughout the study and were responsible for all the healthcare of their cat following adoption from the animal shelter. Adopting shelters fed a variety of cat foods as free feeding without restrictions. The study families were supplied with cat food, and cats were allowed free feeding in their adoptive homes. Families were also supplied with cat litter for the duration of the study. Additional supplies families permanently kept included a litter box, cat carrier, toys, and a scratching post with a two-tier level climbing tree, which included a small covered "apartment" to serve as a safe space for their cat. Parents were required to agree to contact the study staff if their child showed any evidence of aggression toward the cat or purposefully injured the cat. If any cat scored a 7 on the Cat Stress Score (CSS), indicating high stress, the study staff would review the educational information with the parents, and the veterinary behaviorist on the study team was available to consult with the family. Study staff were available through telephone contact throughout the study if families had any concerns or questions.

Instruments and Data Collection

The FTP measures cat temperament, sociability, flexibility, aggressiveness, and cat-human match utilizing scores compiled from 10 items which each include "acceptable" and "questionable" behaviors (16). Each item includes a tester directive such as "while talking to the cat, begin to stroke the cat along the head, back and sides." The tester then observes the cat for behaviors such as "rubs against legs or hand" as an example of an acceptable behavior or "bites/attempts to bite hand" as an example of a questionable behavior. One point is allowed for each behavior observed. The FTP is a reliable instrument with Siegford et al. (16) finding no statistically significant difference in cats scored as acceptable before adoption, and at follow-up evaluation, 3 and 6 months postadoption [$F_{(3, 76)} = 1.29$; $p = 0.28$]. The FTP provided the measure of inclusion criterion for the cats in this study. Shelter staff were requested to identify calm cats they would typically consider suitable for a potentially noisy household with children; neither shelter utilized an objective behavior scoring protocol. Cats referred by the shelter staff were then screened by study staff using the FTP to further assess for adoption suitability by study families.

After the families selected their cats for adoption, the cats were held at the shelter until shelter staff were able to collect a fecal sample. Shelter staff stored the fecal samples in freezers measuring at least −8°C and contacted study staff for pick up. Baseline cat weight and CSS was then obtained by study staff and fecal sample transported in a thermal cooler with ice packs to a laboratory freezer measuring −80°C. After cat baseline data were collected, families were notified their cat was ready to be picked up for adoption. All remaining data collection occurred in the family homes.

The CSS served as the behavior outcome measure. The CSS is a measure of cats' stress in novel environments (17). The cat is rated on a 7-point scale (1 = "fully relaxed" to 7 = "terrorized") for different body parts (e.g., body, belly, legs, etc.) and behavior, including vocalization and activity. For example, a body observation score for "fully relaxed" includes the descriptive of "laid out on back or side" and a score of "terrified" includes the description of "crouched directly on top of all fours, shaking." The reliability coefficient of the CSS was 0.9 in cats housed in boarding catteries (17).

Study staff were regularly trained on administration of the FTP and CSS instruments and reassessed throughout the study. Study staff were trained in behavior rating and data collection by a veterinarian practicing in small animal medicine. This training included videotapes of cat behaviors rated by a board-certified veterinary behaviorist. Videotapes were viewed by team members who rated cat behaviors. If ratings did not reach 90% or greater agreement with the behaviorist's ratings, study staff were required to retrain with the veterinarian until their rating reached 90%. In addition to this, all seven staff raters were required to retrain and their ratings to reach 90% agreement every 6 months during the study.

Cat body weight was measured as a stress indicator in cats, since eating less has been observed in cats under stress resulting in weight loss (10). Cat weights were measured using the Redmon Precision digital pet scale Model 7475 in the shelters and families' homes. Cats were weighed by study staff in homes after CSS score was obtained by placing it directly on the scale by gently picking the cat up or luring the cat with a treat onto the scale. If the cat remained hidden after 5 min and was not visible enough to obtain a CSS assessment, no score was given. At this time, the owner placed the cat in the carrier so a weight could be obtained. If the parent requested assistance to place the cat in the carrier, the study staff assisted by slowly approaching and gently placing the cat into the carrier. After weighing the cat the carrier door was opened to allow the cat to leave the carrier.

Cat fecal cortisol samples served as a physiological stress measure. Adrenocortical activity can be reliably measured through fecal cortisol in cats (18). Cortisol metabolites are stable in fecal samples at room temperature for up to 12 h before freezing (19). The fecal samples can be stored in a household freezer after defecation and transported in a thermal cooler to the laboratory for storage at −20°C until prepared for analysis (20). Fecal glucocorticoid levels were determined using a commercially available corticosterone radioimmunoassay (DA Corticosterone kit, ICN MP Biomedicals), which has been previously validated for domestic cats (18). The lower detection limit of the assay was 0.26 ng/ml and upper detection limit was 20 ng/ml. The assay was performed according to the manufacturer's protocols with the exception that standard diluent was added to the fecal extracts and fecal extraction buffer (containing 50% methanol) to the standards. Concentrations were determined as nanograms per milliliter and then divided by the dry weight of extracted feces to give the results as nanograms per gram feces. All samples were assayed in duplicate. Assay accuracy was assessed by adding a known amount of corticosterone to four fecal extracts that contained low values of glucocorticoids.

Study staff were trained in the non-invasive technique of obtaining, transporting and storing of the fecal samples and weighing the cats. Cat fecal samples were collected by parents who were taught the proper procedure by study staff and instructed to collect a sample within 24 h before the study site visit. Home freezers all functioned at a minimum of −8°C. If no fecal sample was collected by parents, study staff instructed the parents to call the study office when a sample was collected (within three days after visit) and study staff returned and picked up the sample. Samples were transported by study staff in a thermal cooler with ice packs to the laboratory freezer. Samples were shipped using dry ice in batches to the analyzing laboratory.

For fecal hormone extraction, approximately 0.5 g of wet fecal material was weighed then shaken overnight in 5 ml of a modified phosphate-saline buffer containing 50% methanol (21). Liquid extracts were decanted, and solids were removed through centrifugation at 4,000×g. Supernatants were then frozen at −80°C until assay. Fecal solids were placed in a drying oven overnight at 80°C before the assays were conducted. The mean intra assay variation of duplicate samples was 9.7%; the mean inter assay variation of two quality control pools was 7.6%. For assay validation, fecal extracts were tested for linearity by diluting four samples that contained high levels of glucocorticoids by 1/2, 1/4, 1/8, and 1/16 with extraction buffer. Serial dilutions of fecal extracts averaged 90.9 ± 2.6% of expected values. Addition of known amounts of hormone at three dosage levels resulted in the recovery of 101.3 ± 1.7% of added corticosterone.

Statistical Analysis

Descriptive statistics and repeated measures analysis of variance (ANOVA) were used for each of the variables: cat fecal cortisol, cat weight, and CSS. The variables seemed to be normally distributed based on the skewness and kurtosis statistics. A significance level of 0.05 was considered statistically significant for all analyses.

RESULTS

Cat Descriptives and Measures

The shelter staff identified 235 cats as calm and acceptable for adoption by a noisy family. Only 80 of the shelter staff assessed cats met the study criteria of an FTP of 20 or greater for a 34% pass rate. Participating families were allowed to choose a cat from among those passing the FTP criteria. Cats passing the FTP included 46 female and 34 males with a mean age of 21.8 months, and 62 were spayed/neutered. Passing cats had a mean FTP score of 22.4. Adopted cats are described in **Table 1**. Ten cats, seven females and three males were adopted by families. The shelter staff described nine of the cats as domestic shorthair and one as a Russian Blue (cat 1). Cat ages were estimated from 10 months to 4 years with a mean of 18.4 months, and all cats were spayed or neutered before adoption. The FTP acceptable scores ranged from 20 to 29 with a mean of 24.5 (**Tables 1**, **2**). The raw scores for cat fecal cortisol, weight, and CSS at each time point are in **Table 1**. **Table 2** provides the sample means for the demographics as well as all outcomes. Two cats were relinquished to the adopting shelters; one was reportedly due to failure to bond with the child with ASD and house soiling at week 6, and the second reportedly due to undesirable vocal behavior of the cat at week 12.

Fecal Cortisol

Raw scores for all cat fecal cortisol measures are plotted in **Tables 1**, **2** provides sample means for this outcome. Only five cats had complete fecal cortisol data collected at all five time points, thus were used in analysis. Mauchly's test of sphericity indicated that the assumption of sphericity had not been violated, $\chi^2(9) = 13.68$, $p = 0.218$. A statistically significant time effect on fecal cortisol [$F_{(4,16)} = 3.45$, $p = 0.032$] was present. More specifically, fecal cortisol at week 12 was statistically significantly lower than at baseline ($p = 0.032$), although the values at days 2–3 and week 6 were nearly statistically significantly lower than at baseline ($p = 0.065$ for comparison between days 2–3 and baseline, and $p = 0.089$ for comparison between week 6 and baseline).

Cat Weight

Raw scores for all cat weights are plotted in **Tables 1**, **2** provides sample means for this outcome. Three cats (cat 3, cat 7, and cat 8) had incomplete data. Mauchly's test of sphericity indicated that the assumption of sphericity had not been violated, $\chi^2(9) = 10.12$, $p = 0.396$. A statistically significant time effect was observed for cat weight [$F_{(4,20)} = 19.96$, $p < 0.001$]. After an initial nonsignificant drop in weight from baseline (at shelter) to weight at 2 to 3 days after adoption, the average cat weight

TABLE 1 | Individual cat characteristics, signalment, temperament, and stress evaluations.

Cat characteristics					Fecal cortisol (ng/g)					Weight (kg)					Stress score				
ID	FTP A	FTP Q	Sex	Age	BL	T1	T2	T3	T4	BL	T1	T2	T3	T4	BL	T1	T2	T3	T4
1	26	0	F	0.83	759.4	479.6	26.3	388.6	60.3	2.82	2.89	2.89	3.63	3.69	4.0	5.0	2.0	4.0	2.0
2	26	0	F	1	39	54.8	56	107.1	–[d]	3.63	3.40	3.97	3.97	4.20	2.0	2.0	2.0	1.5	1.0
3	22	2	F	2	52.8	166.2	108.5	213.5	–[b]	4.37	4.20	4.37	4.42	–[b]	2.0	3.0	2.0	1.5	–[b]
4	25	2	M	1	100.1	94.7	129.8	56.3	85.3	4.37	4.48	5.28	6.35	6.30	3.0	2.5	3.0	3.0	–[e]
5	26	1	F	1	641.5	118.1	127.5	146.7	116.3	3.80	3.52	3.97	4.82	4.79	3.0	1.0	2.0	–[e]	1.0
6	24	0	M	2	305.1	219.5	322.4	116.4	512.7	4.42	4.31	4.71	5.28	4.99	2.0	2.5	3.0	2.0	1.5
7	23	3	F	1	421.7	73.2	–[a]	–[a]	–[a]	2.89	3.18	–[a]	–[a]	–[a]	2.0	1.5	–[a]	–[a]	–[a]
8	20	0	F	1	826.3	707.2	282.4	205.4	–[a]	2.45	3.01	4.08	–[a]	–[a]	4.0	2.5	2.0	–[a]	–[a]
9	29	1	F	1.5	–[c]	210.3	89.1	282.7	139.5	–[c]	2.61	2.89	2.95	3.12	–[c]	2.0	1.5	2.0	2.0
10	24	0	M	4	756.5	124.2	183.9	90.1	173.1	10.63	4.94	5.67	5.73	5.84	1.0	–[e]	2.0	3.0	1.5

FTP A, number of acceptable feline temperament profile behaviors; FTP Q, number of questionable feline temperament profile behaviors; BL, baseline; T1, 2 to 3 days following adoption; T2, 6 weeks following adoption; T3, 12 weeks following adoption; T4, 18 weeks following adoption. [a]Missing data due to relinquished cat. [b]Missing data due to participant move out of area. [c]Missing data due to shelter failure to collect before adoption. [d]Missing data due to participant inability to collect. [e]Missing data due to cat in hiding.

increased at weeks 6 ($p = 0.008$) and 12 ($p = 0.027$), and cats maintained this weight at week 18.

Cat Stress Score

Raw scores for CSS are plotted in **Tables 1**, **2** provides sample means for demographics and outcomes. Only three cats had complete CSS data collected at all five time points. Missing data included four instances with cats that were in hiding and observation without intervention was unavailable. In one case, a hiding cat occurred on the first visit, 2–3 days after adoption; in another case, it occurred on a visit following the family's return from a 2-week vacation. Lack of CSS data also occurred from two cats that were relinquished before the end of the study and one cat that moved out of state before the final data collection visit. The sphericity assumption was not applicable with the small sample size. There was no statistically significant time effect on CSS [$F_{(4,\ 8)} = 1.82$. $p = 0.218$].

TABLE 2 | Sample characteristics, signalment, temperament, and stress evaluations.

Characteristics *M* (SD) or %				Fecal cortisol (ng/g) *M* (SD)					Weight (kg) *M* (SD)					Stress score *M* (SD)				
FTP A	FTP Q	Sex (F)	Age	BL	T1	T2	T3	T4	BL	T1	T2	T3	T4	BL	T1	T2	T3	T4
24.5	0.9,	70%	1.5	433.6	224.8	147.3	178.5	181.2	3.72	3.67	4.2	4.63	4.72	2.6	2.4	2.2	2.4	1.5
(2.5)	(1.1)		(1.0)	(323.3)	(208.6)	(99.3)	(105.9)	(167.2)	(0.86)	(0.77)	(0.95)	(1.13)	(1.13)	(1.0)	(1.1)	(0.5)	(0.9)	(0.4)

FTP A, number of acceptable feline temperament profile behaviors; FTP Q, number of questionable feline temperament profile behaviors; BL, baseline; T1, 2 to 3 days following adoption; T2, 6 weeks following adoption; T3, 12 weeks following adoption; T4, 18 weeks following adoption.

DISCUSSION

Our exploratory findings suggest the cats in the study, screened for calm temperament using the FTP, acclimated to their adopted homes of families of children with ASD. No empirical literature measuring the acclimation of cats into families with typically developing children could be identified in order to compare results. The FTP, found to be reliable in screening shelter cats for adoption (22), provided an objective screening measure for temperament of cats by identifying cats that were calm, sociable, and without aggressive behaviors during the multiple handling procedures of the assessment. The American Society for the Prevention of Cruelty to Animals (23) reported only 15% of 555 shelters responding to their survey utilized a written score to evaluate cat social skills. In this study, only 34% of cats selected by shelter staff passed the screening criteria to qualify for potential adoption. The utilization of a reliable and objective temperament screening tool by shelter staff may aid in decreasing the relinquishment/return of cats to shelters. Utilizing a temperament screening instrument may aid shelters in helping adoptees to identify a calm cat, which could be particularly important for families of children with ASD. While information on the benefits of dogs for children with ASD appears more often in the literature, cats may also provide benefits (24) when the cat is a good temperament match with the family. Further research could shed light on the value of this assessment procedure in reducing cat relinquishment vs. the time it would take to train and re-assess shelter staff and conduct the FTP screenings.

In addition to screening for temperament, written and verbal educational support was provided to aid families in the adoption process. The education of adult owners and understanding of cat behavior has been found to improve the welfare of cats in homes (25). Of the two cats who were relinquished, neither case was due to aggression; however, one was related to house soiling, which is a common behavioral reason for cat relinquishment (25–27). Therefore, the FTP was successful in identifying calm cats without aggression. Unfortunately, there is no way to predict if an animal will bond with a particular individual. Since the families did not want to pursue help through our veterinary behaviorist, insufficient information was available to determine if the lack of bonding, house soiling, and excessive vocalization in the relinquished cats were due to household stress or other unidentified medical conditions. The educational support, along with supplies including a climbing tree with a scratching post and "apartment" to provide the cat with a private space, which were all provided at the time of adoption, may have also aided the welfare of cats in our study, along with screening for calm temperament.

Elevations in stress may result in behavioral problems leading to relinquishment (28). In a previous study, no significant differences were identified in fecal cortisol levels of cats in shelters compared with their levels after adoption (29). In that study, adoptive owners collected an average of 10 fecal samples over a period of 3 months beginning an average of 3 months after the arrival of their cat (effect size = -0.37, $N = 15$, $p = 0.068$). In Fukimoto et al. (29), it is unclear whether the lack of difference in stress was due to similar stress in the adoptive homes compared with the shelter (i.e., environment) or the adaptability of the cats (i.e., temperament). Cat stress can be very difficult to measure in both the shelter and home environment. Fear and anxiety can result in aggression and the mislabeling of a gentle but fearful cat as an aggressive cat; likewise, a fearful but unfriendly cat may also be mislabeled as calm. Stress can also lead to medical problems as well as behavior problems (30). The potential for environmental stress is high when an animal is placed in a home with unpredictable human interactions. We expected cats to be stressed at the shelter and immediately after adoption; however, we hypothesized the stress would diminish over time. Stress was mitigated in our study through screening both the cat and the home prior to adoption, the education of the owner, as well as environmental enrichment including a safe hiding place for the cat. The reduction in fecal cortisol, as well as no reports of aggression or cystitis [a common sequalae in stressed cats (9, 31)], demonstrates the cat's welfare concerns were adequately addressed in potentially stressful environments.

Several families in this study had unique environmental changes that may have impacted cat stress. For example, in the case of cat 1, which had an elevation in FC on week 12, the parent reported the cat received a new microchip 2 days before the study visit. In addition to this, the parent of cat 1 reported a new significant other who began visiting the house with a dog that the cat reportedly "doesn't like." In the case of cat 3, which also had an elevation in FC on week 12, the child was preparing to move out of state to live with the other parent in the next few days, and this may have created a more chaotic environment with packing and the potential stress of the people in the household. Cat 6 had fluctuations in FC throughout the study. This family included the child with ASD and three siblings under the age of 4 years. One younger sibling was observed to roughly pick up the cat during a visit. The cat wriggled free and jumped down, and the mother reminded the child to be gentle. The child with ASD reportedly had a strong bond with cat 6; however, the busyness of the environment may have been stressful for the cat. Cat 9 had an elevated FC on week 12, and the parent reported that the cat had escaped outside the home in the last few days before the visit but was now back inside.

Cats in our study gained weight after adoption and maintained their weight from 12 to 18 weeks. Buffington (32) reported an increase in stress-related behaviors such as decreased appetite in cats exposed to unusual environmental events. While we did not measure the frequency of behavioral outbursts of the children with ASD in our study, these typically are common occurrences and would have created a potentially stressful environment for the cats. Despite the environment, the initial increase in weight and maintenance of their new weight by cats in this study suggests fear and anxiety did not result in anorexia or decreased appetite, indicating the welfare of the cats in the study was adequate.

Because the sample size for these analyses is very small, while CSS scores overall decreased over time, that change is not statistically significant. Only three cats included a complete data collection set. Data collection for the CSS was particularly challenging with cats that hid on arrival of study staff, especially during the first data collection visit at 2–3 days postadoption. While a cat in this type of hiding would indicate possible fear and stress, accurate scoring was not possible without observation thus resulting in missing data points. Establishing a standard stress score for cats in hiding would have aided in minimizing missing data and would improve findings in future research. An additional measure of asking parents to video the cats between data collection visits might also have added to the understanding of cat welfare in the adoptive homes and would be a valuable addition to future research.

Of the two cats relinquished, the first was at week 6 and the FTP score of this cat was 23 acceptable and 3 questionable (when steady pressure pull of tail: struggles to escape and hisses; when placed on lap: jumps off lap). The parent reported the cat was not bonding well with the child and repeatedly eliminated outside the litter box. Coaching regarding cat behavior was offered by study staff at a 3-week follow-up call, along with an offer of a telephone consult with the veterinary behaviorist on the team, which the parent declined. Based on the FTP score of this cat, cats with any questionable scores might not be a good match for busy/noisy families, even if the cat's total FTP score is 20 or greater. The second cat was relinquished at week 12. The parent reported the child liked the cat, but the cat was vocal during the day while the child was at school and she did not like this behavior. Study staff offered educational behavior support, which was declined by the parent. A third cat was lost to follow-up when the child moved out of state to live with a different parent. Of note is the child took the cat along to the new home.

There are a number of limitations in this exploratory study which minimize the ability to generalize the findings. The original research protocol included a desired sample size of 64 cats. Despite rigorous recruitment techniques including extending the recruitment timeline to over two years, this did not aid in increased numbers of participants. The extended timeline resulted in a turnover of shelter volunteers/staff and one cat being adopted by the family before baseline data was collected. Regular ongoing volunteer/staff training at shelters in future studies would maximize communication with the study staff and minimize missing data. Recruitment efforts also included expanding the geographic area of recruitment up to 125 miles from the study site, sending recruitment flyers by mail, and telephone calling of 534 parents meeting the inclusion criteria from a mid-western autism center database of parents willing to be contacted for possible participation in research. Future studies might benefit from a recruitment site based in a larger metropolitan area. While we can infer from our findings the selection of cats with a FTP score of 20 or greater were likely to be associated with less stress in cats during adjustment, for ethical reasons, cats with lower scores were not selected for adoption by families in our study. Thus, there is no comparison of adopted cats not passing our FTP criteria. This point is moot if cat adoptions are to succeed, every advantage should be in place to provide potential adopters with cat temperament information to aid in a successful match for adoption.

Challenges for the families included an adoption process with two visits to the shelter and fecal sample collection. Despite reminder phone calls from study staff on the day before visits, study staff had to return on multiple occasions to collect samples the next day as parents reported not having a sample ready. Specific reminders during the phone call to collect a fecal sample, rather than just a reminder for the study visit may improve compliance in future studies. However, we acknowledge that even with the incentives provided such as waiver of shelter adoption fees, and cat supplies along with food and litter throughout the study, expecting busy families to collect specimens and have them available for pick up by study staff may be unrealistic.

The small sample in this study did not allow for comparisons of children with differing levels of severity of ASD. Thus, the highly variable symptoms and behavior of each child with ASD eliminated the ability to control for the environment; however, following the families for 18 weeks allowed time for the cats in each "case" to adapt to their environment. Another limitation was not including families with typically developing children for comparison. Future research would benefit from including typically developing children as a comparison group of cat adopting families.

CONCLUSIONS

Screening of shelter cats using the FTP aided in identifying cats with a calm social temperament. Problem behaviors are common among children with ASD, and these may be potentially stressful for cats, especially those with a fearful or timid temperament. Cats adopted in this small exploratory study did not show signs of increased stress after assimilation into their new families. Matching calm cats and providing education to families with a highly variable environment may have aided the acclimation of cats in this study. Due to the small sample size it is not possible to make generalizations about cats adopted by families of children with ASD; however, the methodology provided by this study provides a starting point for future research to explore this important issue for cat welfare.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because Data is owned by the University of Missouri and not publicly available. Requests to access the datasets should be directed to carlislegk@missouri.edu.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by University of Missouri Institutional Review Board. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin. The animal study was reviewed and approved by University of Missouri Animal Care and Use Committee. Written informed consent was obtained from the owners for the participation of their animals in this study.

AUTHOR CONTRIBUTIONS

GC, RJ, JB, and LL: Conceptualization. GC, RJ, and JB: Methodology. GC, RJ, LL, and ZW: Formal analysis. GC: Investigation, Writing—original draft preparation, Project administration. LL, CK, and NC-Z: Resources. GC and ZW: Data curation. GC, RJ, CK, LL, ZW, JB, and NC-Z: Writing—review and editing. GC and RJ: Funding acquisition. All authors have read and agreed to the published version of the article.

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Perspectives of Canadian and American Cat Owners on Provision of Uncontrolled Outdoor Access for Owned Domestic Cats

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While uncontrolled outdoor access can increase opportunities for cat physical and mental stimulation, it can also increase risks of injury and illness, and result in predation of wild birds and small animals. In Canada and the United States, it is often recommended to keep cats indoors, but many owners still provide some level of outdoor access. The objectives of this study were to use a cross-sectional survey to explore the attitudes and practices of cat owners in Canada and the United States toward outdoor access and to identify factors that influence the provision of uncontrolled outdoor access. A convenience sample of cat owners ($N = 7{,}838$) were recruited to complete an online survey, and a mixed logistic regression model was used to examine associations between cat and owner-related factors, and uncontrolled outdoor access for cats, with province/state included as a random effect. In total, 57% of owners kept their cats indoors, and 43% provided some form of outdoor access, with 21% of total owners providing uncontrolled outdoor access. Provision of uncontrolled outdoor access was associated with factors related to cat characteristics (e.g., sex, breed, presence of health, and behavioral issues), the home environment (e.g., living with other pets, types of enrichment provided), owner perspectives on outdoor access (e.g., level of agreement with potential benefits and consequence of outdoor access), and owner demographics (e.g., gender, education, area of residence). For cats with uncontrolled outdoor access, few owners reported their cats having a collar or a microchip, suggesting a need to increase education about precautionary measures to protect the welfare of outdoor cats. Results reveal how owners are caring for their cats in terms of providing outdoor access and generate hypotheses for future research to examine the influence of the owner-pet bond and educational programs on owner practices around providing outdoor access.

Keywords: ***Felis catus*, outdoor access, perspectives, animal welfare, owner, cat**

INTRODUCTION

It has been reported that 37% of Canadian households and 35% of American households own one or more cats (1, 2), which translates to ∼9.3 million companion cats living within households in Canada (1) and 95.6 million in the United States (2). In recent years, both humane societies and wildlife organizations have developed educational campaigns to discourage cat owners from allowing uncontrolled outdoor access (i.e., free-roaming and unsupervised) due to the associated risks to both cats (3, 4) and wildlife (5, 6). Despite these educational campaigns, many cats are still allowed unrestricted outdoor access, without supervision. Based on a report from 2017, Canadian estimates suggest that 56% of owned domestic cats are housed indoors, 16% have outdoor access controlled (e.g., via direct supervision, enclosed area, and kept on a harness), and 28% are allowed at least some level of uncontrolled outdoor access (1).

It has been suggested that outdoor access has welfare benefits for cats since it promotes physical activity and natural behaviors (7), such as hunting, exploring, and climbing, and allows cats some level of autonomy to interact with their environment. Since cats were domesticated primarily for pest control, they remain highly motivated to perform predatory behaviors, including hunting and chasing (8), and have displayed preferences for climbing and perching on higher ground (7). Owned cats in England have also been reported to travel an average of 4.4 kilometers a day (9) when allowed outdoors. Indoor housing has been criticized as providing insufficient opportunities to meet these described needs. Cats confined to homes with limited space or opportunities for exercise are more likely to develop obesity, and other associated health issues (e.g., cardiorespiratory and urogenital disorders) (10). The inability to perform natural behaviors indoors has also been suggested to lead to frustration or boredom, resulting in the development of problematic behaviors (e.g., aggression, furniture scratching, or inappropriate elimination). Studies involving owner-completed surveys have found that some behavior problems are more prevalent in indoor cats than cats with outdoor access (11–14). However, another study found that behavior problems in indoor-restricted cats can be reduced through provision of some forms of enrichment (15).

In contrast, it has also been suggested that outdoor access has the potential to negatively impact cat health and welfare, as it exposes them to increased risks. For instance, cats that are allowed outdoors are at an increased risk of contracting diseases (e.g., feline immunodeficiency virus, rabies, and feline leukemia virus) or parasites through interaction with and exposure to other cats, and to wild or feral animals (8). Outdoor cats also have an increased risk of injury, predation, and poisoning. In areas with heavy traffic, particularly in urban cities, cats are at a higher risk of being involved in vehicle collisions which can cause serious injuries and acute or chronic health issues (7). Predation on cats by predators, such as dogs and coyotes, can also result in trauma and death of cats. Dog bites alone were reported to cause 10% (3/31) of cat trauma fatalities in a study at the Western College of Veterinary Medicine (16). Toxic hazards prevalent in neighborhood gardens or public parks, such as pesticide runoff, water contamination, and certain plants (e.g., lilies) can also increase risks of renal damage, vomiting, or death for outdoor cats (17).

Free-roaming cats can also negatively affect people and other animals. While freely roaming the outdoors, cats can be a nuisance to humans through excessive vocalization or inappropriate elimination on neighbors' properties (18, 19). They can also impact other animals through predation, with one study estimating that cat predation in the United States causes between 6.3 and 22.3 billion mammal deaths and between 1.3 and 4 billion bird deaths per year (20). While these numbers are staggering, most of this predation was attributed to unowned cats, with only 11% being attributed to owned, roaming cats. Further some have suggested these figures might be an overestimation of actual predation levels, and that there is little evidence of population-level impacts in terms of biodiversity as a result of cat predation (21). Regardless of debate over the overall impact of predation by owned cats, it is clear that outdoor access can, at a minimum, contribute to negative effects of cats on welfare and individual survival of wild species (22). Further, if owned cats do not return home they can contribute to unowned (stray or feral) cat population issues, and in turn, related predation. In 2016, Canadian shelters received an estimated 114,131 cats where 56% were admitted as strays and only 10% of these strays were returned to their owners (1).

Limited research has explored factors that influence owner decisions about provision of outdoor access in Canada and the US. In 2001, Clancy et al. (23) released a survey to 184 cat owners to assess owner attitudes toward outdoor access for cats in the US and found that 40% of cats had some degree of outdoor access; however, the authors did not differentiate between controlled and uncontrolled access. They found cats acquired from shelters were less likely to have outdoor access than cats acquired as strays, which they hypothesized was due to increased educational efforts from humane societies. They concluded that owners' decisions to provide outdoor access is multifactorial, suggesting a further study involving a broader population was necessary. In another large-scale study that was international in scope, significant regional differences were noted in attitudes and practices around provision of outdoor access, with owners in the UK, Europe, New Zealand, and Australia being more likely to provide uncontrolled outdoor access than owners in Canada and the US (24). Owners in this study that kept their cats indoors cited several reasons for indoor restriction including concerns about road traffic, protection from other people, animals or wildlife, protection of wildlife from predation, the cat getting lost, and factors related to the individual cat being unable to cope outdoors due to health or temperament. In contrast, reasons that were cited for allowing cats indoor-outdoor access included factors such as improving the cat's mental and physical health, pest control, having a multi-cat household, and the cat having had previous outdoor access.

While research in North America is limited, a number of studies from Australia and New Zealand have examined attitudes and practices of owners around cat containment. Recent figures from this region suggest that a majority of cat owners are allowing cats outdoors, with only 30 and 53% of study participants reporting containment at all times (25, 26). Studies from these regions have examined factors that influence intentions and actions around containment and highlighted various relevant factors. One study found that a majority of owners were concerned about cat safety and protection of native wildlife, with only half of participants being concerned about reducing unwanted breeding and preventing nuisance behavior (25). Further, support for containment at night in cat owners was related to stronger beliefs about impacts on wildlife and cat safety, and beliefs about containment predicted practices around containment. Other studies have also found that owner support for containment is associated with perceived benefits to that cat (26–28) and benefits to the owner (27), and some studies have also found that owner confidence around containment (28) and their perceived control is important (26). However, the influence of concerns about impacts on wildlife has been variable. While Toukhsati et al. (25) found that beliefs about wildlife were important to cat owners, other studies have found either no relationship or only a weak correlation (26, 27) between concerns about wildlife and containment perspectives. One recent study examined interventional messages about wildlife concerns and found that they were effective at increasing motivation to contain and belief that owners could contain (29), so it is possible that these differences between studies reflect a lack of understanding of the potential impact of cats on wildlife.

The overall objective of the current study was to better understand the attitudes and practices of Canadian and American cat owners toward provision of outdoor access through an online cross-sectional survey targeted to current cat owners. A number of specific factors relating to the cat, owner, and home environment have been hypothesized, based on previous literature as described above, to contribute to decisions about providing outdoor access, so a specific objective was to identity factors associated with the provision of uncontrolled outdoor access using regression modeling.

METHODS

This project was reviewed and approved by the University of Guelph (#18-08-019) and The University of British Columbia Research Ethics Boards (#H18-02597) for research involving human participants. A detailed electronic information letter was provided to participants at the landing page for the survey, and consent was demonstrated by participants submitting the survey responses following completion.

Data Collection

Current cat owners completed an online cross-sectional survey that included questions about practices around provision of outdoor access, details of the home environment, and cat and owner demographic information. Inclusion criteria for participants required individuals be 18 years of age or older, a primary caregiver of at least one cat (e.g., routine financial and care responsibilities), and a current resident of either Canada or the United States of America. We used convenience sampling that involved recruitment via snowball sampling on social media, with the initial advertisement shared through Facebook and Twitter. This recruitment method relies on referrals from participants, as participants are encouraged to share the survey to recruit other persons who fit the specific criteria. Thus, from our initial posts, participants were asked to share the social media advertisement with their contacts. This sampling technique has been shown to efficiently reach targeted groups that are otherwise challenging to access (30, 31). The survey was advertised and available from October 31 to November 19, 2018.

Questionnaire

The survey was created using Qualtrics® and was available online. The questionnaire was developed from current literature on topics related to acquisition sources (23), behavioral issues (32), outdoor access (8), and enrichment (15). The questionnaire was comprised of 43 questions categorized into four sections: cat characteristics (e.g., sex, age, breed, source, neuter status, health, and behavioral issues); home environment (e.g., living with other pets, type of outdoor access provided, enrichment techniques used); owner perspectives on outdoor access (e.g., level of agreement with potential benefits and consequences of outdoor access); and owner demographics (e.g., gender, education, age). Specific details about outdoor access were determined by asking yes-no closed-ended questions as to whether owners provide free-roaming unsupervised access, directly supervised access, enclosed outdoor access (e.g., catio), or access on a leash, harness or tie out. If participants owned more than one cat, they were instructed to respond to the survey for only one cat within the household. Selection bias was limited by asking them to respond based on the cat whose name begins with the letter closest to the beginning of the alphabet. In addition, participant responses were not connected to any directly or indirectly identifying information to minimize potential social desirability bias.

Statistical Analysis

All analyses were performed with Stata Statistical Software v.15.1 (StataCorp, College Station, TX, USA).

Data Management

The initial dataset included 107 variables. During data cleaning, questions that had "other" as an option were cross-referenced with existing options to ensure answers were not misrepresented, thereby reducing misclassification bias. For ease of analysis, related variables were collapsed to create the following overarching variables: medical issues (e.g., gastrointestinal issues, skin conditions), aggression (e.g., toward people, cats), ownership of other non-cat pets (e.g., dogs, birds), and interactive enrichment (e.g., small toys, food devices).

Logistic Regression Model

A mixed logistic regression model was developed to test associations between independent variables and the dependent variable, owner-reported provision of uncontrolled outdoor access. Country and province/state were included as random effects. Referent categories for categorical variables were chosen based on biological plausibility or based on the most common response. Correlation analysis was performed on all retained variables, with a correlation coefficient of $>|0.7|$ suggesting collinearity (33). Five correlations related to owner perspectives of outdoor access were detected during this assessment (perspective of access providing natural hunting behavior, natural environment, risk of obesity, natural exploratory behavior, and physical activity), and the most biologically meaningful variables that captured the most information were retained for further analysis (natural hunting behavior, natural environment, and physical activity) (33). Linear relationships between continuous independent variables and the outcome variable (uncontrolled

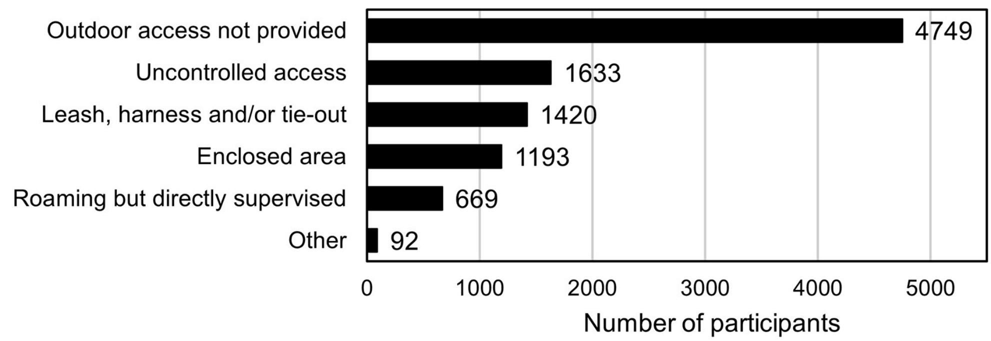

FIGURE 1 | Owner-reported provision of outdoor access for companion cats, including method of provision ($N = 7,838$).

outdoor access) were visually assessed using locally weighted regression curves (lowess) and quadratic relationships were assessed by testing the significance of a quadratic term. If the relationship was quadratic, the quadratic term was retained in the model. If the relationship was neither non-linear nor quadratic, the continuous variable was categorized. As a result of non-linear associations, the following variables were categorized based on biological/practical cut-points: participant age (18–24, 25–44, 45–64, 65+), time spent playing with the cats per day (<1, 1, 2, 3–12 h), and the number of cats owned (1, 2, 3+). Also, cat age was categorized based on the cat life stages presented in the AAFP 2010 guidelines (<4 months, 4–12 months, 1–6 years, 7–10 years, 11–14 years, and >15 years) (34).

Univariable analysis was performed to test each independent variable against the outcome, uncontrolled outdoor access. Variables were retained using a liberal p-value of $p \leq 0.20$ (35). The final main effects model was built using forward stepwise selection method, where significant variables ($p < 0.05$) were retained in the final model. Two-way interactions between biologically plausible variables were tested. Confounders were tested based on their biological plausible relationship with an explanatory variable and the outcome. They were identified as a variable that caused >20% change in a coefficient of another variable in the model. Standardized Pearson residuals were used to detect outliers. The fit of the model was determined by assessing the homoscedasticity and normality of the best linear unbiased predictions (BLUPS). Also, the intra-class correlation coefficients (ICC) were estimated to measure the degree of correlation between cats owned within the same country and province/state.

RESULTS

Descriptive Data

A total of 7,977 responses were collected from the survey and 7,838 complete responses were retained for analysis. The majority of participants resided in Canada (84.5% with 67% of participants residing in Ontario) and 15.5% of participants resided in the United States. Participants were 91.1% women, 5.9% men, and 3% who preferred not to disclose their gender identity or reported their identity was not listed. Participants had a mean age (SD) of 41.6 (13.8) years (range: 18–100+ years) and their corresponding owned cats had a mean age (SD) of 2.2 (1.9) years old (range: <4 months−20+ years). Cats were 50.5% female and 49.5% male, with 72.2% being domestic short-haired, 19.8% domestic long-haired, and 8% purebred.

In total, 43% ($n = 3,370$) of owners provided some degree of outdoor access, with 21% of total owners allowing uncontrolled outdoor access and 22% providing controlled access via direct supervision, enclosed area, or being kept on a harness or leash (**Figure 1**). When owners were asked broadly about their agreement with provision of outdoor access for cats, 46.1% of owners agreed that cats with prior access to the outdoors should continue to be allowed outdoors, with 12.2% of owners unsure how prior access would impact their decision. Also, 78.3% of owners agreed that cats with no previous access should not be allowed outdoor access with 7.4% of owners unsure how no previous access would influence their decision of providing access.

Cat management factors that have the potential to influence cat welfare when cats are allowed outside or kept solely indoors are summarized and presented in **Tables 1**, **2**. Fewer cats with uncontrolled outdoor access were declawed and more were provided with collars or belled collars compared to cats without uncontrolled outdoor access (controlled or indoor). Indoor cats had more access to enrichment, such as interactive toys, elevated platforms, scratching areas, and exploratory items. Similar percentages were detected in regard to being licensed (21.8%, 25.7%) and neutered (97.2%, 97.9%) between cats with uncontrolled and controlled outdoor access.

Risk Factors

Risk factors of uncontrolled outdoor access are presented in **Tables 3–7**, and the final model included factors related to cat characteristics, the home environment, owner perspectives on outdoor access, and owner demographics.

Cat Characteristic Factors

Male cats and cats older than 15 years of age had higher odds of being allowed uncontrolled outdoor access (**Table 3**). Cats who had aggressive behavioral issues directed toward people or other

TABLE 1 | Summary statistics for owner-reported provision of enrichment opportunities for cats with ($n = 1,633$) and without ($n = 4,896$) uncontrolled outdoor access.

		Uncontrolled outdoor access	No uncontrolled outdoor access
Active play time	<1 h	548 (33.7%)	1,366 (28.0%)
	1 h	527 (32.4%)	1,612 (33.0%)
	2 h	324 (19.9%)	1,066 (21.8%)
	3–12 h	229 (14.1%)	843 (17.2%)
Small toys (e.g., furry mice, crinkle sacks)	Yes	1,447 (88.8%)	4,770 (97.5%)
	No	182 (11.2%)	120 (2.5%)
Interactive toys (e.g., feather wand)	Yes	1,115 (69.9%)	4,190 (85.9%)
	No	479 (30.1%)	690 (14.1%)
Feeding device (e.g., puzzle feeders)	Yes	303 (19.4%)	1,349 (27.8%)
	No	1,258 (80.6%)	3,504 (66.0%)
Elevated platforms (e.g., perches)	Yes	1,241 (76.9%)	4,389 (89.9%)
	No	373 (23.1%)	492 (10.1%)
Scratching areas (e.g., scratching post)	Yes	1,311 (81.3%)	4,506 (92.2%)
	No	302 (18.7%)	383 (7.8%)
Exploratory items (e.g., tunnels, boxes)	Yes	1,034 (64.9%)	3,848 (78.9%)
	No	558 (35.1%)	1,031 (21.1%)
Olfactory stimulation (e.g., catnip)	Yes	860 (53.9%)	3,169 (65.0%)
	No	736 (46.1%)	1,703 (35.0%)
Training (e.g., clicker training)	Yes	154 (9.4%)	677 (13.8%)
	No	1,477 (90.6%)	4,213 (86.2%)
Outdoor access under direct supervision	Yes	112 (12.8%)	368 (7.5%)
	No	766 (87.2%)	4,507 (92.5%)
Enclosed outdoor access (e.g., catio, arched cat fencing)	Yes	42 (4.9%)	743 (15.3%)
	No	823 (95.1%)	4,118 (84.7%)
Outdoor access via leash, harness and/or tie out	Yes	27 (3.1%)	1,007 (20.8%)
	No	840 (96.9%)	3,840 (79.2%)

Cats with uncontrolled outdoor access were allowed opportunities to freeroam while unsupervised. Cats with no uncontrolled outdoor access included both indoor-only cats, and cats that were allowed outdoors in a controlled manner (e.g., under direct supervision, kept in an enclosed area, or on a harness or leash).

TABLE 2 | Summary statistics for owner-reported characteristics of cat management that have the potential to impact the welfare of cats during outdoor access for cats with ($n = 1,633$) and without ($n = 4,896$) uncontrolled outdoor access.

Cat characteristics		Uncontrolled outdoor access	No uncontrolled outdoor access
Declaw status	Yes	110 (6.7%)	612 (12.5%)
	No	1,523 (93.3%)	4,282 (87.5%)
Microchip status	Yes	676 (41.5%)	2,632 (53.8%)
	No	910 (55.8%)	2,129 (43.5%)
	Unsure	44 (2.7%)	135 (2.8%)
Collar	Yes	445 (27.3%)	581 (11.9%)
	No	1,167 (71.7%)	484 (9.9%)
	Indoor only	16 (1.0%)	3,811 (73.2%)
Collar with bell	Yes	261 (16.0%)	418 (8.6%)
	No	654 (40.2%)	531 (10.9%)
	Indoor only	13 (0.8%)	3,103 (63.5%)
	No collar	701 (43.0%)	837 (17.1%)
License	Yes	353 (21.8%)	1,258 (25.7%)
	No	1,124 (68.9%)	3,111 (63.6%)
	Unsure	151 (9.3%)	521 (10.7%)
Neuter status	Yes	1,598 (97.2%)	4,758 (97.9%)
	No	31 (2.7%)	133 (1.9%)
	Unsure	4 (0.1%)	3 (0.2%)

Cats with uncontrolled outdoor access were allowed opportunities to freeroam while unsupervised. Cats with no uncontrolled outdoor access included both indoor-only cats, and cats that were allowed outdoors in a controlled manner (e.g., under direct supervision, kept in an enclosed area, or on a harness or leash).

animals in and out of the household, also had increased odds of uncontrolled outdoor access. In contrast, cats who were less than a year old, were purebred, or had an existing medical condition, had decreased odds of being provided with uncontrolled outdoor access. If the owner reported that they had signed an indoor contract upon acquiring the cat, there was lower odds of the owner providing uncontrolled outdoor access.

Owner Demographic Factors

Owners who lived in a village (with a population of less than a thousand people) or resided on a farm had significantly higher odds of allowing their cat uncontrolled outdoor access (**Table 4**). In contrast, owners living in an apartment, condominium, townhouse, or semi-detached house had lower odds of giving their cats uncontrolled outdoor access. Women and owners who had a professional degree (e.g., veterinarian) also had lower odds of providing uncontrolled outdoor access to their cats.

Owner Perspectives

Owners showed a range of perspectives on the benefits and risks associated with outdoor access (**Figure 2**). In general, owners who agreed with risks associated with outdoor access (e.g., contracting a disease) had lower odds of allowing uncontrolled outdoor access, and those who agreed with benefits of providing outdoor access (e.g., increased activity) had higher odds of letting their cats outside uncontrolled (**Tables 5**, **6**).

Home Environment and Enrichment Factors

Cat owners who had additional pets (e.g., dogs, fish, reptiles, and birds) in the home, had higher odds of providing uncontrolled outdoor access (**Table 7**). However, if owners provided interactive enrichment, such as feather wands, small toys, exploratory devices, and elevated platforms, the odds of the owner allowing uncontrolled outdoor access were lower.

Interactions

Significant interactions were found between the: cat's acquisition source and owner's agreement that outdoor access is beneficial for rodent control; cat's age and owner's agreement that cats are highly motivated to go outside; and owner's gender and agreement that outdoor access promotes physical activity. After reviewing the tested interactions, it was determined that the significant interactions involving owner perspectives were not

TABLE 3 | Logistic regression model for risk factors associated with uncontrolled outdoor access for cats based on owner reports, with province/state asLiving location a random effect ($N = 7{,}838$ participants).

Risk factors		OR[a]	95% CI[b]	*P*
Sex		-	-	<0.001
	Female (ref.)[c]	-	-	-
	Male	1.58	1.28, 1.94	**<0.001**
Breed		-	-	<0.001
	Domestic short-haired cat (ref.)	-	-	-
	Domestic long-haired cat	1.03	0.75, 1.26	0.832
	Purebred cat	0.30	0.16, 0.56	**<0.001**
Age		-	-	<0.001
	1–6 years (ref.)	-	-	-
	<4 months	0.02	0.001, 0.29	**0.005**
	4–12 months	0.24	0.13, 0.45	**<0.001**
	7–10 years	1.24	0.95, 1.61	0.116
	11–14 years	1.36	0.99, 1.88	0.060
	15+ years	2.33	1.54, 3.52	**<0.001**
Medical condition		-	-	0.003
	No (ref.)	-	-	-
	Yes	0.68	0.53, 0.88	**0.003**
Aggression		-	-	<0.001
	No (ref.)	-	-	-
	No opportunity to assess	0.38	0.09, 1.68	0.203
	Yes	1.70	1.38, 2.10	**<0.001**
Scratch		-	-	0.0068
	No (ref.)	-	-	**-**
	No opportunity to assess	5.06	1.84, 13.90	**0.002**
	Yes	1.01	0.82, 1.25	0.924
Indoor contract acquisition source		-	-	<0.001
	No (ref.)	-	-	-
	Unsure	0.59	0.39, 0.88	**0.010**
	Yes	0.43	0.29, 0.63	**<0.001**
		-	-	0.003
	Cat rescue or shelter (ref.)	-	-	-
	Cattery	0.69	0.24, 2.03	0.504
	Classified advertisement	1.05	0.70, 1.56	0.825
	Family or friend	1.21	0.89, 1.65	0.224
	Free-roaming stray	1.88	1.39, 2.56	**<0.001**
	Pet store	1.36	0.86, 2.14	0.187
	Other	0.83	0.41, 1.70	0.614

*Cat characteristics reported here, with other aspects of the model reported in **Tables 4–7**.*
[a]*Odds ratio based on the output of mixed logistic regression model.*
[b]*95% confidence interval of the odds ratio.*
[c]*Referent category.*
Bolded values indicate significance ($p < 0.05$).

TABLE 4 | Logistic regression model for risk factors associated with uncontrolled outdoor access for cats based on owner reports, with province/state as a random effect ($N = 7{,}838$ participants).

Risk factors		OR[a]	95% CI[b]	*P*
Gender		-	-	0.013
	Man (ref.)[c]	-	-	-
	Woman	1.64	1.03, 2.60	**0.037**
	My gender identity is not listed above	4.02	1.41, 11.50	**0.009**
	Prefer not to answer	3.23	1.29, 8.13	**0.013**
Education		-	-	0.007
	College Certificate or Diploma (ref.)	-	-	-
	Elementary school	0.25	0.04, 1.56	0.138
	Secondary school	1.26	0.91, 1.75	0.170
	Bachelor's degree	0.78	0.60, 1.02	0.068
	Master's degree	0.68	0.46, 1.00	0.050
	Doctor of Philosophy (Ph.D.) degree	0.67	0.34, 1.33	0.250
	Professional degree	0.49	0.30, 0.78	**0.003**
	Prefer not to answer	0.61	0.29, 1.29	0.198
Living location		-	-	<0.001
	Large city (300,000–1 million people) (ref.)	-	-	-
	Village (<1,000 people)	1.85	1.22, 2.79	**0.003**
	Small town (1,000–20,000 people)	1.30	0.92, 1.82	0.134
	Large town (20,000–100,000 people)	0.97	0.68, 1.38	0.858
	Small city (100,000–300,000 people)	0.76	0.54, 1.07	0.116
	Metropolis (>1 million people)	1.19	0.74, 1.91	0.471
Household type		-	-	<0.001
	Detached house (ref.)	-	-	-
	Apartment/condo	0.15	0.10, 0.24	**<0.001**
	Townhouse/semi-detached	0.60	0.43, 0.83	**0.002**
	Trailer home	1.43	0.55, 3.73	0.466
	Farm/acreage	6.92	3.17, 15.11	**<0.001**
	Other	1.48	0.47, 4.62	0.505
	Prefer not to answer	0.69	0.13, 3.60	0.662

*Owner demographics reported here, with other aspects of the model reported in **Tables 3, 5–7**.*
[a]*Odds ratio based on the output of mixed logistic regression model.*
[b]*95% confidence interval of the odds ratio.*
[c]*Referent category.*
Bolded values indicate significance ($p < 0.05$).

meaningful. As a result, the interactions were not included in the final model, allowing for a more intuitive and parsimonious model. No biologically plausible confounders were identified for further assessment. Country was not a significant random effect and was thus excluded. The random effect, province/state, was significant, and based on the ICCs (95% CI) of the model, cats within the same province/state have a correlation of 0.055 (0.017, 0.17) (**Table 7**).

DISCUSSION

Despite recent educational messages from animal welfare and conservation organizations in Canada and the US, results

TABLE 5 | Logistic regression model for risk factors associated with uncontrolled outdoor access for cats based on owner reports, with province/state as a random effect ($N = 7,838$ participants).

Risk factors		OR[a]	95% CI[b]	P
Cats are highly motivated to go outside		-	-	<0.001
	Somewhat agree (ref.)[c]	-	-	-
	Strongly agree	1.65	1.27, 2.13	**<0.001**
	Somewhat disagree	0.40	0.27, 0.60	**<0.001**
	Strongly disagree	0.17	0.08, 0.38	**<0.001**
	Unsure	0.46	0.30, 0.70	**<0.001**
Cats can help with rodent control		-	-	0.0046
	Somewhat agree (ref.)	-	-	-
	Strongly agree	1.01	0.78, 1.31	0.952
	Somewhat disagree	0.92	0.64, 1.33	0.670
	Strongly disagree	0.411	0.24, 0.71	**0.001**
	Unsure	0.66	0.46, 0.94	0.022
Promotes natural hunting behavior		-	-	0.0029
	Somewhat agree (ref.)	-	-	-
	Strongly agree	0.83	0.62, 1.12	0.188
	Somewhat disagree	1.72	1.20, 2.47	**0.0030**
	Strongly disagree	1.69	0.99, 2.88	0.054
	Unsure	1.33	0.97, 1.81	0.075
Reduces risk of behavioral issues		-	-	<0.001
	Somewhat agree (ref.)	-	-	-
	Strongly agree	1.53	1.11, 2.11	**0.010**
	Somewhat disagree	0.62	0.43, 0.90	**0.013**
	Strongly disagree	0.69	0.41, 1.18	0.1810
	Unsure	0.72	0.55, 0.95	**0.018**
Promotes physical activity		-	-	<0.001
	Somewhat agree (ref.)	-	-	-
	Strongly agree	1.36	1.05, 1.76	**0.018**
	Somewhat disagree	0.31	0.16, 0.63	**0.0010**
	Strongly disagree	0.15	0.03, 0.72	**0.018**
	Unsure	0.64	0.37, 1.09	0.1000

Owner perspectives on the benefits of outdoor access reported here, with other aspects of the model reported in ***Tables 3***, ***4***, ***6***, ***7***.
[a]*Odds ratio based on the output of mixed logistic regression model.*
[b]*95% confidence interval of the odds ratio.*
[c]*Referent category.*
Bolded values indicate significance ($p < 0.05$).

TABLE 6 | Logistic regression model for risk factors associated with uncontrolled outdoor access for cats based on owner reports, with province/state as a random effect ($N = 7,838$ participants).

Risk factors		OR[a]	95% CI[b]	P
Increases risk of contracting diseases		-	-	<0.001
	Somewhat agree (ref.)[c]	-	-	-
	Strongly agree	0.49	0.38, 0.64	**<0.001**
	Somewhat disagree	1.31	0.85, 2.02	0.221
	Strongly disagree	1.13	0.60, 2.13	0.714
	Unsure	1.05	0.76, 1.45	0.758
Cats hunt small mammals and birds		-	-	<0.001
	Somewhat agree (ref.)	-	-	-
	Strongly agree	1.75	1.37, 2.25	**<0.001**
	Somewhat disagree	0.99	0.70, 1.41	0.960
	Strongly disagree	1.53	0.88, 2.67	0.133
	Unsure	0.98	0.58, 1.67	0.948
Increased risk of injury or death		-	-	<0.001
	Somewhat agree (ref.)	-	-	-
	Strongly agree	0.49	0.36, 0.67	**<0.001**
	Somewhat disagree	0.64	0.29, 1.44	0.281
	Strongly disagree	0.55	0.13, 2.32	0.411
	Unsure	0.49	0.20, 1.17	0.109
Increased risk of being lost or stolen		-	-	0.0125
	Somewhat agree (ref.)	-	-	-
	Strongly agree	0.65	0.49, 0.85	**0.0020**
	Somewhat disagree	1.04	0.64, 1.69	0.864
	Strongly disagree	1.53	0.57, 4.07	0.399
	Unsure	1.23	0.72, 2.13	0.443
Increased risk of being harmed by coyotes or other wildlife		-	-	<0.001
	Somewhat agree (ref.)	-	-	-
	Strongly agree	0.50	0.38, 0.67	**<0.001**
	Somewhat disagree	1.23	0.69, 2.20	0.480
	Strongly disagree	1.21	0.26, 5.51	0.809
	Unsure	1.25	0.67, 2.36	0.486
Cats with prior outdoor access should continue to have outdoor access		-	-	<0.001
	Somewhat agree (ref.)	-	-	-
	Strongly agree	2.43	1.86, 3.17	**<0.001**
	Somewhat disagree	0.45	0.32, 0.63	**<0.001**
	Strongly disagree	0.15	0.07, 0.29	**<0.001**
	Unsure	0.76	0.44, 1.07	0.118

Owner perspectives on the consequences of outdoor access reported here, with other aspects of the model reported in ***Tables 3–5***, ***7***.
[a]*Odds ratio based on the output of mixed logistic regression model.*
[b]*95% confidence interval of the odds ratio.*
[c]*Referent category.*
Bolded values indicate significance ($p < 0.05$).

from the current study suggest that a large proportion of cat owners are providing uncontrolled outdoor access to their cats. While the majority of owners believed that cats with no prior outdoor experience should be kept indoors, there were still 1,119 owners (14.3%) who disagreed. This suggests that outdoor access does not depend on prior access experience as close to 21% of owners would still offer access to a new, inexperienced cat. There are also many owners allowing controlled outdoor access by having their cat on a leash, harness or tie-out, offering a catio or an enclosed area with cat-specific fencing, or letting the cats roam but only under direct supervision.

For cats who were allowed uncontrolled outdoor access, the majority of owners neutered their animals, which is important for reducing cat overpopulation and preventing hormonally mediated roaming. While 93% of outdoor cats had their claws, 7% of the uncontrolled outdoor cats were declawed, which is concerning as these animals are likely to be unable to defend themselves against predation. Few owners in this sample took measures to reduce potential cat loss through identification via microchip or collar or through licensing. One previous study found that a majority of cat owners agreed that microchipping helps lost cats reunite with their owners, but did not agree with cat licensing (19). This study did not assess the actual practices of these owners around microchipping and licensing, but another recent study from Australia found that 72% of cat owners reported microchipping their cat, which is much higher than what was found for the current study (36). Permanent identification (e.g., via microchip or tattoo) or provision of identification on a collar are commonly recommended to ensure the cat and owner can be identified and reunited if the cat is injured or becomes lost while outdoors (37).

Cat Characteristic Factors

The current results suggest that male cats are more likely to be provided uncontrolled outdoor access than female cats, which corresponds to the findings of another recent study with international scope (24). In a previous US study on outdoor access, access did not differ between female and male cats (23), but the sample size in that study was relatively small. It has been suggested that female cats might be more suited to live solely indoors compared to male cats based on differences in home range sizes. Mertens and Schär (38) observed that indoor, neutered males had a home range of 4–5 rooms, compared to 3–3.6 rooms for neutered females. As a result, male cats might be more motivated to roam than females, potentially leading to frustration and behavioral issues when restricted. However, the home range differences are relatively small and differences in motivation to roam have not been assessed in neutered male and female cats. Alternatively, owners might be more worried about female cats having uncontrolled outdoor access because of the potential for pregnancy. However, in the current study, 97% of the cats were neutered or spayed, so this hypothesis is unlikely to be a primary contributor to the provisioning of outdoor access.

TABLE 7 | Linear regression model for risk factors associated with uncontrolled outdoor access for cats based on owner reports, with province/state as a random effect ($N = 7,838$ participants).

Risk factors		OR[a]	95% CI[b]	P
Home Environment and Enrichment				
Other pets (non-cats)		-	-	<0.001
	No (ref.)[c]	-	-	-
	Yes	2.14	1.69, 2.70	**<0.001**
Interactive toys		-	-	<0.001
	No (ref.)	-	-	-
	Yes	0.31	0.17, 0.56	**<0.001**
Elevated platforms		-	-	<0.001
	No (ref.)	-	-	-
	Yes	0.61	0.46, 0.81	**0.0010**
Random effect				
Province/State	ICC	0.055	0.017, 0.17	<0.0001
	Province/State-level variance	0.19	0.006, 0.67	-

*Home environment and enrichment factors plus random effects reported here, with other aspects of the model reported in **Tables 3–6**.*
[a] *Odds ratio based on the output of mixed logistic regression model.*
[b] *95% confidence interval of the odds ratio.*
[c] *Referent category.*
Bolded values indicate significance ($p < 0.05$).

Cat aggression toward people or other animals was also a factor associated with increased likelihood of outdoor access. However, the directionality of the relationship between aggression and outdoor access is unknown; cats might be let outside because of aggressive behavior, or cats might become aggressive due to the outdoor access provided. Levine et al. (39) observed that households with at least one cat with outdoor access experienced more inter-cat aggression than when all cats were kept indoors. They hypothesized that either cats with outdoor access bring new smells into the home creating aggression in the indoor cat(s), or inter-cat aggression results from redirected frustration from not receiving outdoor access (39).

In addition, cats older than 15 years had higher odds of outdoor access and cats younger than a year of age had lower odds. Foreman-Worsley et al. (24) also found that juvenile cats under 2 years of age were more likely to be kept indoors. It is possible that older cats have a higher probability of having previous outdoor access based on recently updated recommendations for keeping cats indoors, as owners reported strong agreement with continuing to provide outdoor access for cats with prior experience. In contrast, younger cats may be kept inside because they are not large enough to protect themselves or because they are not fully vaccinated or spayed/neutered [procedures typically done before 6 months of age (40)]; unvaccinated cats, particularly those younger than 4 months of age, would be more susceptible to contracting diseases, parasites, or illness, and unneutered young cats that are past sexual maturity would be capable of reproduction.

Similar to the results of Foreman-Worsley et al. (24), the current study found that cats who have an existing medical problem were less likely to have uncontrolled outdoor access. Cats with existing medical issues might be more susceptible to acquiring a disease or infection and/or vulnerability to predation. For example, particular diseases that are immunosuppressive and increase the risk of contracting secondary infections (41), such as Feline Leukemia Virus, might result in owners being less likely to allow their cat outdoors. Additionally, some medical issues (e.g., cancer and diabetes) require supportive care, such as assisted feeding and scheduled medication delivery (42), which could deter owners from allowing uncontrolled outdoor access as returning times could be unpredictable.

At many humane societies and animal shelters, adopters are required to sign contracts that ensure cats remain solely indoors, and our results suggest these contracts are effective at reducing the provision of uncontrolled outdoor access. It is possible that owners who acquired their cats from shelters are more educated about the potential consequences associated with outdoor access through educational materials provided by the shelter or breeder, and thus may be less likely to provide uncontrolled access. A similar relationship was discussed by Clancy et al. (23), who found a significant difference in provision of outdoor access between cats that were initially acquired from a shelter vs. as a stray, suggesting the prevention of uncontrolled outdoor access was due to the education provided by the shelters. However, some owners who had signed contracts were still providing uncontrolled outdoor access, suggesting that these contracts are not fully effective.

Owner Demographic Factors

The types of dwellings and areas that cat owners reside in influenced whether cats are allowed outside, with more uncontrolled outdoor access provided for cats in rural areas in comparison to urban areas; these results correspond with another study that found indoor restriction is associated with city centers and urban areas (24). Owners in urban areas have a greater likelihood of living in an apartment or housing with multiple floors that lack direct outdoor access compared to living in rural areas. Higher outdoor access in rural and farm areas might also relate to cats being kept as domestic predators to control pests (43), as confirmed by some participants in this study, who specifically stated in their comments that they owned cats for this purpose. Also, free-roaming cats have a higher likelihood of being involved in road traffic accidents in areas with heavy traffic, like urban or metropolitan cities, compared to rural areas. These accidents could cause serious injuries (e.g., rupturing internal organs or broken bones) that may result in financial or welfare ramifications (e.g., amputations) or death (16), and may deter owners from allowing outdoor access in high-traffic areas.

Women were less likely to allow uncontrolled outdoor access than men. Studies have shown that women tend to display more positive behaviors and concerns toward animal welfare and animal rights than men (44, 45). Research also suggests female pet owners have a stronger bond with their animals than male owners and this factor increased the likelihood of bringing their pets to the veterinarian for care (46). Furthermore, women have been found to interact with their cats (i.e., physically and verbally) more often than men, supporting the suggestion that women develop higher quality relationships with their cats (47). If women have stronger bonds with their cats, they may be more concerned about the risks associated with outdoor access. Owners with professional degrees (e.g., veterinarians or doctors) also had reduced odds of providing uncontrolled outdoor access, which might be attributable to greater awareness about the risks about this form of outdoor access (e.g., contractible diseases) and about general recommendations for pet care.

Owner Perspectives Factors

The majority of owner perspectives aligned as predicted, where owners who were concerned about risks to their cat's welfare (e.g., being injured or contracting a disease) had lower odds of providing uncontrolled outdoor access, and owners who agreed with factors related to outdoor access that could enhance their cat's welfare (e.g., reduce risk of behavioral issues) had

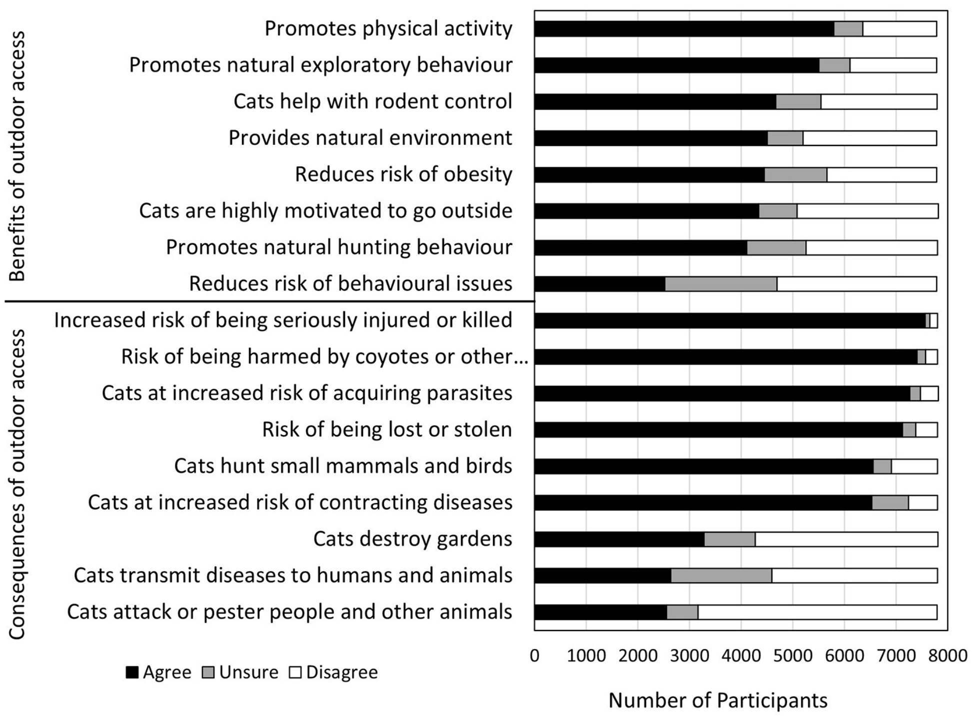

FIGURE 2 | Owner responses on level of agreement with statements on the benefits and consequences of outdoor access for companion cats ($N = 7,838$).

higher odds of providing uncontrolled outdoor access. These findings are similar to those of another owner-completed survey that found that owners cited various outdoor risks as reasons for keeping their cats indoors (24). Our findings are further supported by previous research with Australian cat owners. One study found that a major barrier to containment was a belief that cats need to wander for mental and physical health (27), and another study found that owners that keep their cats indoors are more likely to believe confinement protects cats from injury (25).

However, not all perspectives aligned. For example, owners who agreed that "outdoor access for cats is problematic because cats hunt small mammals and birds" had higher odds of providing outdoor access. Similarly, other studies have found that beliefs about cats influencing wildlife are either not or only weakly correlated with cat owner behaviors and intentions around keeping cats indoors (26, 27). This misalignment could be due to cognitive dissonance, which is a result of conflict between attitudes and behaviors (48). According to Akpan et al. (49), people's actions do not always align with their beliefs, which could explain how even though owners are aware of the associated risks with outdoor access, they continue to provide access. Alternatively, some owners might have had positive feelings about pest control by cats. For example, Foreman-Worsley et al. (24) found that some owners relied on cats for control of rats and mice on their property. We might have found different results in the current study had we separated reporting for species thought of as pests from songbirds and other "attractive" wildlife. Additionally, there were owners who were not aware of certain risks. For example, only 33.8% of owners agreed that outdoor cats can transmit diseases to humans and animals; however, as Kasbaoui (9) demonstrated, contact with wildlife and other animals can increase transmission of diseases and parasites to cats, and also to other animals via cats. Even when certain risks are widely recognized, owners are still providing uncontrolled access, suggesting a disconnect between knowledge and action. Interestingly, one recent intervention study found that wildlife protection messaging was effective at increasing both motivation to contain and belief that containing was possible in a sample of Australian cat owners, suggesting that further education could be effective for altering cat containment activities (29).

Enrichment and Home Environment Factors

Other pets living in the cat's home environment increased the odds of having outdoor access. This corresponds to the results of Foreman-Worsley et al. (24) which found that owners cited having a multi-cat household as one of the reasons why they allow their cat outdoor access; open-text responses from owners in this study suggested outside access provided additional space for the cats to get away from each other. Without a safe place to allow escape from unfamiliar or undesired situations (8) the likelihood of having inter-animal aggression or problems between pets is greater. Further research is necessary to explore this relationship.

The provision of interactive enrichment in the home reduced the odds of cats being given uncontrolled outdoor access. This relationship is likely not causal; instead, owners who keep their cats indoors are probably more likely to provide enhanced enrichment to account for the limited and confining indoor environment. The current study found that cats without uncontrolled outdoor access were provided with more enrichment types (e.g., small toys, interactive toys, and scratching areas) than cats with uncontrolled access. Enrichment promotes species-specific behavior, such as chasing, climbing, or biting by imitating prey or natural environments (8). For animals without outdoor access, their indoor environment may be enhanced with enrichment, minimizing boredom and behavioral issues, such as aggression (15). Therefore, while indoor housing can limit physical activity and the ability to perform natural behaviors, providing interactive enrichment can improve their housing quality and promote their well-being.

Limitations

The majority of the participants reported that they resided in Canada, and most of them resided in Ontario. Furthermore, as is common for online surveys (50), this survey also had more women respondents than men. Due to the disproportionate gender ratio and number of participants from particular regions, it is possible that findings and trends may not generalize broadly to the target population. However, the sample size was relatively large, with reasonable representation from males and different geographical areas. In addition, the regression model accounted for gender through inclusion in analysis as well as geographical clustering through inclusion of participant state/province as a random effect, and while significant, the effect size for state/province was small and significance was likely a result of the large sample size. Additionally, since this survey relied on owner self-reporting, social desirability bias, a bias involving answering based on what is believed to be favorable or are society's norms, may have occurred. Accompanied with owners being unable to accurately recall details, such as average time spent outside, the results of how owners care for their cats and perceive cat welfare may have been skewed.

Since the survey was cross-sectional, capturing prevalence data at one period in time, it is not possible to infer causation or illustrate longitudinal trends. Also, because this was an exploratory and hypothesis-generating study, the high number of variables tested increased the chance of type one errors. The cross-sectional and exploratory nature of this current study, however, highlights areas for future research through controlled studies.

CONCLUSIONS

One fifth of owners in the current survey allowed their cats with uncontrolled outdoor access, and many owners that provided outdoor access failed to implement management strategies that are commonly recommended to protect the welfare of cats and of wildlife, such as microchipping and using a collar with a bell. Several factors that were associated with the provision of uncontrolled outdoor access were identified, including factors related to cat characteristics (e.g., sex, breed, cat age, existing medical conditions, aggression), the home environment (e.g., other animals in the home), owner perspectives (e.g., benefits and risks associated with outdoor access), and owner demographics (e.g., gender, level of education, location, and type of household). The majority of owners were aware of the primary risks and benefits associated with outdoor access, but their attitudes were not the sole factor that influenced the provision of outdoor access. Based on the current results, further research is needed to explore domestic cat needs and the other outdoor alternatives to promote and protect the welfare of owned domestic cats. Outdoor access is a multifactorial decision and future research should explore the impact of outdoor access on cat welfare, the effect of owner-pet bonds on outdoor access and the efficacy of educational programs on owner perspectives toward outdoor access.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because consent was not provided for distribution during ethical approval. However, particular details can be provided upon request. Requests to access the datasets should be directed to Lee Niel at niell@uoguelph.ca.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by University of Guelph Research Ethics Board-Natural, Physical and Engineering Sciences and The University of British Columbia Behavioral Research Ethics Board. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

ST and AS organized the database and performed the statistical analysis. ST wrote the first draft of the manuscript. All authors contributed to conception, design of the study, contributed to manuscript revision, read, and approved the submitted version.

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BRIEF RESEARCH REPORT
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Comparative Assessment of Heart Rate Variability Obtained via Ambulatory ECG and Polar Heart Rate Monitors in Healthy Cats: A Pilot Study

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Chronic exposure to stressful environments can negatively impact cats' health and welfare, affecting behavioral, autonomic, endocrine, and immune function, as with cats in shelters. Low-stress handling practices likely improve shelter cat welfare, but data supporting improved outcomes remain limited. Cardiac activity, particularly heart rate variability (HRV), is an indicator of stress and emotional state in humans and non-human animals, tracking important body functions associated with stress responsiveness, environmental adaptability, mental, and physical health. HRV studies in cats are limited, involving mainly anesthetized or restrained cats. This pilot study tested the feasibility of obtaining HRV data from unrestrained cats, using a commercially available cardiac monitoring system (Polar H10 with chest strap), compared with data from a traditional ambulatory electrocardiogram. Simultaneous data for the two systems were obtained for five adult cats. Overall, the Polar H10 monitor assessments of HRV were lower than the true HRV assessment by ambulatory ECG, except for SDNN. Correlation between the two systems was weak. Possible reasons for the lack of agreement between the two methods are discussed. At this time, our results do not support the use of Polar H10 heart rate monitors for studies of HRV in cats.

Keywords: cat, physiological stress measures, heart rate, heart rate variability, Holter monitor, Polar H10

INTRODUCTION

Chronic exposure to stressful environments can negatively impact cats' health and welfare (1, 2). Threatening environments can be a significant factor contributing to disease, and environmental enrichment likely plays an important role in recovery of health and well-being (1, 3). Cats in shelters can be subject to high levels of environmental threat (4–6), and require medical evaluation and routine handling and care by staff. Use of low-stress handling practices has been recommended to improve the welfare of sheltered cats (7), but data supporting improved outcomes (reduced stress, leading to safer handling, better welfare, more accurate exam data) from using low-stress handling remain limited.

Heart rate variability (HRV) is an indicator of stress and emotional state in humans and non-human animals (8–13). HRV describes variation between successive heart beat intervals (R-R intervals), which reflects changes in activity of the autonomic nervous system (ANS). The ANS, composed of sympathetic and parasympathetic (vagal) branches, participates in the control of heart rate and rhythm (14). Recent research demonstrates the importance of HRV as an indicator of important body functions associated with stress responsiveness, environmental adaptability, and mental and physical health (15). In humans, decreased measures of HRV have been associated with adverse outcomes in cases of cardiovascular disease and lupus disease activity (16). Elevated stress responses, such as those caused by chronic environmental stressors (in humans, stressors present in a poor work environment), enhance the risk of cardiovascular disease (17). Assessment of HRV is common in animal research (8), and has been performed in cats on a limited basis [e.g., (18, 19)].

Psychological states such as anxiety and fear can impact the sympathovagal balance of the ANS in the absence of any detectable changes in heart or respiration rates, and changes in HRV can occur in the absence of detectable changes in heart rate (8). For example, in a study of lamb responses to aversive events, learning to prevent an aversive event was associated with elevated HRV, but was not reflected in changes in heart rate; conversely, lack of control over the aversive event was associated with decreased HRV, suggesting greater sympathetic control over cardiac activity (10, 11). Thus, measures of HRV appear to indicate ANS function more reliably than heart rate alone. Unfortunately, studies of HRV in domestic cats are limited, and often involve anesthetized or restrained cats; for example, reports used restrained cats at home vs. in the clinic (20), cats restrained in the hospital vs. freely moving at home (18), and anesthetized cats during pharmacological manipulations (19). In addition, the R-R interval used for HRV calculations is usually determined from an electrocardiogram (ECG). Use of ECGs obtained from ambulatory cats using wireless, non-invasive Holter recorders has been validated using direct recordings in cats, but analysis of the data obtained with the commercially available software is expensive and requires specific training for interpretation (18, 19, 21, 22). Preliminary studies suggest that wireless, smartphone-based heart rate sensors can generate similar data (23–25), while potentially allowing less discomfort and improved mobility for the cat.

We conducted a pilot study to test feasibility of obtaining ECG data for assessment of HRV from time domain variables, from conscious, caged cats using modifications of an inexpensive, readily available, cardiac activity monitoring system, the Polar H10 (Polar Electro Inc., Bethpage, NY). This study compared cardiac activity data collected simultaneously using two methods: Polar H10 Heart Rate Sensor units with Polar Pro soft straps to secure the electrodes around the chest of the cat, and standard ambulatory ECG recorders (Burdick H3$^+$ Holter Recorder, Mortara Instrument Inc., Milwaukee, WI). Our hypothesis was that the alternate method of obtaining HRV data would provide data comparable to the Gold Standard ambulatory ECG.

MATERIALS AND METHODS

Animals and Housing

Eight adult intact domestic cats (4 males, 4 females) between the ages of 2 and 7 years, with weights of ≥4.5 kg, and with body condition scores between 4 and 5 (on a 9-point scale) were enrolled in this pilot study. The health status of cats was assessed based on a complete veterinary exam within 6 months of enrollment, and only clinically healthy cats, with no heart disease and normal blood pressure, participated in the study. Cats used for this study are part of a university-owned campus research cat colony; cats in this colony normally live indoors in large, shared enclosures. During data collection, cats were contained in individual cages (∼3 × 3 × 3 ft, containing a litter box, water, and elevated resting perch) but allowed to move freely within their cages.

Data Collection

Heart rate interval data were collected simultaneously from the subjects using the two different systems, the ambulatory Holter ECG monitor and the Polar H10 heart rate monitor with a Polar Pro soft strap (with two electrodes). The Polar system collected heart rate data wirelessly and transmitted data via Bluetooth® to an iPhone application (Heart Rate Variability Logger, Marco Altini: A.S.M.A.B.V.). Prior to the start of the data collection, the non-invasive cardiac sensors were fitted to the cats using low-stress handling techniques; cats were sedated for monitor application to minimize stress using sedatives butorphanol (0.2–0.3 mg/kg IM) and alfaxalone (1–3 mg/kg IM). To ensure complete contact between monitor electrodes and the subject's skin and to guarantee continuous readings from both HR monitors, a 4-inch-wide strip of fur was shaved from the cats' left and right hemithorax, and electrically conductive gel (Spectra® 360, Parker Laboratories, Fairfield, NJ) was applied between sensors and the cats' skin to optimize electrode-skin contact. First, the 5-electrode Burdick ambulatory ECG monitor with three-channel recording was attached to areas of the shaved chest that optimized the electrocardiographic signal, in a standard precordial configuration (**Figure 1**). Next, the Polar H10 heart rate monitor with a Polar Pro soft strap with two electrodes was attached around the cats' chest, just caudal to the ECG device (**Figure 1**); the sensor unit was centered ventrally, positioning an electrode on each side of the cats' thorax. Elastic bandage material (VetWrap; 3M, Maplewood, MN) was then wrapped around the cat to cover both devices and minimize slipping. Cats were allowed to recover from sedation and acclimate to the HR monitors for ∼30 min, after which time cats were moved to individual cages. Simultaneous data was recorded for 6–7 h. Smartphones used to record data from the Polar monitors were located just outside the cats' cages, but as close to each cat's kennel as possible, to improve the reliability of the Bluetooth® connection. Following data collection, both monitors were removed from the cats using low-stress handling approaches; additional sedation was not required for any of the cats for monitor removal. Cats were monitored by researchers, colony facility, and veterinary staff for any adverse effects (e.g., excessive drop in HR or lack of consciousness) during sedation,

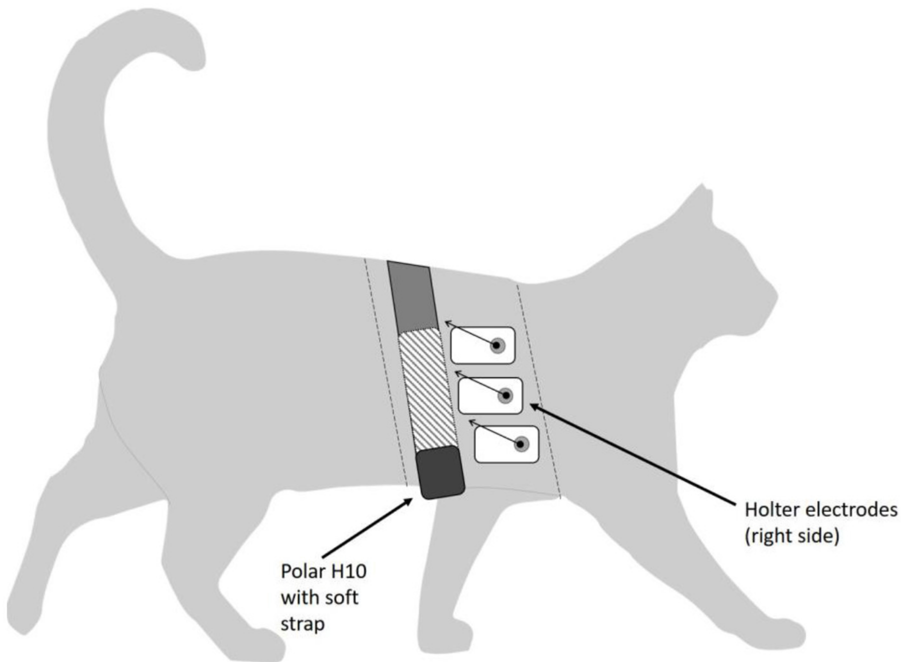

FIGURE 1 | Diagram of study cat, showing placement of Holter electrodes and Polar H10 sensor with elastic strap. Dashed lines represent approximate cranial and caudal edges of the shaved area. Polar electrodes are located within the soft strap (shown as hatched area of strap). Leads on the Holter electrodes are shown as abbreviated arrows for image clarity.

and post-sedation monitoring was done on all cats on intervals of at least every 15 min. All cats were fully alert and responsive by the end of the monitoring sessions and were directly returned to the main colony. All procedures involving the cats were done under approval from the UC Davis IACUC, protocol # 21188, and in accordance with the Winn Feline Foundation's Humane Use of Animals Guidelines (March 2015).

Heart Rate Variability Analysis

All data from the ambulatory ECG monitors was uploaded to the software analysis system, Burdick Vision 5 software (Mortara Instrument, Inc., Milwaukee, WI) following device removal from each subject. Data processing and reporting was performed as previously described (26). Briefly, analysis and interpretation of the uploaded ECG recording was made prospectively. The software analysis system automatically annotates normal and abnormal complexes, however incorrect labeling of beat type and QRS timing occurs frequently in feline recordings. Therefore, all recordings were visually inspected on a beat-by-beat basis in their entirety and all mis-labeled beats were corrected in order to accurately determine the frequency and complexity of any ectopy. QRS complexes labeled as normal but with incorrect timing, for example over the T or P wave, were manually corrected to allow for accurate and precise HRV analysis. Portions of the recordings with motion-related artifact that was significant enough to preclude accurate labeling and interpretation was labeled as artifact, discarded and not quantified for analysis. HRV was analyzed using standard time-domain techniques in accordance with published recommendations (27). All of the time-domain measures of HRV were calculated for each 1-h period using the Burdick Vision 5 ECG analysis software. The normal-to-normal (NN) intervals were calculated from one R wave to the next R wave for all sinus beats by the software. The mean, minimal, and maximal HR were recorded, based on the NN intervals. For each disclosure, the square root of the mean squared differences of successive NN interval (RMSSD), the standard deviation of all NN intervals (SDNN), the standard deviation of the average NN intervals over 5 min (SDANN), and the number of interval differences of successive NN intervals >50 ms divided by the total number of NN intervals (pNN50) were obtained. The NN intervals were also converted to the triangular index value, defined as the integral of the density distribution of the NN intervals divided by the maximal density distribution.

Polar H10 data was downloaded from the HRV Logger application into Microsoft Excel (Microsoft Corp., Redmond, WA) spreadsheets for processing and analysis. The Polar H10 data was pre-processed for analysis using the following steps: first, data was plotted (sensor readings vs. time) and visually inspected for gaps (for example, due to temporary loss of Bluetooth® connection with the smartphones); data segments with gaps were removed from the analysis, in order to ensure that comparable time periods for both data sources were being compared. As Polar H10 monitors record IBI (vs. ECG), automatic artifact correction must be used for these types of data (27, 28). As one goal of the present study was to assess a simple, user-friendly approach to use of Polar monitors for assessing heart rate and HRV in cats, and as artifacts generally present as outliers (vertical spikes) in the heart rate data, we used a straightforward outlier identification formula (29), based on removal of sensor readings >1.5 times the Interquartile Range (IQR) below 1st quartile and above 3rd quartile. This automatic outlier correction process was conducted for each cat individually. The artifact removal threshold (25%) within the HRV Logger app was not used during data collection. Cardiac data from the two data collection methods (recording start and stop times) were examined to ensure temporal synchrony of measurements during collection and prior to analysis.

From the cardiac activity data recorded during all sessions, the following time-domain cardiac parameters (27) were calculated for each cat, and for each hour of simultaneous data collection: Heart rate (HR), in beats/min (max, min, mean); root mean square of successive interbeat interval differences, RMSSD (ms); standard deviation of all interbeat intervals, SDNN (ms); and RMSSD/SDNN ratio, an index of vagosympathetic balance (12, 14, 30, 31).

Statistical Analysis

Initial estimates of sample size for this pilot study were made according to recommendations of Ruxton and Colegrave (32), to meet or exceed sample sizes in published studies successfully able to answer similar research questions, in this case pilot studies involving HRV analyses in mammals: $n = 2$ (23), $n = 7$ (19); $n = 8$ (17, 25); $n = 9$ (33). For correlation analyses, we determined that a sample size of 8 would be necessary to achieve 80% power to detect a correlation of 0.80 between the two measures at $\alpha = 0.05$ (G*Power 3.1.9.2). In order to compare data collected concurrently using the two alternate cardiac data collection methods, Bland Altman plots (34, 35) were constructed for all the cardiac activity parameters. Data were assessed for normality using Shapiro-Wilk tests. In addition, Pearson's correlation coefficients were calculated for each of the cardiac parameters between data collected with the Polar vs. ambulatory Holter ECG, using the hourly values of each of the cardiac parameters and including all usable hours of concurrent data collection. All statistical analyses for this study, including creation of Bland Altman plots, were done using XLSTAT (Addinsoft; NY, NY) in Microsoft Excel.

RESULTS

Eight cats were fitted with dual cardiac monitoring systems for this study. On two of the cats, the ambulatory Holter monitors malfunctioned, causing loss of those data. The Polar H10 sensor on a third cat suffered significant connectivity lapses on the Bluetooth® connection with the smartphone, resulting in the unreliability of those data. Loss of sensor data for these three cats meant we were not able to obtain our desired sample size. Filtering of outliers and gaps from the Polar data resulted in removal of some R-R interval data for each cat (mean loss per cat 24.5%; range 13.2–50.9%), and 6 h segments (19% of all hourly segments) were removed from the comparisons between Holter and Polar data due to unacceptably high levels of error. Usable simultaneous data for the two cardiac activity monitoring systems were available for five cats (**Table 1**). Once recovered from sedation and acclimated to the monitors, the cats appeared to tolerate the presence of the monitors well, throughout data collection. No adverse events occurred with any of the cats.

Summary data, by hour of simultaneous data collection, for all cats are available in **Supplementary Materials**. Mean HRs recorded for the duration of data collection for both methods—Polar H10 filtered data, and the Holter data—are shown in **Table 1**. Normality of the data for all cats was confirmed ($p > 0.64$ for all cats).

The limits of agreement between the two cardiac data collection methods are shown in the Bland Altman plots for all cardiac parameters (**Figure 2**). Mean difference between the two methods is shown as a solid orange horizontal line on all plots; a mean difference = 0 (i.e., $y = 0$) would indicate strong agreement between the two methods. Upper and lower limits of agreement are shown as dashed green horizontal lines on the Bland Altman plots (**Figure 2**). Overall, the Polar monitor readings (filtered) were lower than the Holter monitor readings, except for SDNN, as follows:

- $HR_{minimum}$ average difference −28.5 bpm
- $HR_{maximum}$ average difference −32.6 bpm
- HR_{mean} average difference −19.3 bpm
- RMSSD average difference −2.9 ms
- SDNN average difference +13.0 ms
- RMSSD/SDNN average difference −0.5.

Correlations between Polar data (raw and filtered) and the Holter data for all cardiac parameters and cats are shown in **Table 2**. Strength of the correlations varied widely between cats, and by cardiac parameter; only some of the correlations were statistically significant, suggesting a lack of consistent agreement between the two methods.

DISCUSSION

Although Polar HR monitoring systems are well-regarded for data accuracy and reliability, and have been used in a number of published research studies on dogs (12, 30, 36, 37), there was not strong and consistent agreement between data from the Polar H10 chest-strap sensors and the Holter ECG recorders for the cats in our study. Possible reasons for this lack of agreement are listed below. At this time, these results would not support the use of Polar H10 HR monitors with chest strap attachment for studies of HRV in free-ranging cats.

Mean HR during data collection for these cats ranged from 160.3 to 234.3 bpm, with most cats averaging over 200 bpm (**Table 1**). For comparison, resting HRs in non-stressed cats range from 120 to 140 bpm (38), with stressed cats' HR reaching up to 220 bpm. Abbott (18) reported mean HRs for 16 healthy young cats, noting that HR varied with location and stress level of the animals: mean HR when restrained (measured via electrocardiogram) was 187 ± 25 bpm; mean HR while resting in the veterinary clinic (measured via radiotelemetry device) was 150 ± 23 bpm; and mean HR at home (radiotelemetry device) was 132 ± 19 bpm. Regardless of method of cardiac data collection, mean HRs of cats in this study were high, suggesting that these cats were stressed by dual monitor presence and/or

TABLE 1 | Cats used for Polar-Holter cardiac data comparisons for this study, showing mean, min, and max HR recorded for the duration of data collection for both methods (Polar H10 filtered data, and the Holter data).

Cat ID	Age (years)	Kg	Sex	Polar H10		Ambulatory ECG (Holter)		*n* (hours)
				HR Mean ± SD	HR Min/Max	HR Mean ± SD	HR Min/Max	
13099	7	5.3	F	202.3 ±9.6	188/217	205.3 ±15.1	188/235	6
14011	6	5.4	F	160.3 ±24.3	127/184	234.3 ±4.8	230/241	3
14077	6	5.3	F	203 ±6.5	193/213	212.8 ±20.5	193/252	5
16010	4	5.2	M	188.2 ±9.3	175/204	190.2 ±9.9	179/204	6
18013	2	5.2	M	183.4 ±15.0	155/195	223.4 ±10.0	210/241	5

Note that detailed data for all HRV variables by hour of data collection is available as ***Supplementary Materials****.*

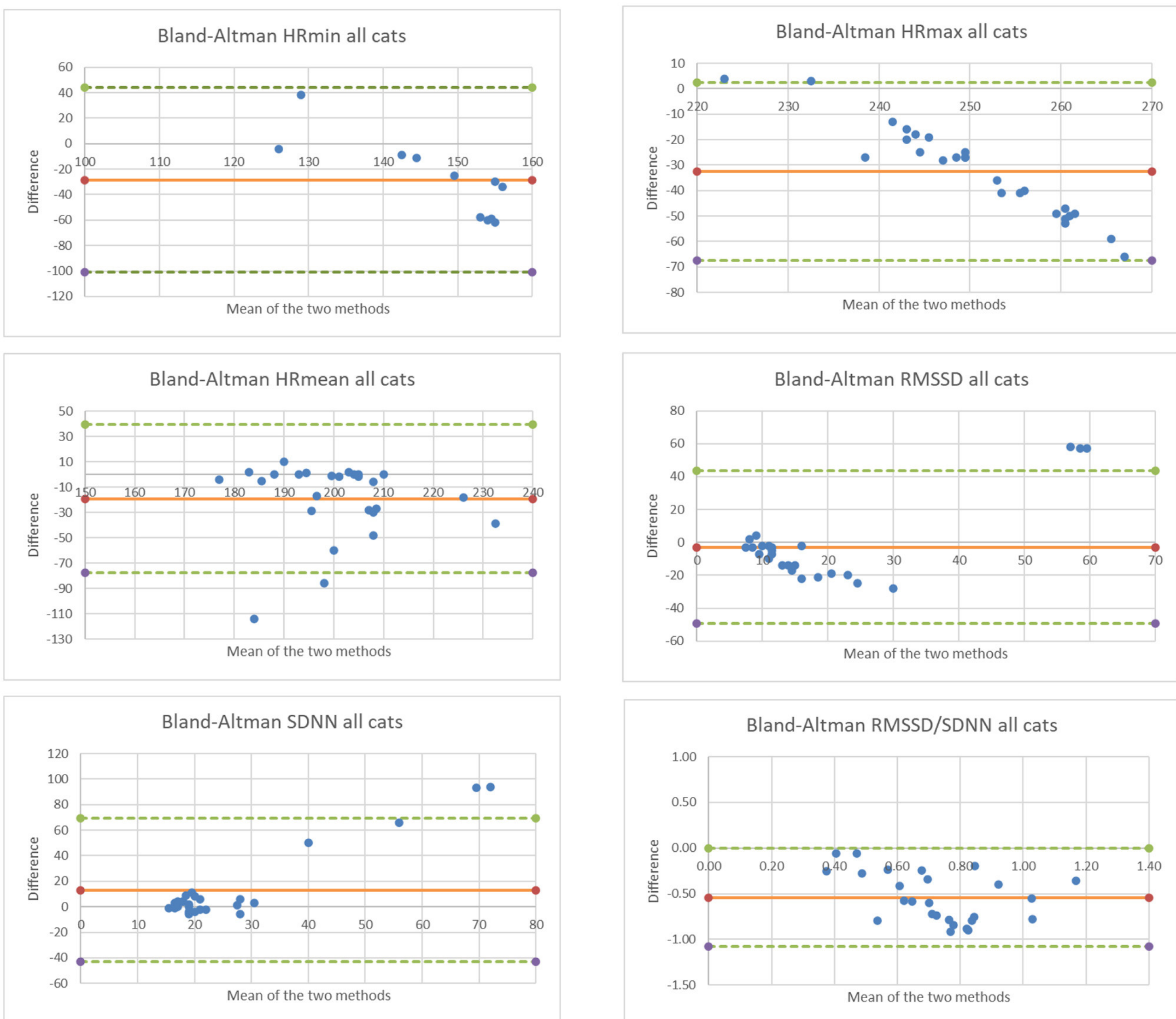

FIGURE 2 | Bland Altman plots comparing data collected for 5 cats and for all cardiac parameters using the two methods. Note that the x-axis represents the mean measurement (Holter and Polar H10), and the y-axis represents the difference between measurements (Polar H10 minus Holter).

TABLE 2 | Correlations between Polar H10 data (raw data, and data filtered using outlier removal methods described in the text) and the ambulatory ECG (Holter) data for all cardiac parameters and all cats used for data analysis.

Cat ID		HR (min)		HR (max)		HR (mean)		RMSSD		SDNN		RMSSD/SDNN	
		(Raw)	(Filtered)	(Raw)	(Filtered)	(Raw)	(Filtered)	(Raw)	(Filtered)	(Raw)	(Filtered)	(Raw)	(Filtered)
13099	*r*	0.203	0.619	**0.858**	**0.858**	−0.509	**0.946**	0.662	0.326	0.366	0.162	−0.302	0.290
	p	0.70	0.19	0.029	0.029	0.30	0.004	0.15	0.53	0.48	0.76	0.56	0.58
14011	*r*	**0.999**	**0.999**	−0.500	−0.500	−0.917	−0.917	0.681	0.982	−0.160	0.577	0.922	0.716
	p	0.005	0.005	0.67	0.67	0.26	0.26	0.52	0.12	0.90	0.61	0.25	0.50
14077	*r*	−0.336	0.272	0.671	0.671	**0.908**	**0.888**	**−0.945**	−0.466	−0.635	−0.450	0.210	0.637
	p	0.52	0.60	0.15	0.15	0.012	0.012	0.004	0.35	0.18	0.37	0.70	0.17
16010	*r*	**−0.912**	**−0.819**	0.463	0.463	0.547	0.624	0.350	**0.883**	0.095	0.610	0.522	**0.855**
	p	0.011	0.046	0.36	0.36	0.26	0.19	0.50	0.020	0.86	0.20	0.29	0.030
18013	*r*	0.444	0.250	0.706	0.706	−0.687	−0.681	0.824	−0.214	0.028	−0.318	−0.722	−0.785
	p	0.45	0.69	0.18	0.18	0.20	0.21	0.09	0.73	0.96	0.60	0.17	0.12

For each correlation, the correlation coefficient (r) and p-values are shown. Significant correlations are shown in bold font.

their containment in the holding cages (separate from their normal living quarters), despite lack of obvious behavioral signs of stress. This should not have impacted comparisons, however, as presumably readings from both monitoring systems on the same cat would have been similarly impacted.

The small size of the study animals made concurrent fitting with both ambulatory Holter monitors and Polar H10 monitor chest straps challenging; the influence of the close proximity (**Figure 1**) on data quality is unknown. In studies of other smaller species such as rodents (39, 40), more invasive methods (i.e., implanted transmitters) are sometimes used to obtain good quality HRV data. The Polar H10 with chest strap was designed for use on a human chest; distance between the electrodes located within the chest strap may have resulted in suboptimal placement of the electrodes on the cat's thorax. However, as artifacts were discarded from the data as described above, slipping or shifting of the electrodes, while potentially impacting ECG configuration, should not impact the R-R interval data used in these analyses. Although ambulatory Holter monitors alone have been used successfully on cats (39), Von Borell et al. (8) cautioned in their review that long-term HRV monitoring should only be measured while animals are stationary, with at most minimal (or unvarying) activity. Within the confines of their individual cages, the cats in this study were free to move at will during data collection.

Bluetooth® connectivity issues between the Polar H10 sensors and the smartphones were common; for some cats, the connection between sensor and tag was lost seemingly at random intervals, and had to be manually reconnected by the researcher using the HRV logger app on the phones. As a result, despite periodic checks during the 7-h data collection sessions, data was lost due to dropped connections, which reduced the sample size (amount of continuous, synchronous Polar data) available for analysis. The Polar H10 tag on one cat suffered sufficient connectivity lapses that data from that cat was considered unreliable and was removed from the analysis. Anecdotally and based on recent experience using Polar H10 monitors on dogs (Grigg and Hart, unpublished data), this issue may be exacerbated by the presence of multiple Polar monitors and smartphones within a relatively small area. The colony housing space utilized in this study measured $\sim 15' \times 25'$, and housed 4 monitored cats at a time.

It is important to note that, if either of the two problems above were causing the lack of agreement between the two cardiac monitoring systems, it may be that—if Polar monitors were used alone (w/o concurrent Holter monitoring) and/or without other Polar monitors nearby—they may function reliably. Our study design did not allow us to investigate that possibility. In addition, two of the Holter monitors suffered a malfunction prior to data download, resulting in loss of all Holter data for two study cats.

Finally, although guidelines for prospective analysis of the Holter data were followed carefully and completely (27), and every effort made to remove anomalous readings from the Polar data, it may be that user error in pre-processing or analyses of the Holter and/or Polar cardiac data impacted our results. No trend removal was done for the Polar data. And, although our artifact removal method did, overall, appear to improve the accuracy of the Polar sensor data (see **Supplementary Materials**), the artifact removal was automatic and therefore may have removed valid IBI data.

In conclusion, this study did not find sufficient agreement between standard ambulatory ECG and Polar monitor HRV data to suggest the utility of Polar H10 monitors in future feline HRV studies. HRV analyses have been used to assess emotional state (reflecting stress levels and welfare) of a number of mammalian species (e.g., horses, cows, dogs, and rats) under different handling, housing, training, and management protocols and routines (30, 38, 41–45). Physical restraint and manipulation during physical examination alter physiological parameters such as HR and HRV (20). Identifying a method of accurately and reliably determining HR and HRV in unrestrained cats during handling, daily husbandry procedures, among others, at a reasonable cost, would provide researchers and veterinarians with a valuable tool to assess stress levels associated with these procedures. Additionally, this method could be used to measure efficacy of interventions designed to reduce stress and increase welfare (such as low-stress handling procedures) of cats housed in shelters, clinics, and homes. Further evaluation of alternate methodologies for processing Polar monitor HRV data is warranted, as it remains our goal to identify an accessible, user-friendly, but reliable method to obtain HRV data on freely-moving domestic cats.

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 at: https://figshare.com/s/eda5ed5d9249e57f7d79.

ETHICS STATEMENT

The animal study was reviewed and approved by UC Davis Institutional Animal Care and Use Committee (IACUC).

AUTHOR CONTRIBUTIONS

EG conceived of the study, obtained funding and ethics approval, participated in data collection, performed data analysis, and drafted the manuscript. YU, JS, and AW assisted in study design, ethics approval, animal procedures, data collection, data analysis, and manuscript review and editing. SS generated the Holter data. LH reviewed and edited the funding proposal and manuscript. 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.2021.741583/full#supplementary-material

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A new method proposed to explore the feline's paw bones of contributing most to landing pattern recognition when landed under different constraints

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Felines are generally acknowledged to have natural athletic ability, especially in jumping and landing. The adage "felines have nine lives" seems applicable when we consider its ability to land safely from heights. Traditional post-processing of finite element analysis (FEA) is usually based on stress distribution trend and maximum stress values, which is often related to the smoothness and morphological characteristics of the finite element model and cannot be used to comprehensively and deeply explore the mechanical mechanism of the bone. Machine learning methods that focus on feature pattern variable analysis have been gradually applied in the field of biomechanics. Therefore, this study investigated the cat forelimb biomechanical characteristics when landing from different heights using FEA and feature engineering techniques for post-processing of FEA. The results suggested that the stress distribution feature of the second, fourth metacarpal, the second, third proximal phalanx are the features that contribute most to landing pattern recognition when cats landed under different constraints. With increments in landing altitude, the variations in landing pattern differences may be a response of the cat's forelimb by adjusting the musculoskeletal structure to reduce the risk of injury with a more optimal landing strategy. The combination of feature engineering techniques can effectively identify the bone's features that contribute most to pattern recognition under different constraints, which is conducive to the grasp of the optimal feature that can reveal intrinsic properties in the field of biomechanics.

KEYWORDS

animal biomechanics, cat paws, feline landing, post-processing of finite element analysis, feature engineering techniques, metaheuristic optimization algorithms

Introduction

Much of modern human motion technology was gathered and developed from animals (1, 2). Naturalistic development of the world would not be possible without the knowledge gained from animal models (3, 4). Cats are generally acknowledged to have natural athletic ability, especially during jumping and landing (5). Cats can land safely from high positions without any injury, because of the landing buffering mechanics that they possess. The adage, "cats have nine lives", seems applicable when we consider the animal's ability to land safely from heights (6). Several studies have reported that there have been <10% of cat's fatalities recorded while falling from heights (6–8). Vnuk et al. investigated that there was a 96.5% survival rate when a feline fell from height (6). This interesting phenomenon has attracted much research attention. Research has focused on the inner mechanical principles of the cat for providing information to reduce landing fall injuries in humans (9).

Paw pads of cats during landing are the only body parts in contact with the ground. It is believed that paw pads play an important role in the landing phase for buffering of impact force (7). The Felida family such as cats, tigers, leopards and so on are representative of the padded paw, which is commonly located beneath the distal metacarpophalangeal joints and interphalangeal joints (10). It is logical to discuss that the paw pads of cats are one of the main parts for absorbing impact force because they have relatively long tarsals and carpals. The paw pads also help to optimize stress distribution in the phalanx region (11). The paw pad is the main component area that contacts the ground in activities such as standing, jumping, walking, and running. This special morphological structure allows felines to absorb two to three times their body weight while resting on their small distal joints (7, 12). Conventional biomechanical experiments (such as animal experiments, *in vitro* cadaveric specimens, etc.) often cannot fully reflect the real biomechanical changes of internal bones, but three-dimensional finite element analysis (FEA) can simulate the complex mechanical environment in a mathematical form and provide internal mechanical information (13–15). FEA facilitates the measurement of external forces and the analysis of internal stresses during the experimental investigation, which also can provide a better understanding of the cat's special landing mechanism (1, 11).

However, the FEA also has certain drawbacks when comparing the stress characteristics of different models after the FEA (15, 16). In other words, such comparison after FEA is usually based on stress distribution trends and maximum stress values (13, 16, 17), which is a certain contingency (15, 18). For example, the maximum stress value is often related to the smoothness and morphological characteristics of the finite element model, so the comparison method of maximum stress value cannot be used to comprehensively and deeply explore the mechanical mechanism of the bone. Previous studies have explored the stress values at all nodes of a piece of bone using the *F*-test method (17). This method can effectively avoid the contingency of maximum stress value, but it ignores the effective information of stress distribution characteristics. Therefore, it has become a challenge in the field of biomechanics in the post-processing of FEA to analyze the stress distribution characteristics of bones effectively while avoiding the chance of the existence of stress extremes (15, 19–21).

In recent years, machine learning methods that focus on feature pattern variable analysis have been gradually applied in the field of biomechanics (1, 22–24). Meanwhile, the progress of motion capture technology, mechanical sensing technology, and signal processing technology makes biomechanical data acquisition diversified and refined, which provides the prerequisite for the application of big data-driven machine learning methods in the feature recognition and selection in the field of biomechanics (1, 24, 25). Metaheuristic optimization algorithms are a fascinating research hotspot in the field of machine learning, and it has been significant in solving complex and difficult feature optimization problems (26, 27). At present, there have been a large number of studies using metaheuristic optimization algorithms to select and classify characteristics of biological data (28, 29). Particle swarm optimization (PSO) is a classical and widely researched algorithm in the field of metaheuristics, which aims to deal with optimization problems in continuous or discrete spaces based on population search (30, 31). The construction of a bone stress distribution pattern recognition and feature selection model based on PSO can provide some methodological reference for the problem of stress feature exploration in the field of biomechanics and provide unique new insights into the results.

Therefore, this work aimed to explore the cat forelimb paw biomechanical characteristics when landing from different heights by using FEA, and feature engineering techniques for post-processing of FEA. Specifically, the ground reaction force (GRF) data waveform during the cat landing was first reconstructed using principal component analysis (PCA), and the optimized data was substituted into a finite element model simulation to calculate the bone stress distribution. After that, by extracting the node stress values of each bone in the finite element model as model input data, a feature selection model was constructed based on PSO in the metaheuristic optimization algorithm to select the optimal bone stress distribution features that can identify landing patterns when landing from a different height. Meanwhile, a feature classification and recognition algorithm model was constructed to determine the accuracy of recognizability of each bone stress distribution feature for landing patterns when landing from a different height. Finally, the aim of exploring the cat landing patterns characteristics and law during landing from different heights was achieved by combining the above results, and the advantages of FEA

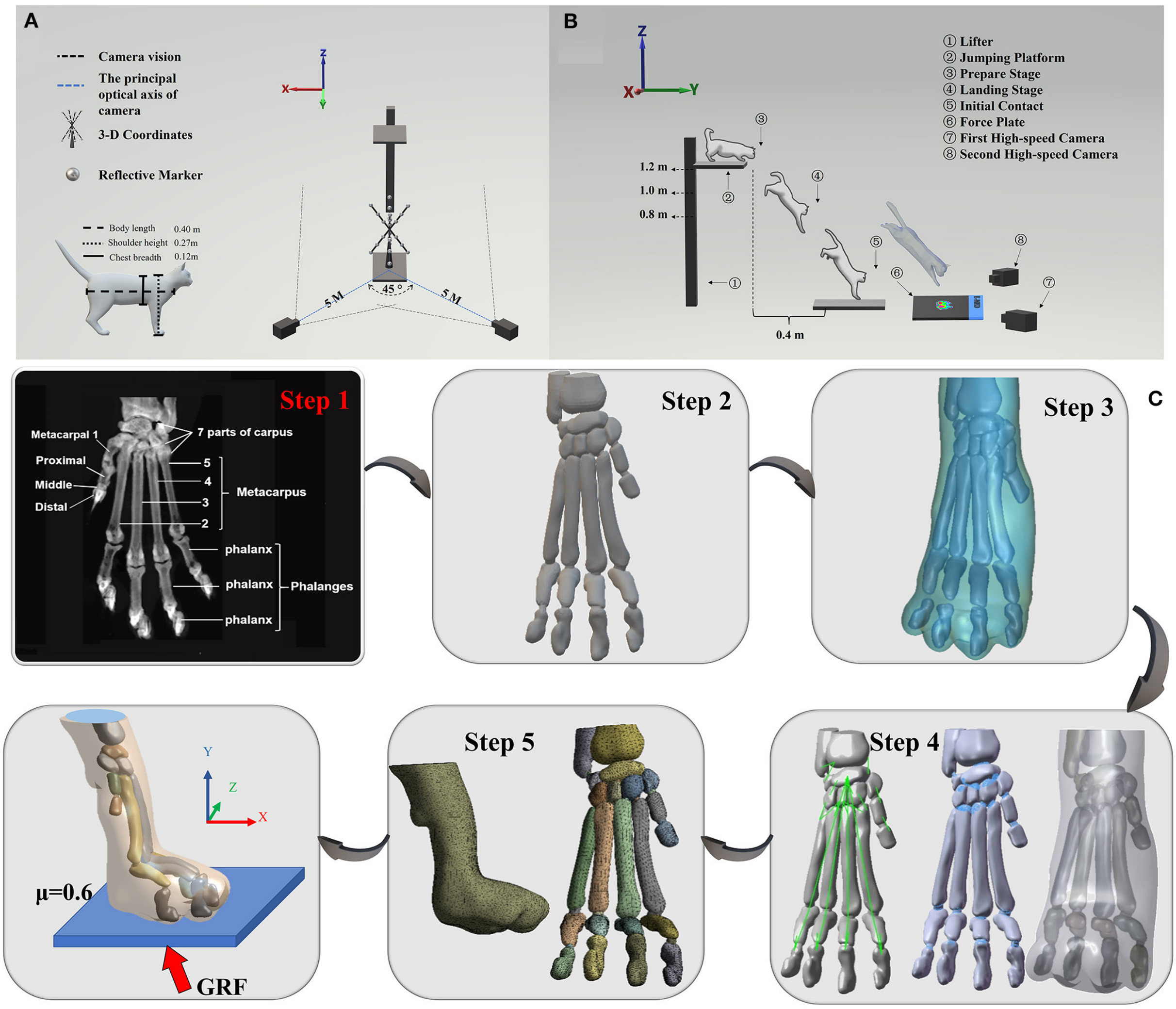

FIGURE 1
(A) Illustration of the position of 3-D coordinates and two high-speed cameras. **(B)** Illustration of cat landing experimental procedure from the ready position of jumping platform to initial forelimbs contacting the force plate. **(C)** Illustration of the process of FEA. Step 1 is to obtain the coronal CT images of the right forelimb paw. Step 2 is the 3D model obtained by processing CT images through Mimics software, and then importing the 3D model into Geomagic software (Step 3) for post-processing such as noise reduction, spike removal and smoothing. After that, Step 4 was performed by using SolidWorks software to get cartilage, ligaments, and soft tissue (from left to right). Finally, Step 5 was executed by using ANSYS Workbench software to grid processing, then load and boundary conditions were applied to execute FEA.

post-processing based on feature engineering techniques have also been demonstrated.

Materials and methods

Animals

Written agreement from the breeder in the local area was obtained for the voluntary involvement of a healthy male domesticated cat: aged 2.85 years, body mass of 4.32 kg (Figure 1A shows the specific body length of the test cat). There was a comprehensive clinical assessment prior to data collection in order to guarantee that there were no health conditions that would affect the study's results. A computerized tomography (CT) scan of the cat was taken. The CT scan was conducted by a veterinarian at a pet hospital. In order to ensure that there were no health issues or foot injuries, the cat was inspected by a veterinarian. The Animal Care and Use Ethics Committee of Ningbo University gave its approval to this research (NBUAEC20200621).

Experiment protocol and procedures

All tests were performed in the biomechanics laboratory at Ningbo University Research Academy of Grand Health.

The landing task was performed on a force platform (Kistler, Switzerland) using a 1,000 Hz sampling frequency for GRF data collecting. During each landing task, kinematic data were collected using two high-speed cameras (Fastcam SA3, Photron, Japan) set at 1,000 Hz. At the same time, the other landing task was performed on a pressure sensing mat EMED-AT system (Novel, Germany) to collect the E-med data (EMED-AT system: 700 × 403 × 15.5 mm with a sensor area of 475 × 320 mm, containing 6,080 sensors with a recording frequency of 100 Hz). The cat was completely acclimated to the setting (test room) prior to data collection, with toys and food used to entice the cat's interest. To ensure a smooth experiment, the cat was brought to the laboratory by its owner before the official start of the trial. This procedure was repeated three times a week for 1 h each time until the cat could be lured by food and toys and precisely leap to the appropriate place (the force platform). Three heights of 0.8, 1, and 1.2 m were taken as the heights selected for this experiment. Twenty groups of data were collected by a force platform and E-med for each height, and a total of 120 groups of data were collected.

The cat owner urged him to sit in a squat posture on the leaping platform while the table height was changed to the exact height necessary. To minimize erroneous data collection due to fatigue, a 5-min break was implemented between each landing task. The cat's head and body were both facing forward when it fell, so there was no obvious tilt to the body. When the cat's forelimb landed in the defined region and the cat proceeded to travel ahead from the indicated area, the experiment has judged a success. There were no injuries or negative responses following the experiment. Two high-speed cameras were mounted at the diagonal level of the force plate at a distance of 5 m from the landing target region, producing a 45-degree angle between the major optical axes of the two cameras, as shown in Figure 1A. Three-dimensional (3-D) coordinates were put in the center of the force platform to create the space coordinate. Figure 1B shows the landing test procedure of the cat from a preparation stage to an initial contact phase.

Data processing and statistical analysis

The first point of contact with the force plate was determined using a vertical GRF > 10 N (1, 32). The landing phase was defined as the first point of contact (0% landing phase) to maximum elbow flexion from the first peak vertical GRF time point to the second (100% landing phase). The GRF data was filtered using Butterworth lowpass filters (filter order: fourth-order zero-phase lag, cut-off frequency: 50 Hz) (33). SIMI-Motion 7.50 is a motion simulator developed by SIMI-Motion (Simi Reality Motion Systems GmbH, Munich, Germany), which was used to analyze the cat landing phase. After that, the elbow sagittal plane joint angles were taken as an output from SIMI -Motion, and the time point corresponding to the maximum elbow flexion angle was derived to intercept the data waveform of the GRF. Then, each landing height (0.8, 1.0, and 1.2 m) of each direction (X-axis: lateral and medial GRF; Y-axis: anterior and posterior GRF; Z-axis: vertical GRF) of the determined GRF data were expanded into 101 data points using a self-written MATLAB script, which represents the 0–100% landing phase (1). Finally, the data waveform of the GRF was run in MATLAB by a custom MATLAB script to execute the PCA to reconstruct the waveforms of the principal GRF.

At the same time, the time point corresponding to the maximum elbow flexion angle was also used to determine the E-med data. The SPSS 24.0 for Windows^{TM} software was used for statistical analysis (SPSSs Inc., Chicago, IL, USA). Prior to statistical analysis, the Shapiro Wilk normality test was applied to all E-med data. If non-conformity was observed then the Wilcoxon matched-pairs signed-rank test was conducted for non-parametric data. Independent *t*-tests were performed to determine if there were any significant differences in different biomechanics values between left and right forelimbs. A one-factor repeated ANOVA was performed to determine the effect of landing heights during the landing phase on the right forelimb. The Least Significant Difference (LSD) was used in the post-test of analysis of variance, and the *P*-value was also corrected based on the result of the post-test.

Principal component analysis reconstructed data waveform of ground reaction force

PCA is a multivariate statistical analysis technique that uses orthogonal rotation transformation to convert multiple indexes into several comprehensive indexes to reduce dimensionality and sacrifice as little information as possible (34). The principle component is the name given to the comprehensive index produced by transformation, in which each principal component is a linear combination of the original variable and is unrelated to the others (1, 34, 35). When investigating complex problems, it is possible to consider only a few principal components without missing too much information. As a result, it is simpler to identify the major contradiction, disclose the regularity between the internal variables of objects, and reduce the problem in order to increase analytical efficiency. See Supplementary Text 2 for more details on the application of PCA in current research.

Finite element analysis technology simulated the bone stress distribution of cat claw

The specific FE model feline paw model was created using Computer Tomography (CT) images. CT scans were obtained and conducted at a pet hospital by a qualified veterinarian. Before obtaining the CT data, the cat was examined by a veterinarian to confirm that there were no health problems or foot injuries.

The whole process of FEA is shown in Figure 1C. Coronal CT images of the whole body were collected with a space interval of 0.5 mm in the unloaded position, while only the right forelimb paw was analyzed in this experiment (1, 15). The body of the cat was oriented in the scanner in a specific way to mimic the posture of the cat landing. The structures of 23 bones, which included 1 radius, 1 ulna, 7 carpus, 5 metatarsals, and 9 components of the phalanges together with the encapsulated volume were segmented using MIMICS 20.0 (Materialise, Leuven, Belgium). To obtain the boundaries of the skeleton, the bones were saved in STL format. Secondly, they were imported into specific software (Geomagic, Inc., Research Triangle Park, NC, United States) for post-processing. This included noise reduction, spike removal, and smoothing. The file was then imported to SolidWorks (SolidWorks Corporation, Massachusetts, 2017) in Iges format SolidWorks. SolidWorks was utilized for the conversion of all volumes to solid parts individually. To simulate the real situation of the cat's paw, the solid volume of the articular cartilaginous structure was shaped. Eventually, 23 cartilages were created according to the feline paw anatomical structure. Additionally, the encapsulated soft tissue was built by subtracting all bones and cartilages and converting them into a solid format. The ligaments were then generated based on anatomical characteristics (36). All 76 parts of the paw, which included 23 bones, 23 cartilages, 30 ligaments, and an encapsulated soft tissue. Using ANSYS Workbench 17.0 (ANSYS, Inc., Canonsburg, United States) for meshing each part. The solid model of each bone was divided into a high-quality mesh using the self-adapting dynamic biomechanical FE grid of the Modeler. The length of the mesh was designated as 1–2 mm. Finally, load and boundary conditions are applied, and FEA is performed on the model. More details about the material properties, loading, boundary conditions and connections for FE models are shown in Supplementary Text 2.

Optimal feature selection of landing patterns based on bone stress distribution

Based on the three landing heights, the optimal features can be selected in two cases: landing from 0.8 m vs. landing from 1.0 m, landing from 1.0 m vs. landing from 1.2 m. Data was entered 5 times in each of the two comparisons, a total of 10 data sets: M_{data1}, M_{data2}, M_{data3}, M_{data4}, M_{data5}, M_{data6}, M_{data7}, M_{data8}, M_{data9}, M_{data10}. Refer to Supplementary Text 2 for details of what each dataset represents.

When the metaheuristic swarm intelligence algorithm performs optimization calculations, the population of individuals represents different meanings for different optimization problems (26, 37). The essence of feature selection in this study is binary optimization. Specifically, the present work uses the construction of a binary particle swarm optimization feature selection algorithm model to select the stress characteristics of the cat's metacarpal and the phalanx of claws that can identify the landing patterns of cats at different altitudes. At each time step, the PSO idea involves accelerating each particle toward its *Pbest* and *Gbest* positions by modifying its velocity (global version of PSO). Random numbers are created for *Pbest* and *Gbest* acceleration sites, which are weighted by a random term. For the binary particle swarm optimization (BPSO), the cognitive factor was set to 2, the social factor was set to 2, and the inertia weight was set to 0.9. The population in BPSO is referred to as a swarm, which consists of N particles that move around the search space in multiple dimensions. Potential solutions are represented by particles that travel across the search area to find the best option. According to its own experience and knowledge, each particle looks for the global maximum or minimum. More detailed descriptions of BPSO are shown in Supplementary Text 2.

After optimization, the representation of the feature selection result is limited to 0 and 1. The value 0 means that the feature is not selected, and the value 1 means that the feature is selected (37, 38). When optimizing the selection of features, the individual solution of the swarm can be regarded as a one-dimensional vector, and the original data value of each dimension is compared to 0.5. If the value is $\geq$0.5, the value is defined as 1, and the feature is selected; otherwise, the value is defined as 0, and the feature is unselected. For example, if the solution $X = a\{0.82, 0.63, 0.35, 0, 0, 1, 0.98, 0.87, 0.14\}$, it represents six features (1st, 2nd, 6th, 7th, 8th) are selected. The number of iterations for all optimization algorithms was set as 100, and the fitness function can be defined as:

$$Fitness\ value = \alpha E_R + (1-\alpha)\frac{|R|}{|S|} \tag{1}$$

$$E_R = \frac{Number\ of\ wrongly\ predicted\ instances}{Total\ number\ of\ instance} \tag{2}$$

where the E_R is the error rate calculated by the learning algorithm, $|R|$ is the feature subset's length, $|S|$ denotes the total number of features, α is the parameter of control of the weight (between the ratio of selected features and error rate). In this study, the α was set to 0.9 since the classification performance was the most essential measurement. The k-nearest neighbor (KNN) algorithm was selected as the learning algorithm for fitness evaluation (Supplementary Text 2). For performance evaluation, the hold-out validation method was applied, and the value ratio of validation data was set as 0.2.

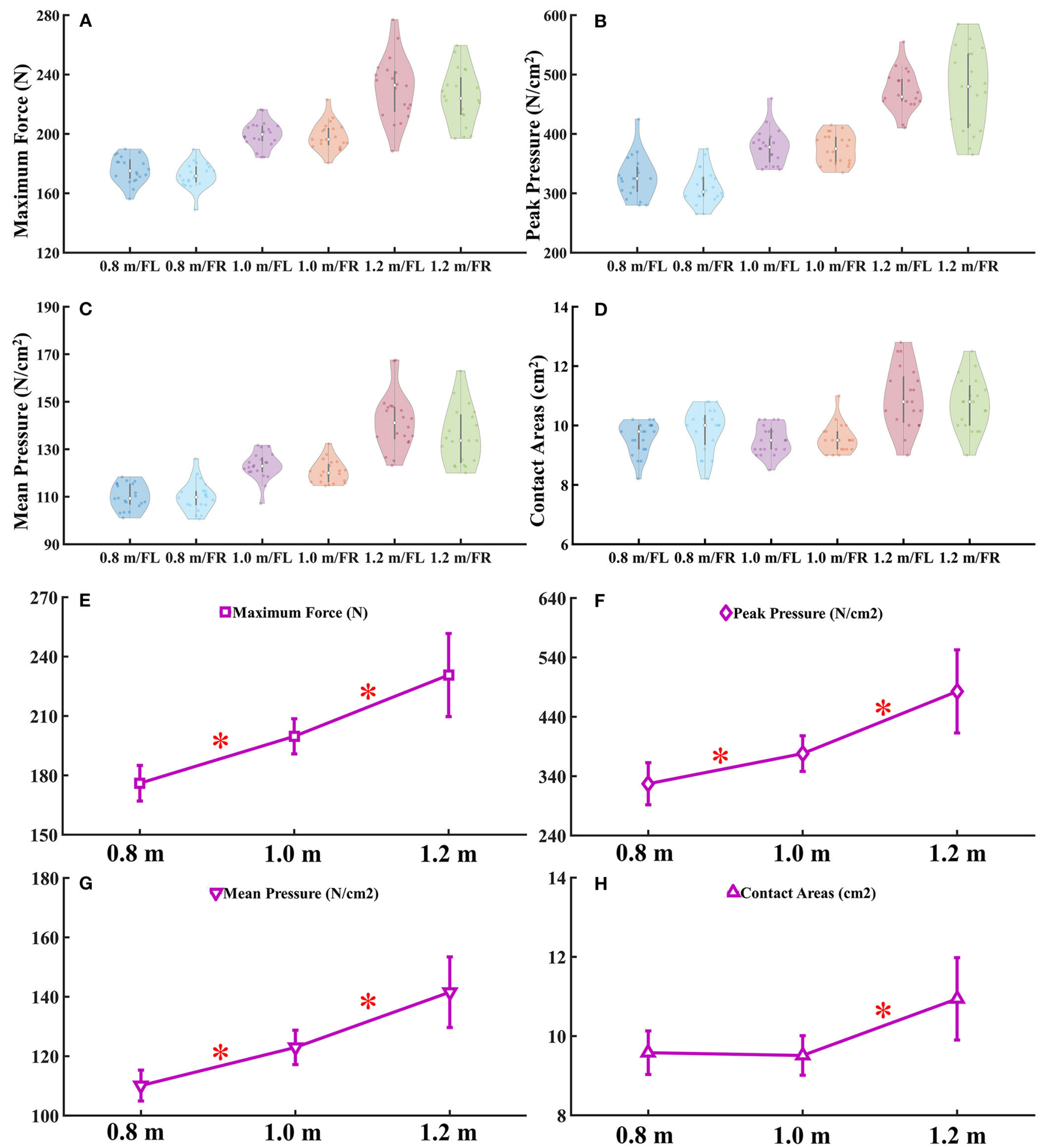

FIGURE 2
(A–D) The violin plot of E-Med data distribution. **(E–H)** Comparison of forelimb paw right in maximum force, peak and mean pressure and contact areas during landing from different heights. FL, Forelimb paw left; FR, Forelimb paw right; "*" represents significant difference between heights. 1 MPa = 1,000 N/cm^2.

After that, the top three features that have been selected the most times based on 20 random seeds were selected as the final extracted features. The realization of the whole algorithm is through MATLAB self-written scripts based on previous research and MATLAB built-in toolbox.

Feature classification and recognition based on bone stress distribution

For the classification and recognition algorithm model of landing features, the current research is also divided into two cases to test the classification and recognition accuracy of features. A total of 10 data sets (M_{data1} to M_{data10}) were substituted into the constructed model. In this study, the KNN (39), support vector machine (SVM), and artificial neural network (ANN) (40) were selected to classify in this study because they have been widely used in pattern recognition and classification. More detailed descriptions of recognition and classification model building are shown in Supplementary Text 2. The 10-fold cross-validation was used in all classification models.

Results

Pressure and force distribution on cat from E-Med

There were no significant differences found in maximum force (Figure 2A), peak pressure (Figure 2B), mean pressure (Figure 2C), and contact areas (Figure 2D) during the landing task from three different heights between left and right forelimb paw. The detailed data analysis results are shown in Supplementary Table S3. Significant differences were found in right forelimb paw at maximum force (Figure 2E), peak pressure (Figure 2F), mean pressure (Figure 2G), and contact areas (Figure 2H) during the landing task between 0.8, 1.0, and 1.2 m, respectively. The detailed data analysis results are shown in Supplementary Table S4.

Reconstructed waveforms of principal component analysis

The data waveform of GRFs in three directions when the cat landed from three heights are shown in Figure 3A, with a total of 20 waveforms for each case. Results of PCA based on these data are reported. The first four PC scores PC_i of each landing height and each direction GRF are shown in Figure 3B. For the first PC scores PC_1 of GRF, the PC_1 covers the most important characteristic information of the waveform. This highlighted that PC_1 can reconstruct the principal GRF $\overrightarrow{PF}$ (1, 35). Therefore, the first PC scores PC_1 was selected to reconstruct the principal GRF PF in each direction. The waveform difference between different landing height of reconstructed principal GRF PF is shown in Figure 3C. According to the reconstructed waveform of principal GRF, the GRF value for each landing height of the maximum elbow flexion was extracted (the detailed values are shown in Figure 3D). Finally, the GRF data values of each landing height at the time point of the end of the landing phase (maximum elbow flexion) are extracted from the reconstructed waveform and substituted into the finite element model to investigate the stress distribution of the cat right forelimb paw bone (metacarpal and phalanx).

Finite element model validation

During the process, 4-note linear tetrahedral elements were used on the irregular geometries such as bones, cartilage, and encapsulated tissue. The established three-dimensional FE models include 215,885 elements, 359,299 nodes. The structures of 23 bones included 1 radius, 1 ulna, 7 carpus, 5 metacarpals, and 9 components of the phalanges. Referring to the numerical model of the human foot, the FE model foot models were validated by plantar pressure distribution (1). Detailed procedures and results are provided in Supplementary Text 1. The results showed that the numerically determined pressure distribution in the left forelimb paw was in good agreement with experimental data (Supplementary Figure S1).

Right forelimb paw stress distribution

Twelve bones surrounding the cat's paw pad were selected as features. The number of finite element model nodes corresponding to each bone is shown in Supplementary Table S5. The overall stress distribution of the right forelimb paw is shown in Figure 4A. The stress is mainly concentrated at the metacarpal and proximal phalanx. The MP2 had the highest stress level. Specifically, the stress was mainly concentrated in the middle and rear of the MP2 and the MP5, and the distal end of the MP3. The pressure between the MP4 and the MP5 was similar, but the stress distribution of the MP4 was more uniform. The maximum stress value of the MP5 was always greater than that of the MP4 during landing from each height. The proximal and distal phalanges were less stressed. The detailed stress distribution heatmap and Pareto distribution results of stress values at all nodes of MP2 are shown in Figures 4B–D. The detailed stress distribution of other 11 bones are shown in Supplementary Figures S2–S12.

The left side of the figure is the detail heatmap diagram of stress distribution, and the right side is the distribution diagram of stress values of all nodes [Pareto distribution (41): the stress values of all nodes are arranged in descending order, and then divided into 30 distribution ranges in order]. The number of nodes were arranged according to the stress value from top to bottom, each bones stress distribution ranges of all nodes and of the last 50, 80, 90, and 95% nodes, as well as the first 5% nodes are shown in Supplementary Table S6. For the MP2, the stress was mainly concentrated in the middle and rear. The stress distribution ranges of all nodes were 0.0135–1.2166, 0.0179–1.6274, and 0.0211–1.8862, respectively, the stress distribution ranges of the last 50% nodes were 0.0135–0.2550, 0.0179–0.3418, and 0.0211–0.3936, respectively, the stress distribution ranges of the first 5% nodes were 0.8772–1.2166, 1.1748–1.6274, and 1.3588–1.8862, respectively (Supplementary Table S6; Figures 4B–D).

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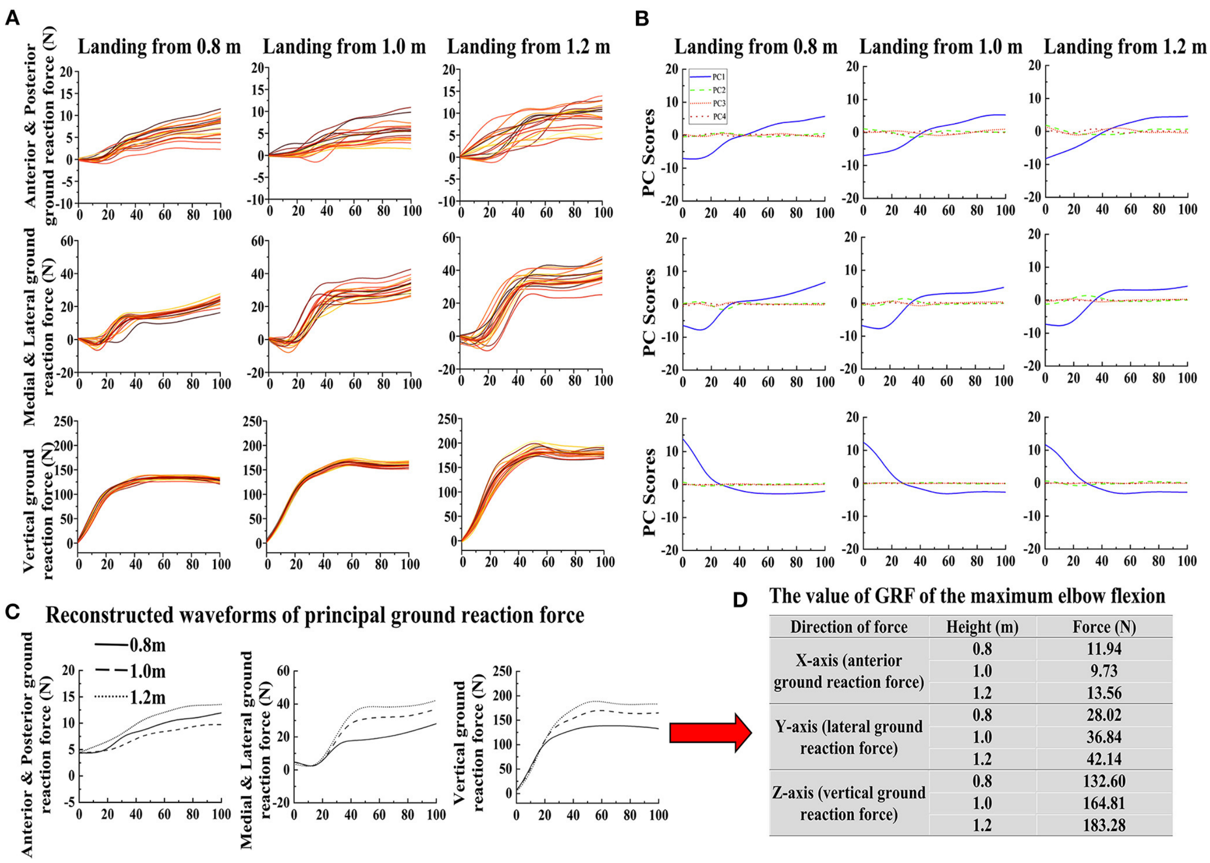

Direction of force	Height (m)	Force (N)
X-axis (anterior ground reaction force)	0.8	11.94
	1.0	9.73
	1.2	13.56
Y-axis (lateral ground reaction force)	0.8	28.02
	1.0	36.84
	1.2	42.14
Z-axis (vertical ground reaction force)	0.8	132.60
	1.0	164.81
	1.2	183.28

FIGURE 3
(A) The raw data waveform of GRF for each direction (X-axis: anterior and posterior GRF; Y-axis: lateral and medial GRF; Z-axis: vertical GRF) in each height (0.8, 1.0, and 1.2 m). **(B)** The first four PC scores PC_i of each landing height and each direction GRF. **(C)** The reconstructed waveforms of each landing height and each direction GRF. **(D)** The extracted principal GRF value of the maximum elbow flexion data point based on the reconstructed waveform in each direction during landing from different heights.

Feature selection results based on the bone stress distribution

For each random seed (20 random seeds) in each contrasting situations (10 kinds of input data), the results of fitness value are shown in Supplementary Figure S13. The detailed results of the feature selected in each contrasting situations in each random seed based on the constructed feature selection algorithm model are shown in Figure 5A. See Supplementary Text 1 for the detailed description of Figure 5A. Finally, the stress distribution features that contribute most to the landing pattern recognition at different heights mainly focused on MP3, MP4, PP2, PP3, PP5 (Figure 5B). In terms of MP4 and PP2, PP2 basically exists in most node control cases, and MP4 mainly exists in the results based on the stress value data corresponding to the first 200 and 500 nodes with the highest stress values.

Feature classification and recognition results based on the bone stress distribution

The detailed results of features classification and recognition accuracy rate in each contrasting situation of the three different classification algorithm models are shown in Figure 6. In each contrasting situation, the total exact classification recognition accuracy obtained by the three classification models is shown in Supplementary Table S7. The classification of each bone stress distribution when landing from different heights can be objectively and accurately detected by combining the three classification models. The bone stress feature recognizability between landing from 0.8 m and landing from 1.0 m is significantly higher than that of landing from 1.0 m and landing from 1.2 m (Figures 6B,C). For the results based on the data of stress value corresponding to all nodes, they both

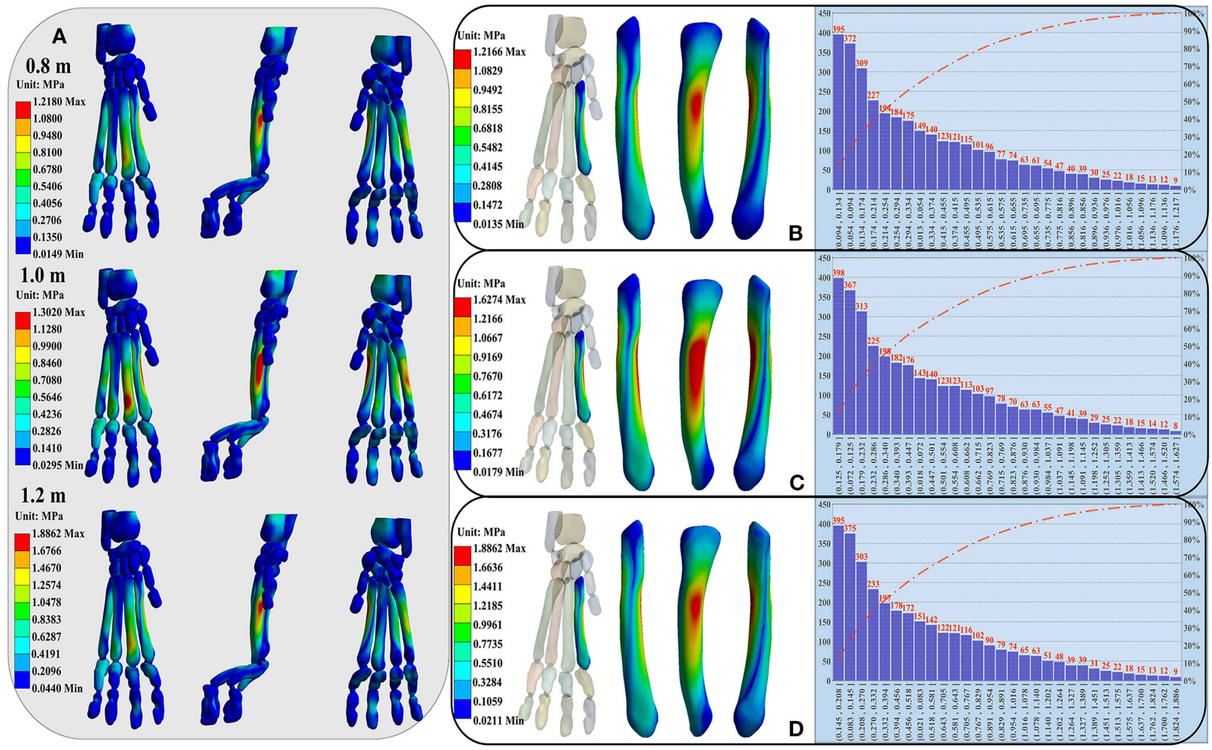

FIGURE 4
(A) Illustration of the right forelimb paw stress distribution of the cat landing from different heights. From left to right are front, side and back views of the overall stress distribution. **(B–D)** Display the detailed stress distribution heatmap (left side) and Pareto distribution (right side) results of stress values at all nodes of MP2. From left to right are front view, side view and back view of the MP2. The stress distribution from top to bottom corresponds to the landing heights of 0.8, 1.0, and 1.2 m.

show a poor classification in the landing height between the 0.8 and 1.0 m, 1.0 and 1.2 m. As the stress value of the selected nodes gradually increases (from the data of stress value corresponding to all nodes to the data of the first 200 nodes with the highest stress values), the classification and recognition accuracy of the stress distribution features of each bone gradually increases (Figure 6D; Supplementary Table S7). In each contrasting situation, features with higher classification recognition accuracy compared with other features are shown in the red mark in Figure 6A, and these features contribute more to the recognition of different landing patterns. More details on this are shown in Supplementary Text 1.

Discussion

The current work investigated the biomechanical characteristics of the cat forelimb paw during landing from different heights using FEA and feature engineering techniques for post-processing of FEA results. The main contribution of the current study is to fill the field gap of cat's paw biomechanics during landing, and the proposed combination of feature engineering technology to solve the problems that include incomplete analysis, and difficulty in feature mining in the post-processing of FEA.

This study explored the differences between the left and right forelimbs for maximum force, peak and mean pressure and contact areas during a landing task from different heights, and the results show that there were no significant differences between left and right forelimbs. A previous study also demonstrated that when a cat jumps from a height of 1 m, the force on its forelimbs is equal (42). It was consistent with our results. Wang et al. proved that when a cat jumps from a height of 30 and 50 cm, the force on its forelimbs is equal (43). This work further demonstrated that the contact area of paw pads is equal. Slingerland et al. concluded that cats are forelimb-dominant, and it might explain the findings of this study (44). The forelimbs are the dominant part of the cat, so in the landing process, the forelimbs also play the role of direction and posture control. When falling from a high place, due to this excellent symmetry, the impact force generated by the landing can be fully and evenly distributed to the two forelimbs, so that forces can be transmitted to other joints in a positive and even manner. This explains in part and is one of the reasons why cats can fall

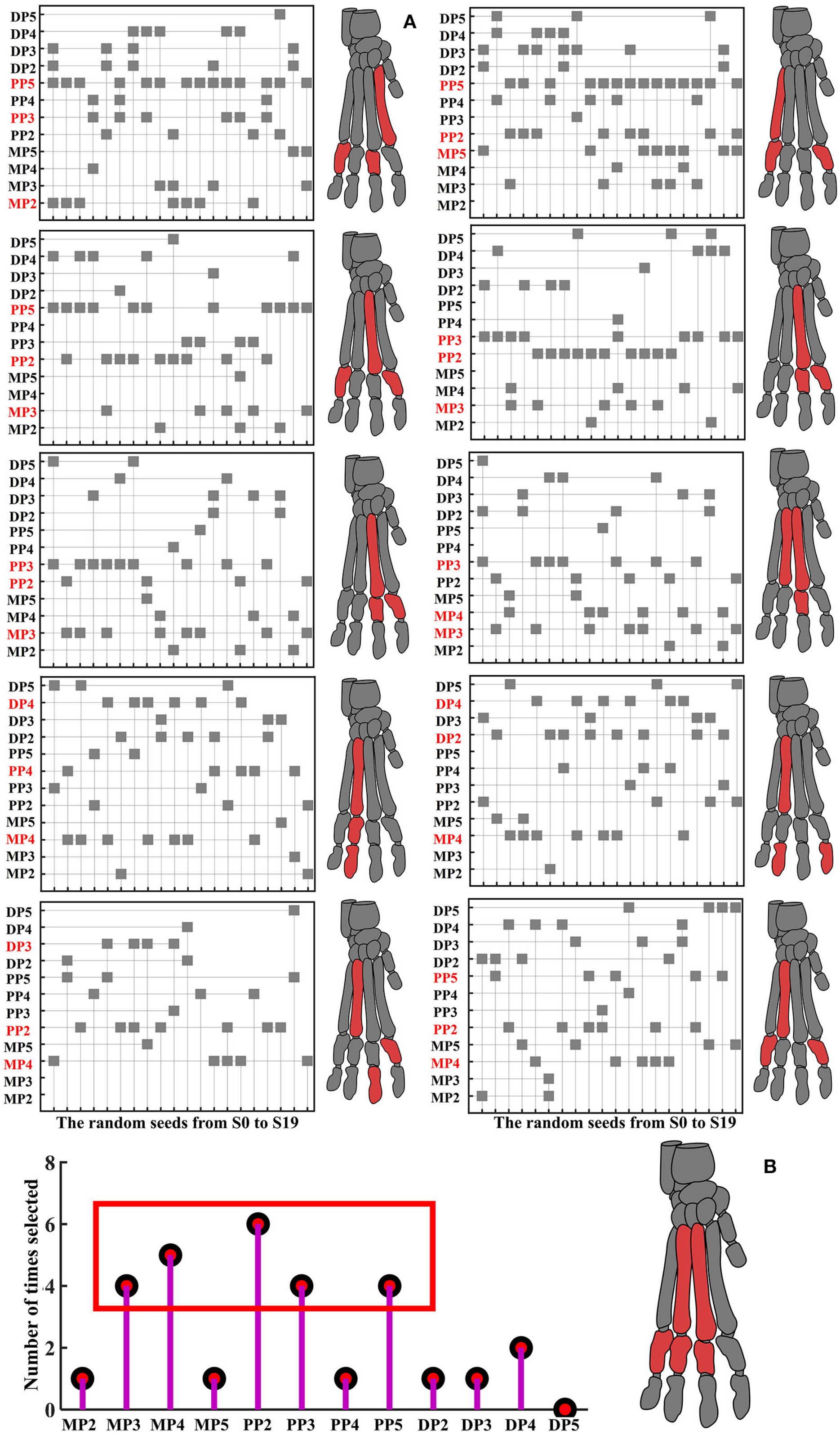

FIGURE 5

Detailed results of features selected in each contrasting situations in each random seed. **(A)** The left side is the feature selection results based on the data of landing from 0.8 to 1.0 m, and the right side is the feature selection results based on the data of landing from 1.0 to 1.2 m. From top to bottom are the results based on the data of stress value corresponding to all nodes, the data of the first 2,000 nodes with the highest stress

(Continued)

FIGURE 5 (Continued)
values, the data of the first 1,000 nodes with the highest stress values, the data of the first 500 nodes with the highest stress values, the data of the first 200 nodes with the highest stress values, respectively. The shaded square indicates that this feature was selected under the random seed, the claw bones marked red are the top three stress distribution features selected the most times. **(B)** The number of times of each selected feature based on the three stress distribution features selected the most times for each contrasting situations.

from great heights without injury. However, Wang et al. also mentioned that the symmetry of the forelimbs would increase with increases in jumping heights (11). This was inconsistent with our results, we did not find any asymmetry values at 0.8, 1.0, and 1.2 m, which is probably because these heights are still within the acceptable range for a cat to land normally.

In a previous study, the findings indicated that the muscle or soft tissue of cats absorbed impact force when landing or walking (40). We partly agree with the findings of the T. Kohonen et al. According to our study, the skeleton of the cat also plays an important role when cats perform landing or walking tasks. It is difficult to confirm which parts are more important and contribute the most. Xu et al. believe that the MP pad has a larger surface area than the digital pad, and its special columnar structure provides better support for the body while playing a dominant role in distributing and absorption of impact (1, 45). From the view of the overall stress distribution of the right forelimb paw, the stress is mainly concentrated on the rear of MP2, MP5 and the front of MP3, MP4, and the average stress of MP except MP2 tends to be consistent. The uniform stress distribution during the landing of the cat reduces the risk of fracture, which may be related to the small range of motion of the distal joint. Previous studies have shown that there was a limit on the wrists during cat movements (12). The carpal bone, which is part of the wrist joint, shows more degrees of freedom than the hinged joint (36). In order to counteract the multi-dimensional motion of the wrist, the movement of the MP joint may also be limited to maintain the stability of the upright posture of the lower extremities. The cat's forelimb is subjected to a greater impact during landing, and the forelimbs of the cat would move toward the palm (46). Under these conditions, the wrist provides full engagement in its supporting function, while increasing the contact area between the ground and the sole of the paw, thereby reducing the landing impact load (1).

By extracting the stress values of all nodes in the finite element model, the current research results found that the number of nodes with large stress values only accounts for 5–10% of the total number of nodes (Figure 4; Supplementary Table S6; Supplementary Figures S2–S12). In this case, it is often "fatal" to simply discuss the distribution of maximum stress values under different constraints just like in previous studies, because a large number of nodes without obvious changes may cover up the true nature of data change rules. As a result, the internal law of stress distribution feature cannot be truly excavated and cannot be effectively explored in terms the biomechanical characteristics of cat landing. Based on this, this study proposes for the first time to explore the inherent regularity of stress distribution characteristics by combining characteristic engineering techniques, to solve problems such as insufficient mining in the post-processing of FEA. By controlling the stress values corresponding to 5 different selected nodes as input data, the current study constructed the classification and recognition model to detect the recognition accuracy of the selected 12 stress distribution feature in different landing patterns at different heights. The results demonstrated that the classification and recognition are very low, only reaching about 50–60% (Figure 6; Supplementary Table S7), when the corresponding stress values of all nodes are taken as input data. As the input data of the model changes continuously (from all the stress values corresponding to the 3,300 nodes to the stress values corresponding to the first 2,000 nodes with the highest stress values, and finally to the stress values corresponding to the first 200 nodes with the highest stress values), the classification and recognition accuracy of each feature in landing patterns at different altitudes also continue to improve. In particular, for the metacarpal and proximal phalanges when the landing height is 0.8 and 1.0 m, the classification and recognition accuracies were almost 100% when the input data to the model was the stress values corresponding to the first 200 nodes with the highest stress values (Figure 6; Supplementary Table S7).

Regarding MP4 and PP2, the classification recognition accuracy rate of MP4 and PP2 was significantly higher in 5 different node selection cases than in other features. Meanwhile, both for the results based on the input data of landing from 0.8 to 1.0 m, and for the results based on the input data of landing from 1.0 to 1.2 m, among the features selected based on the feature selection model, there are many cases in which the stress distribution feature of the MP4 and PP2 were selected as the optimal feature to identify different landing patterns (Figure 5; Supplementary Table S6). This also suggests that MP4 and PP2 play an important role in cat landing. The results are different from those obtained by the traditional analysis method based on the comparison of stress distribution trend and maximum stress value. Traditional analysis results show that the stress distribution of cat landing is mainly concentrated in MP, especially in MP2, and its overall stress distribution is larger than that of other bones. In the feature selection model, the MP2 feature was selected as the optimal landing pattern recognition feature only when the data set M_{data1} was used as the model input data (M_{data1}: based on the data of stress value corresponding to all nodes, when landing from 0.8 to 1.0 m). This suggests that a large number of nodes with no obvious

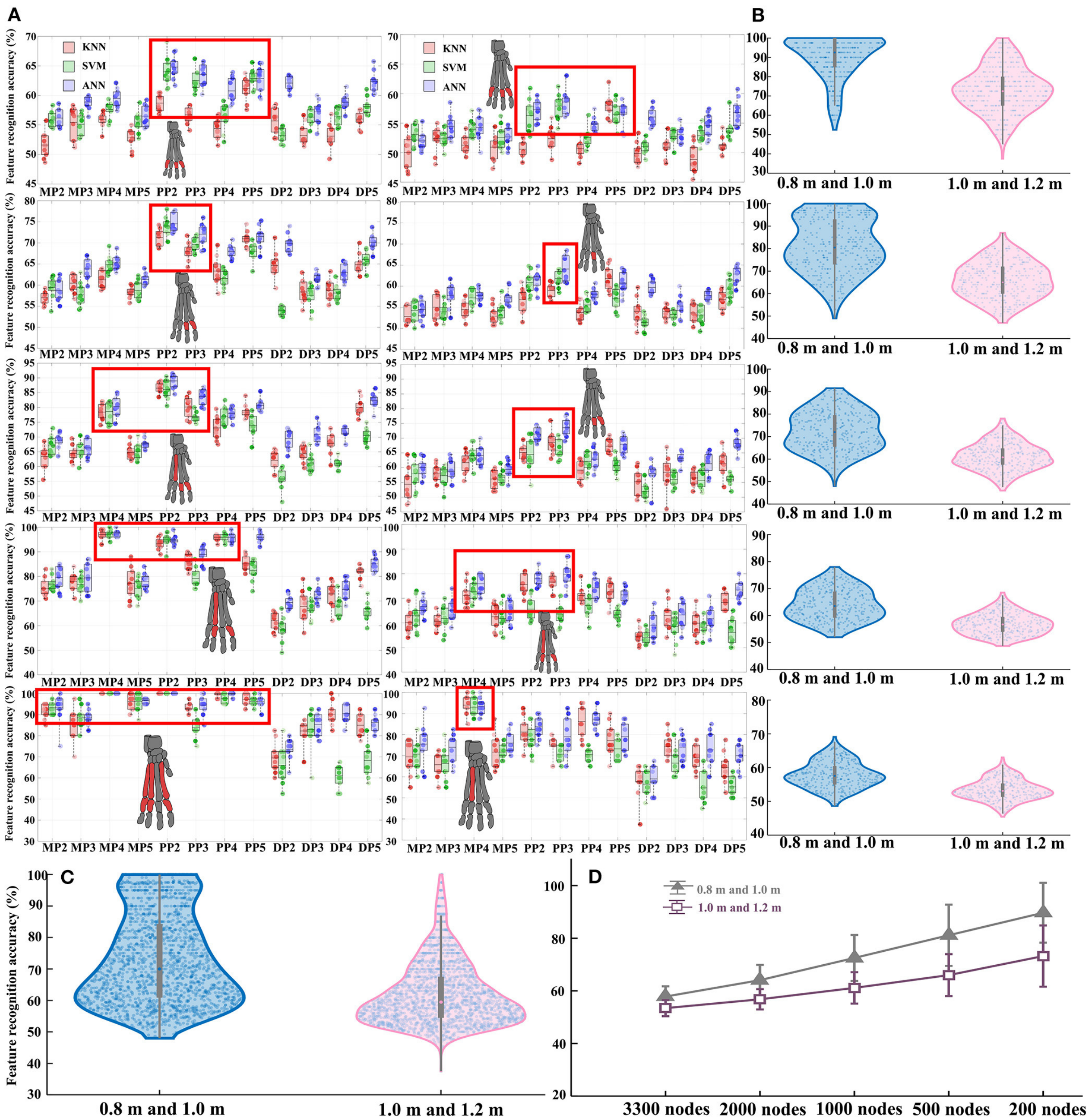

FIGURE 6
(A) Detailed results of features classification and recognition accuracy rate in each contrasting situation of the three different classification algorithm models. The left side is the feature classification and recognition results based on the data of landing from 0.8 to 1.0 m, and the right side is the feature classification and recognition results based on the data of landing from 1.0 to 1.2 m. From top to bottom are the results based on the stress value data corresponding to all nodes, the data of the first 2,000 nodes with the highest stress values, the data of the first 1,000 nodes with the highest stress values, the data of the first 500 nodes with the highest stress values, and the data of the first 200 nodes with the highest stress values, respectively. In the red box are the features with higher classification and recognition accuracy than other features, corresponding to the claw bones marked in red. **(B)** Total classification and recognition accuracy data distribution of all features in each node control case. **(C)** Total classification and recognition accuracy of all features under two contrasting situations. **(D)** The final classification recognition accuracy trend of all features in each node control case.

change do indeed cover up the true nature of the data change law, so that the inherent law of stress distribution characteristics cannot be truly excavated. Therefore, considering only the maximum stress distribution does not effectively identify the features that contribute most to pattern recognition under different constraints, which is often not conducive to the grasp of the optimal feature that can reveal intrinsic properties in the field of biomechanics.

Another interesting result of the current work is that the stress distribution characteristics of the DP show low identifiability under almost all node selection conditions (Figure 6; Supplementary Table S7). At the same time, among the features selected based on the feature selection model, there are few cases in which the stress distribution feature of the DP is selected as the optimal feature to identify different landing patterns (Figure 5). This is also consistent with the results of the detailed stress distribution trend (Figure 4), that is, the stress distribution of the DP is much smaller than that of the MP and PP. This suggests that the DP may have played little role in cushioning the impact load when the cat landed. This may be due to the special physiological anatomical structure of the cat's paw pads fitting closely to the DP (36), which results in the cat's paw pads bearing most of the impact during the landing process, thereby reducing the force on the DP to avoid musculoskeletal injury. The recognition and classification accuracy of stress distribution features based on the input data of landing from 0.8 m and landing from 1.0 m is significantly higher than the results based on the input data of landing from 1.0 m and landing from 1.2 m (Figure 6; Supplementary Table S7). The results indicate that the difference in landing characteristics between cats landing from 1.0 to 0.8 m is higher than that between cats landing from 1.0 to 1.2 m. Previous studies have shown that landing height can alter the contribution ratio of skeletal energy dissipation in the forelimbs and hindlimbs, thereby reducing the risk of injury in cats landing from greater heights (9, 47). From the point of view of muscle activation, limb muscles become tense before initial ground contact, and the amount and timing of muscle activity are adjusted to avoid landing injuries (48–50). Therefore, when the landing height is increased from 0.8 to 1.0 m, the variations in landing pattern differences may be a response of the cat's forelimb by adjusting the musculoskeletal structure to reduce the risk of injury with a more optimal landing strategy.

There are some limitations inherent in the present study that need to be considered. The results of the current work are constrained by the breed, weight, sex, and age of the cats tested. Based on this, in our follow-up study, we intend to expand the diversity of the test sample to verify the reliability and applicability of the current findings. Another factor to consider is that the current study takes into account the economics and operability of modeling and simulation in the FEA, so it does not take into account the change of the specific position of the ligament during the landing. While this may have some minor impact on the results, it is acceptable when combined with the performability of the entire simulation.

Conclusion

The current work investigated the cat forelimb paw biomechanical characteristics when landing from different heights by using the FEA, as well as first proposed to combine the feature engineering techniques for post-processing of FEA. The stress distribution feature of the MP2, MP4, PP2, and PP3 are the features that contribute most to landing pattern recognition when a cat landed under different constraints. The DP may have played little role in cushioning the impact load when the cat landed. With the landing altitude increases, the variations in landing pattern differences may be a response of the cat's forelimb by adjusting the musculoskeletal structure to reduce the risk of injury with a more optimal landing strategy. The combination of feature engineering techniques can effectively identify the features that contribute most to pattern recognition under different constraints, which is conducive to the grasp of the optimal feature that can reveal intrinsic properties in the field of biomechanics.

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 animal study was reviewed and approved by the Animal Care and Use Ethics Committee of Ningbo University. Written informed consent was obtained from the owners for the participation of their animals in this study.

Author contributions

DX, HZ, and YG conceived the idea of the study. DX, HZ, QZ, JB, UU, and ZR collected the data. DX, HZ, QZ, XM, FG, and MW performed the analyses. DX, HZ, QZ, and YG drafted the manuscript. JB, UU, ZR, XM, FG, and YG provided major comments and revisions. All authors contributed critically to the drafts and gave final approval for publication.

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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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Supplementary material

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Outdoor domestic cats and wildlife: How to overrate and misinterpret field data

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1. Introduction

Lynn et al. (1) have questioned the moral panic over outdoor domestic cats destroying wildlife and reducing biodiversity. Although some early studies in Australia drew attention to the problem of free-ranging outdoor cats, two other recent studies about cat predation have attracted broader international media attention (2, 3) and have become the focus of considerable controversy. The current author attempts a fair appraisal of such studies and their conclusions, or rather of the interpretation and conclusions drawn by others at the expense of outdoor cats. In this review, I explain why the results of published studies purporting to show that cats are a main culprit for the disappearance of endemic wildlife on the species level, on the continents as opposed to small oceanic islands, should be questioned. This will indicate the information we still need, and need to integrate, before drawing any conclusions that condemn or exonerate free- roaming cats, in order to examine correctly the role that outdoor cats actually play in relation to wildlife.

Quite often domestic cats are considered by conservationists to be an invasive species. The cat itself is mostly responsible for its domestication ("self- domestication," albeit with some help from ancient peoples) and the expansion of its geographic range from the Fertile Crescent area to the East, North and South. The domestic cat is an extremely flexible, adaptable species and a successful predator, in most cases capable of surviving without human support (4, 5). But as Ottoni et al. (6) have shown the domestic cat's dispersal gained momentum during the Classical period, when the Egyptian cat successfully spread throughout the Old World.

Further, people arguing against cats usually assume one of two vantage points: either that of (prey) animal protection and welfare ("the poor prey animals"), or that of prey species/biodiversity conservation. This essay critically addresses only the second vantage point.

2. What is known about domestic cat predatory behavior and predation?

Various facts are available from field studies throughout the world and need to be considered in any study examining the effect of cats on wildlife. A review of all published studies (over 60) on various aspects of cat predatory behavior in 1986 by Fitzgerald (7) brought many facts to light which should be considered in any estimate of the impact of cats on their prey populations.

Many of those studies were based on *prey carried home by the cats* and collected by the owners for the researchers. However, it has been shown that there are differences both in the numbers and species between prey carried home and prey consumed in the field (8, 9), also implying that any estimates of the numbers of prey killed by cats may be higher. Further, it is known that there are differences between the species of prey killed and consumed and those abandoned [e.g., (8, 10, 11)].

Gut analyses of road killed cats and cats shot in different habitats also yield information that needs to be considered. These have indicated that most mammalian prey are from those species living on fields/meadows or (at most) forest edges; male cats examined from forest areas rarely have prey species in their digestive tracts that live in the forest, but rather field prey species or "human prepared foods" (12, 13). Further, some studies report on prey consumed based on percent volume in the gut, while others use estimated percent occurrence of the different prey types (7). These differences should be taken into account when combining the data from different studies to assess impact on prey types, but that is rarely done.

Both the habitat type (fields/meadows or forest) and general housing density (rural, suburban, urban) where a study was/is conducted should also be considered. What one sees in urban or suburban areas is not necessarily representative or problematic. Some potential prey species (e.g., house sparrows, house mice or rats, so-called "culture followers") have been inadvertently favored in the past by human settlements and have unnaturally high populations. These of course attract predation by local cats and is what people see in their own back yards and gardens. This is not necessarily representative, however, of cat predation impacts elsewhere (see Section 5 on biodiversity, below). Unfortunately for the cats, analysts tend to forget other anthropogenic factors influencing prey populations, e.g., habitat loss due to expansion of housing areas, elimination of rodent prey by various means, and replacement of endemic plant species with exotics, among other things (14); factors that are more difficult to account for than is the singling out of a "scapegoat" such as the local predatory activities of cats.

3. Studies purporting to show the massive effect of cats on wildlife

Coming back to the two studies receiving the most international media attention mentioned at the outset of this review, both implied or were interpreted by others to indicate alarming predation of house cats on prey populations.

Churcher and Lawton (2) investigated predation by ca. 70 cats in one *English village* over a 1-year period, based on *prey brought home* (535 mammals, 297 birds, 258 remains unidentifiable). Of the identified prey, 17% were wood mice, 16% house sparrows and 14% bank voles. They calculated an average of 14 prey items were brought home per cat per year but presumably many more prey were consumed in the field. *Prey types varied with position within the village*: Core cats brought in more birds than did cats on the edge of the village. The authors estimated that *30% of the sparrow deaths in the village were due to cats*, but stated that the village sparrow population was much higher than the average in other British villages. Although the authors were cautious in their interpretation, the media took off with alarming extrapolations of these very limited data across all of the UK.

Loss et al. (3), in a study of importance to the Lynn et al. (1) *Conservation Biology* article inspiring this essay, conducted a thorough literature review of free-ranging domestic cat predation on birds and mammals in the U.S.A. They acknowledged that cats have contributed to multiple wildlife extinctions on islands [as Fitzgerald (7) previously concluded] but stated that the magnitude of mortality in mainland areas was largely speculative. Their systematic literature review to quantitatively estimate mortality caused by cats concluded that they kill 1.4 to 3.7 billion birds and 6.9 to 20.7 billion mammals in the U.S.A annually. They also stated that un-owned cats (as opposed to owned pets) cause the majority of this mortality and concluded that free-ranging cats are likely to be the single greatest source of anthropogenic mortality for U.S. birds and mammals. However, most of the field studies in their literature review and in their data extrapolation have not taken the above-mentioned known *facts* about cat predatory behavior into account, although their own calculations based just on prey carried home are correct. Among the various studies they considered many lacked a correction for prey eaten or left when away from home, different methods of gut analysis, no control for habitat where the data were collected (suburban, city, farmland), or other causes of prey decimation (e.g., habitat destruction). The media had a field day nonetheless and was quite biased against cats with reports e.g., in *USA Today* [(15), CBS News (16), or BBC World Service (17)].

But the most serious criticism of all such studies is that none of them even mentions a rough estimate of the total population size of a prey species (supposedly being threatened by cat predation) or of the yearly reproduction and replacement of lost individuals. What good does it do to headline that "Cats kill up to 3.7 billion birds annually" if the estimated total population of birds in the USA is *at a minimum* 10 billion *pairs* breeding every year and that as many as *20 billion* are in the country during the fall migratory season [US Fish and Wildlife Service (18), cited January 19, 2011]? Free-ranging cats might be taking about 10–15% of the population of birds annually, but that is not exceptional for a normal predator-prey relationship and is insufficient to eliminate a prey species. Further, estimates of the owned and non-owned free-ranging cat populations are just that–rough estimates.

To date there has been only one "long-term" (3-year) field study by ornithologists to determine the effect of cat predation on a songbird species: Black redstarts (*Phoenicurus ochruros*) which were thought to be particularly vulnerable to nest predators (cats) in a high cat-density area (19). The authors measured yearly production and mortality attributable to cats. Predation by cats caused 33% of egg fatalities, 20% of nestling deaths, ca. 10% of fledgling fatalities and ca. 3% of adult losses. Their conclusion: Predation by cats indeed reduced the productivity of this population by 12% (from 1.20 to 1.06) but did not convert it into a "sink" population. The rate of population increase was sufficient to retain "source" population status. The current author suggests that this might be an exception and highly recommends more such studies before "judgment" is passed on the local cat population.

4. Methods to reduce predation by cats

While one can agree or disagree with the necessity to find ways to reduce predation by house cats allowed outdoors, it should be mentioned that a number of studies have considered the effectiveness of methods to do this. Quite often wearing collars with small bells is recommended as a deterrent to successful cat predation, especially on birds. But the results of studies are mixed: Both Barratt (20) and Morgan et al. (21) found that rates of predation by belled cats were not significantly reduced. However, Gordon et al. (22) found reductions of 50% for bird and 61% for rodent predation for belled cats in a 6 weeks on/6 weeks off trial.

Calver et al. (23) showed that wearing a bib to interfere with the cat's ability to pounce greatly reduced predation on birds and was somewhat less successful in reducing predation on reptiles, amphibians and mammals.

However, there was no control to assess how the bib affected the cat's welfare, e.g., to climb a tree when chased by a dog. Such a bib probably reduced the cat's welfare in such cases. More recently Willson et al. (24) reported results of field tests with a two-inch wide brightly colored band mounted over a quick release-collar: Cats wearing this colorful band killed 19 times fewer birds than un-collared cats in the spring trial and 3.3 times fewer birds in the Fall. Small mammal predation was decreased by one half in the Fall.

Finally, the most recent study on methods to reduce cat predation was non-invasive: Cecchetti et al. (25) found that households feeding a high meat protein, grain-free food to their cats, and households where 5–10 min of daily object play with the cats was introduced, recorded decreases of 36 and 25% respectively, in numbers of animals captured and brought home by cats, relative to controls and the pre-treatment period. But again, we have the problem of prey carried home, as mentioned above.

5. Effects on biodiversity

There is widespread agreement that biodiversity is important (to our survival) and on the decline (26, 27). Lay conservationists have time and again argued that free-ranging cat predation is reducing biodiversity by eliminating prey species. While this is certainly true for small oceanic islands, Fitzgerald (7) and with the addition of even more field studies (28) have countered that there is simply no evidence that free-ranging cats on the continents are the main cause of species disappearance (and biodiversity reduction) since there is usually a suite of predators utilizing the same prey species and other causes can be cited. Further, the "biodiversity" that most lay conservationists refer to (and see disappearing locally, also with cat predation) is not the only or most important meaning of the word. There are three levels of biodiversity: alpha-, beta-, and gamma biodiversity. *Alpha* diversity is measured very locally in individual habitats; *beta* diversity is a measure of the heterogeneity between habitats while *gamma* diversity (or biodiversity) is the overall species diversity of a range of habitats or communities within a larger region [Oxford Reference for "gamma diversity in ecology," accessed June 7, (29)]. What we see locally (e.g., in suburbs or villages) is not necessarily representative of what is happening in a wider geographic area. A particular (prey) species may be eliminated locally but thriving in another area or habitat. Beta and gamma diversity are what count (30, 31).

6. Free-ranging cats as hosts of zoonotic disease

Lynn et al. (1) also criticize the overgeneralizations and misinterpretation by Loss and Marra (32) and Marra and Santella (33) about the dangers of free-ranging domestic cats transferring zoonotic diseases, and for painting cats as a "looming public health crisis." This is precisely the type of fear-generating generalization that members of the EU's CALLISTO project on companion animals and zoonoses have cautioned against and have said is unfounded (34).

7. Concluding remark

The author does not deny that free-ranging cats affect wildlife populations and it is important that field researchers continue to monitor their effect. But future studies need to take into account what is known about cat predatory behavior, estimates of total prey population size, and interpret the data without prejudice. It remains to be seen whether the media consider and publish reports of less dramatic findings.

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Author contributions

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

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Why can't we be friends? Exploring factors associated with cat owners' perceptions of the cat-cat relationship in two-cat households

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Most research examining cat behavior in multi-cat households lacks focus on one group size. This gap in knowledge reduces generalizability of research findings to specific compositions of cats in multi-cat households. Given that many cat-owning households in Canada and the US are comprised of two cats, the following study used a cross-sectional survey to explore cat owners' perceptions of the cat-cat relationship in two-cat households in Canada and the US. A total of 6,529 owners of two cats completed the online questionnaire. Descriptive statistics were used to summarize the data and a logistic regression model used to assess various explanatory variables (i.e., household, management, and cat-specific factors) associated with participants perceiving their cats' relationship as negative. The logistic regression model showed that owners of two-cat households are more likely to perceive their cats' relationship as negative if both cats are spayed females, adult or mature, have a large gap in age, not related, one or both have access to the outdoors, or show aggression toward people or other animals in the home. Having multiple litterbox and feeding areas were also associated with a more negative cat-cat relationship. Overall, the complex interplay, directionality, and temporality of these factors requires further investigation for a full understanding of how to improve the cat-cat relationship in two-cat households. More research is needed to provide evidence-based recommendations for managing and supporting a positive cat-cat relationship in the home.

KEYWORDS
multi-cat household, inter-cat conflict, cat behavior, cat welfare, social structure

1. Introduction

In Canada and the US there are an estimated 70 million pet cats (1, 2), with many cat-owning households consisting of two cats [average of 1.6 cats/ Canadian household, average of 1.8 cats/ US household; (1, 2)]. Although current house cats descend from a wildcat thought to be largely solitary (*Felis silvestris lybica*), partial domestication has adapted cats to group living associated with food availability near human settlements (3). As cats made their way into our homes, owners often choose to house cats with conspecifics, without understanding the impact on the cats themselves. Thus, multi-cat households vary in composition, with cats housed together that are unrelated, related, acquired together, and/or acquired separately. The welfare of pet cats in multi-cat households is dependent on many factors including their relationship with conspecifics (4, 5), the physical home environment (6–8), and caretaker interactions (4, 9). Cat-cat interactions include positively valenced interactions such as affiliative behaviors (example: allo-grooming, playing), as well as negatively valenced interactions such as agonism (example: staring, resource guarding), with negative interactions garnering more research and attention.

Inter-cat conflict is one of the most frequent owner-reported problems in multi-cat households (4, 10–12) and one of the main reasons cats are presented to behavior clinics (13–16). A UK-based survey suggests 62% ($N = 616$ cats) of multi-cat owners see signs of inter-cat conflict (hissing, spitting, or blocking) in their household (17). Similarly, 50% of cat-owner participants from a Canadian survey assessing ($N = 1{,}146$) fostered kittens adopted into multi-cat households, reported seeing behavioral signs of aggression between cats in their home (18). When inter-cat conflict is not mitigated, the welfare of both cats may be compromised due to prolonged stress (5, 19) leading to health and behavioral problems such as house soiling (20–22), as well as increased risk of owner-directed bites and scratches (23). In addition, behavior problems can diminish the human-animal bond (9, 24) and may lead to relinquishment (25–27).

Many factors impact the cat-cat relationship, including resource provision, outdoor access, and cat characteristics (28–30). Research shows that inadequate resource availability and distribution may increase inter-cat conflict in the home (30). Thus, it is recommended to provide multiple, well-distributed resources (example: food bowls, litter boxes, and environmental enrichment items) throughout the home to reduce individuals from monopolizing resources (30). To further support this recommendation, observational studies of group-housed indoor cats have found that cats time-share resources, meaning they choose to access valuable resources at different times (29, 31). A large survey of US and Canadian cat owners by Tan and colleagues shows that owners providing cats with uncontrolled outdoor access are less likely to provide important in-home resources such as those necessary for cats to perform naturally motivated behaviors such as perching and playing (32). In addition, allowing cats outdoors has been associated with continued fighting (12) and an increased likelihood of aggression between household cats (18). However, in contrast, other research has not found associations between outdoor access and agonistic interactions in multi-cat households (33, 34). Although no consensus exists, the study by Tan and colleagues suggests that uncontrolled outdoor access is more likely to be provided by owners of cats showing aggression toward other cats or people in the home (32). Thus, there is some evidence to support a relationship exists, however the temporal directionality of this relationship is unknown.

Cat characteristics such as sex, age, weaning age, neuter status, as well as familiarity and relatedness have been suggested to impact the cat relationship in multi-cat households. Neuter status is known to reduce conflict behavior in both neutered male and female cats compared to intact cats of the same sex (35). Barry and Crowell-Davis (36) found that indoor, neutered males choose to spend more time in close proximity than other sex combinations. As well, age may impact cat-cat behavior; for example, Ramos and colleagues (37) found adult cats have significantly higher fecal glucocorticoid levels than young cats in multi-cat households (3-4 cats). As well, a UK-based survey of cat owners ($N = 833$) suggests cats 11 years and older tend to be less sociable toward other animals (including dogs, cats, etc.) in the home as they get older (38). In contrast, one survey ($N = 2492$) reports that young and adult cats display more active conflict-related behaviors (such as chasing and stalking) than households with mature or senior cats (34). However, chasing and stalking are also indicative of play behavior in cats, and thus may not be negative for all cats involved. As cats age, they are at an increased risk of developing diseases which may cause pain or discomfort (39), and thus their tolerance of interactions with other cats may change. The age at which cats are weaned from their mother also impacts the inter-cat relationship, with early weaned cats (<8 weeks of age) more likely to show aggression toward other cats (40). Furthermore, kittens that are reared without their littermates during the early socialization period (approximately between 2 and 7 weeks old) display more agonistic interactions with conspecifics (41). Generally, social deprivation from the mother and littermates during the socialization period may negatively influence cats' subsequent social interactions with conspecifics (4). In addition, related and unrelated but familiar kittens and cats show more affiliative interactions compared to unfamiliar and unrelated cats (42–44).

Although there is an increasing body of research examining factors impacting the inter-cat relationship in multi-cat households, one large problem is the lack of research focusing on one group size. This gap in knowledge reduces generalizability of the research findings to specific compositions of cats in multi-cat households (10). This is important, given that it is generally recognized that varying the number of animals in a group impacts social structure and social complexity (45). Studies assessing multi-cat households often include large cohorts of cats (17, 29, 34, 46) which may have an increased risk of conflict compared to smaller cohorts of cats (34). To the authors' knowledge, one study has examined indoor-only cat dyads in the home, with results suggesting that neutered male dyads spend more time in close proximity than female dyads or male-female dyads (36). However, more research is needed to assess these findings in a larger population and achieve a better understanding of the factors impacting cat dyad behavior in the home. Overall, research focused on improved understanding of the social relationship between cats of a defined number in a household is needed. Since many households in Canada and the US contain two cats (1, 2), research focused on two-cat households may be more impactful. Given the limited research focusing on two-cat households, we aimed to explore and describe associations between cat owners' perceptions of their cats' relationship, management factors, and cat-specific characteristics. A cross-sectional questionnaire was used to survey US and Canadian owners of two adult cats (≥1 year old) and included questions on owner demographics, owner's self-perceived knowledge of cat behavior, owner's subjective perception of their cats overall relationship, household and management factors, and cat dyad characteristics. We predicted that cat owners rating their cats as having a negative relationship would be associated with provision of a single resource area (example: one litter box, one feeding area) compared to households with multiple resource areas (example: two or more litter boxes and feeding areas), and reduced odds of a negative relationship in households with related cats compared to unrelated cats.

2. Materials and methods

This study was approved by the University of California Davis Institutional Review Board (IRB #1786341-1) to recruit human participants for research. Participation was anonymous and respondents provided consent before being able to participate in the questionnaire.

2.1. Data collection

An online cross-sectional questionnaire was developed using an online survey software program (Qualtrics Software Company, Provo, Utah, USA). Participation required respondents to be at least 18 years old, currently living in Canada or the USA, and identify as the current primary owner of two companion cats that spend at least fifty percent of their time indoors. The survey was in English and required internet access to participate. Recruitment involved advertising on social media sites such as Facebook and Twitter using snowball sampling (47). Data collection occurred during September 13th–17th, 2021.

2.2. Questionnaire

The questionnaire consisted of five sections and 77 questions total: (1) inclusion criteria (4 questions), (2) participant demographics (nine questions), (3) resource provision and distribution (four questions), (4) cat characteristics, health and behavior information, and cat-cat interactions (20 questions), and (5) 10 videos depicting various two-cat interactions asking participants to rate each video's cat-cat interaction, and rate how often they see their own cats display similar behaviors (40 questions). The research reported here includes questionnaire sections 1–4; section 5 is not reported here.

Participant demographic questions included age (18–29, 30–39, 40–49, 50–59, 60–69, 70+, prefer not to say but over 18), gender (male, female, non-binary, other, prefer not to say), US state or Canadian province currently residing, self-perceived knowledge level of cat behavior (extremely, very, moderately, somewhat, not at all), previous experience working with companion cats (yes, no) and if yes, number of years of combined experience (1 year, 1–5 years, 6–10 years, 11–15 years, 16+ years). We also asked questions designed to understand the cats' household including the area of the household (< 500 square feet (sq ft), 500–1,000 sq ft, 1,000–1,500 sq ft, >1,500 sq ft, prefer not to answer), the total number of adults (18 years of age or older; numeric entry), children (<18 years of age; numeric entry), and dogs in the household (0, 1, 2, 3, 4+). Cat specific information asked about each cat including their names, declaw status (no, yes all 4 paws, yes front paws only, yes back paws only, not sure), where each were obtained (breeder, pet store, shelter or rescue, family friend relative or neighbor, found as stray or feral cat, previous cat's litter), breed (domestic, purebred, purebred mix, not sure), coat pattern (select all that apply: solid, tabby, bi-color, tortoiseshell, calico, other), coat color (select all that apply: beige, black, brown, gray, lavender, orange, red, white), sex (female spayed, male neutered, female intact, male intact, not sure), current age in years (numeric entry), age introduced into the home (<1 year, 1–3 years old, 4–6 years old, 7–10 years old, >10 years old), outdoor access (strictly indoor, indoor with supervised outdoor access, indoor with unsupervised outdoor access), and current/previous health and behavioral problems (see Supplementary material for full questionnaire).

Questions about the owner's perspective of the cats' relationship asked participants to rate the valence of their cats' first encounter, as well as their current overall relationship using a 5-point Likert scale (extremely negative, somewhat negative, neutral, somewhat positive, extremely positive, not sure or previously introduced). Other cat-cat relationship questions included relatedness (not related, siblings, mother and offspring, father and offspring, other) and time spent living together (<1 year, 1–3 years, 4–6 years, 7–9 years, 10+ years).

Resource questions were designed to understand the number and distribution of resources in two-cat households. To reduce competition in multi-cat households, behaviorists and veterinarians recommend placing multiple resources (i.e., litter boxes, food, and water stations) in different locations, and suggest that two of the same resources in close proximity may be viewed as a single resource by cats (48). Based on this reasoning, if two litter boxes are side by side this should count as one litter box. It is also suggested that multi-cat households follow the *n + 1 rule* for determining the number of litter boxes to provide, with "n" being the number of cats in the household (49). Thus, in a two-cat household, the gold standard would be to provide 3 litter boxes dispersed around the home. It should be noted there is no scientific evidence to corroborate these recommendations. Nonetheless, based on these recommendations, we asked participants how many scratching posts (0–10+), litter boxes, food bowls, and sleeping areas (in the same room side by side, in the same room not side by side, in different rooms, one resource is provided, no resource is provided) they provide in their household. Since cats may sleep on various surfaces and areas throughout the home, the following examples were provided: cat beds, owners' bed, furniture, and cat trees or hammocks. Perching and hiding areas were not included in the questionnaire, despite their importance for cat welfare (5, 7, 50). Since different areas in the home may be used for perching (example: cat tree or shelves) and hiding (ex. behind furniture, under bed) owners may have difficulty identifying and quantifying these areas which may reduce accuracy of the data.

2.3. Statistical analysis

Only complete responses were included in analyses, and thus incomplete and duplicate responses from the same IP address were excluded. Data from 6,529 owners of two cats ($N = 13{,}058$ cats) were included for analysis. To reduce misclassification bias during data cleaning, questions with the option 'other' and participant typed responses were evaluated to ensure accurate response allocation. Descriptive statistics (percentages, frequencies) were generated using RStudio (Auckland, New Zealand), and all other analyses were conducted using SAS Studio v3.7 (SAS Institute, Cary, North Carolina, USA). Descriptive statistics were generated for each survey question, initially by country (US and Canada) and later combined due to their similarity.

A logistic regression model was used to evaluate explanatory variables associated with participants rating their cats' relationship as negative. The Likert-scale variable "overall relationship" was consolidated to create a binary outcome variable: extremely positive and somewhat positive were combined into a "positive" category, while somewhat negative and extremely negative were combined into a "negative" category; neutral ($n = 895$) was not included as it did not fit into a binary positive/negative variable). Potential explanatory variables included a total of 48 variables (cat owner demographics, cat characteristics and relationship information, resource variables, and health and behavior variables), and thus many were collapsed to simplify the variables for analyses. For example, the 16 health variables (i.e., diabetes, osteoarthritis, heart disease) were combined to create 'at least one cat in household with a health condition (yes/no)' variable to assess the overall impact of health conditions on the cat-cat relationship. Similarly, an overall "at least one cat in household with a behavior problem (yes/no)" variable was created by collapsing the 10 behavior problem variables (i.e., animal-directed aggression, human-directed aggression, excessive night time activity). However, individual behavior problem and health condition variables were also tested for inclusion in the model. Other explanatory variables tested for inclusion in the model were: owner and household variables (household size, number of adults in the house, dogs in the house, children in the house, owner's knowledge of cat behavior, owner's experience working with cats), cat demographics (both cats' sex, breed combinations, cats' age combinations, ages of cats when obtained, where cats were obtained, cats' relatedness, time living together, declaw status combinations, and outdoor access), and resource-related information (feeding areas, litter box areas, sleeping areas, and number of scratching posts). First encounter data were not included in the model as we found misclassification bias present in this variable. Of the respondents, 25.6% reported their cats to be related or previously introduced, answered the first encounter question, even though their cats' would not require an introduction. Given this, we did not analyze this variable any further.

To evaluate which of the variables should be included in the model, two-way analyses were run with each potential explanatory variable and the outcome (overall cat-cat relationship). A liberal p-value ($p < 0.2$) was used to guide which variables to include in the model. The final logistic regression model was built using a stepwise model building strategy where variables with a $p < 0.05$ were retained. All plausible two-way interactions were testing during model building, and due to all explanatory variables being categorical, model fit was based on evaluation of the 2-way interaction terms. *Post-hoc* pairwise comparisons with 4 or more pairs used a Tukey's adjustment for multiple comparisons to reduce the potential for type I errors. Results are reported using odds ratios (OR), 95% CI's and p-values.

3. Results

3.1. Descriptive results

The majority of survey participants ($N = 6{,}529$) resided in the US (6,118/6,529, 93.7%; Table 1), with the most frequently reported states being California (15.5%), New York (6.3%), Texas (5.5%), and Washington (5%). Of Canadian respondents (411/6,529, 6.3%), the provinces most frequently reported was Ontario (45.5%), British Columbia (22.9%), Alberta (10.9%), Quebec (7.3%), and Nova Scotia (5.1%). In total, the majority of respondents were female (71.5%) and living in a household with two adults including the participant (63.1%; Table 2), live with no dogs (76.4%) and no children (77.8%). The most frequently selected household area was more than 1,500 square feet (41.1%) and most frequently selected age ranges were 30–39 (31.4%) and 40–49 (24.4%) years old. Most participants indicated they did not have work experience with cats (72.4%) and most frequently rated themselves on a Likert scale as "very knowledgeable" about cat behavior (44.5%). Of the participants with cat-related work experience (27.6%, 1,802/6,529), 40.7% had more than 16 years of experience.

TABLE 1 Demographic descriptive information for 6,529 owners of two adult cats residing in US or Canada that completed the online questionnaire regarding resource provision and perception of their cats' overall relationship.

Variable	Category	No. (%) of respondents
Country	USA	6,118 (93.7)
	Canada	411 (6.3)
Age	30–39	2,053 (31.4)
	40–49	1,590 (24.4)
	50–59	1,108 (17.0)
	18–29	758 (11.6)
	60–69	739 (11.3)
	70+	229 (3.5)
	Prefer not to say	52 (0.8)
Gender	Female	4,669 (71.5)
	Male	1,635 (25.0)
	Non-binary	151 (2.3)
	Prefer not to say	61 (0.9)
	Other	13 (0.2)
Previous cat experience	No	4,725 (72.4)
	Yes	1,804 (27.6)
Years of experience (if "Yes" to above)	16+	734 (40.7)
	1–5	444 (24.6)
	6–10	283 (15.7)
	11–15	184 (10.2)
	<1	159 (8.8)
Self-reported knowledge of cat behavior	Very knowledgeable	2,908 (44.5)
	Moderately knowledgeable	2,211 (33.9)
	Extremely knowledgeable	1,036 (15.9)
	Somewhat knowledgeable	364 (5.6)
	Not at all knowledgeable	10 (0.2)

TABLE 2 Household descriptive information for 6,529 owners of two adult cats residing in US or Canada that completed the online questionnaire regarding resource provision and perception of their cats' overall relationship.

Variable	Category	No. (%) of respondents
Household area	More than 1,500 sq ft	2,683 (41.1)
	1,000–1,500 sq ft	2,108 (32.2)
	500–1,000 sq ft	1,544 (23.6)
	<500 sq ft	1,33 (2.0)
	Prefer not to say	61 (0.9)
Dogs	0	4,988 (76.4)
	1	948 (14.5)
	2	440 (6.7)
	3+	153 (2.4)
Adults	2	4,116 (63.1)
	1	1,612 (24.7)
	3	557 (8.5)
	4+	178 (2.7)
	0	64 (1.0)
Children	0	5,076 (77.8)
	1	749 (11.5)
	2	540 (8.3)
	3+	163 (2.5)

A few participants did not answer all questions, therefore the number of responses varies among variables.

TABLE 3 Cat descriptive information collected from 6,529 US and Canadian owners of 2 cats (total of 13,058 cats) who completed an online questionnaire.

Variable	Category	No. (%) of respondents
Sex	Male neutered	6,508 (49.8)
	Female spayed	6,439 (49.3)
	Female intact	77 (0.6)
	Male intact	30 (0.2)
	Not sure	4 (0)
Declaw status	No	12,020 (92.1)
	Yes, all four paws	120 (0.9)
	Yes, only front paws	915 (7.0)
	Yes, only back paws	3 (0.0)
Origin	Shelter	7,794 (59.7)
	Family or friends	2,165 (16.6)
	Found	2,148 (16.4)
	Other	951 (7.3)
Age adopted	Kitten (0–1 year)	9,641 (73.8)
	Young adult (1–3 years)	2,382 (18.2)
	Adult (4–6 years)	662 (5.1)
	Mature/senior (7+ years)	373 (2.9)
Age (in years)	1–3	3,971 (30.6)
	4–6	3,124 (24.1)
	7–10	3,122 (24)
	10+	2,768 (21.3)
Breed	Domestic	9,977 (76.4)
	Not sure	1,828 (14.0)
	Purebred	832 (6.4)
	Purebred mix	421 (3.2)
Outdoor access	Indoor only	8,758 (67.1)
	Indoor + supervised outdoor	3,073 (23.5)
	Indoor + unsupervised outdoor	1,227 (9.4)
Coat pattern	Tabby	4,630 (35.5)
	Bicolor	2,948 (22.6)
	Solid	2,541 (19.5)
	Other	880 (6.7)
	Tortoiseshell	755 (5.8)
	Calico	713 (5.5)
	Mixed patterns	591 (4.5)

Some participants did not answer all questions, therefore the number of responses varies among variables.

Response data from 13,058 cats were analyzed (two cats per respondent). Respondents' cats were 49.8% neutered males and 49.3% spayed females (Table 3). Most were not declawed (92.1%) and were acquired from a shelter (59.7%). Cats were most frequently acquired at kitten age (73.8%), 1—3 years old (30.6%), domestic breed (76.4%), and had a tabby coat pattern (35.5%). Most participants indicated that their cats are strictly indoors-only (67.1%) and some reported providing supervised outdoor access (23.5%).

Participants most frequently rated (Likert scale: extremely positive, somewhat positive, neutral, somewhat negative, extremely negative) their cats' first encounter as "somewhat negative" (26.2%) or "extremely positive" (24.1%), and their cats' overall relationship as "extremely positive" (39.8%) or "somewhat positive" (33.7%; Table 4).

When asked about resource distribution in the home, most respondents indicated they provide their cats with a single feeding area (59.1%; multiple areas: 40.9%), single litter box area (57.1%; multiple litter box areas: 42.1%; no litterbox: 0.8%), and multiple sleeping areas (83.4%; single sleeping area: 10.0%). When asked about the quantity of scratching posts, respondents provided 4 or more posts (30.7%), 2 posts (26.1%), 3 posts (22.1%), 1 post (15.5%), or none (5.6%).

The majority of cat owners reported at least one cat (3,911/6,529, 59.9%) in their household has $\geq$ 1 current or previous diagnosed health issue (Table 5). Of cats with at least one current or previous health issue, the most frequently reported health issues were obesity (25.2%) and dental disease (23.4%). The majority of cat owners also reported that at least one cat (78.5%) in their household has $\geq$1 current or previous behavioral issue (Table 6). The most frequently reported behavioral issues were fears/phobias (45.7%), unwanted behaviors (45.2%) and destructive behaviors

TABLE 4 Owner's perception of their cats' relationship collected from 6,529 owners of two cats in US and Canada.

Variable	Category	No. (%) of respondents
First encounter	Somewhat negative	1,713 (26.2)
	Extremely positive	1,575 (24.1)
	Neutral	1,145 (17.5)
	Somewhat positive	858 (13.1)
	Previously introduced	545 (8.3)
	Extremely negative	470 (7.2)
	Not sure	223 (3.4)
Overall relationship	Extremely positive	2,598 (39.8)
	Somewhat positive	2,199 (33.7)
	Neither positive nor negative	895 (13.7)
	Somewhat negative	747 (11.4)
	Extremely negative	90 (1.4)
Time together (years)	1–3	2,640 (40.4)
	4–6	1,582 (24.2)
	7–9	935 (14.3)
	10+	904 (13.8)
	<1	468 (7.2)
Cats' relation	Not related	4,620 (70.8)
	Siblings	1,673 (25.6)
	Other	236 (3.6)

TABLE 5 Current and/or previously diagnosed health issues reported for at least one cat by 6,529 US and Canadian owners of two cats ($N = 13,058$ cats).

Health issues	*N*	%
Obesity	984	25.2
Dental disease	915	23.4
Other	763	19.5
Gastrointestinal disorders	685	17.5
Dermatological disorders	659	16.9
Eye disorders	622	15.9
External parasites	611	15.6
Non-obstructive urinary diseases	388	9.9
Obstructive urinary diseases	364	9.3
Respiratory diseases	342	8.8
Internal parasites	318	8.1
Hypothyroidism	217	5.6
Renal disease	197	5
Osteoarthritis	153	3.9
Diabetes	140	3.6
Heart disease	136	3.5

TABLE 6 Current and/or previous behavioral issues reported for at least 1 cat by 6,529 US and Canadian owners of 2 cats ($N = 13,058$ cats).

Behavioral issues	*N*	%
Fear/phobias	2,346	45.7
Unwanted behaviors	2,317	45.2
Destructive behaviors	2,080	40.6
Separation anxiety	1,355	26.4
Animal aggression	1,179	23
Stereotypic and compulsive disorders	1,052	20.5
Excessive night time activity	789	15.4
People aggression	615	12
Gastrointestinal and ingestive disorders	575	11.2
Other	537	10.5

(40.6%). Almost half of participants reported at least one cat (49.7%) in their household has ≥1 current or previous health and behavioral issue.

3.2. Logistic regression model results

Factors that influenced cat dyads having a negative relationship are presented in Table 7 with associated ORs, 95% CIs, and *p*-values. The final model included explanatory variables: outdoor access, sex, age, litter box areas, feeding areas, cat aggression shown toward people, cat aggression shown toward other animals, and relatedness. No other significant effects were detected.

4. Discussion

Our survey results suggest many factors impact cat owner ratings of their cats' relationship. Interestingly, spayed female dyads were more likely to have an owner perceived negative relationship compared to neutered male dyads, or mixed sex dyads. This is in line with other literature on the influence of sex on the cat-cat relationship in the home. One study by Barry and Crowell-Davis (36) shows that indoor neutered male dyads choose to spend more time in closer proximity than females or mixed sex combinations, suggesting male dyads may get along better than other sex combinations. However, there is conflicting results from behavioral clinic data, with one study from Australia suggesting that female cats display more inter-cat aggression than male cats (13), while another study in the US by Lindell and colleagues (4) suggests that male cats are more likely to act as aggressors toward other male or female cats. Albeit, behavioral clinic data stems from a limited sample and likely represents more severe cases of inter-cat conflict that may not be generalizable to the average two-cat household. Given that our results, as well as much of the existing scientific evidence, suggests spayed female dyads show more negative interactions, this could be something for cat adopters to consider when they already have one female cat

TABLE 7 Multi-level logistic regression model results showing social and physical environmental factors associated with two cats from the same household having an overall more negative relationship, based on owner perception ($N = 6,529$ participants).

Explanatory variables	Category	OR (95% CI)	*P*-value
Feeding areas	Single (Ref)	-	-
	Multiple	2.04 (1.72–2.42)	<0.0001
Litterbox areas	Single (Ref)	-	-
	Multiple	1.48 (1.25–1.76)	<0.0001
Sex	NM and SF (Ref)	-	-
	Both SF	1.61 (1.23–2.11)	* <0.0001
	Both NM (Ref)	-	-
	Both SF	3.32 (2.34–4.72)	* <0.0001
	NM and SF	2.07 (1.48–2.88)	* <0.0001
Age groups	Both young (Ref)	-	-
	Adult and mature	3.89 (2.32–6.53)	* <0.0001
	Both adult	2.46 (1.41–4.29)	* <0.0001
	Both mature	4.15 (2.63–6.54)	* <0.0001
	Young and adult	0.45 (0.26–0.81)	*0.0012
	Young and mature	0.28 (0.17–0.48)	* <0.0001
	Young and adult (Ref)	-	-
	Adult and mature	1.77 (1.09–2.86)	*0.0098
	Both mature	1.88 (1.22–2.90)	*0.0004
	Both adult (Ref)	-	-
	Both mature	0.59 (0.39–0.90)	*0.0049
Relation	Other (Ref)	-	-
	Not related	2.68 (1.50–4.80)	0.0009
	Siblings (Ref)	-	-
	Not related	2.02 (1.57–2.60)	<0.0001
Aggression toward people	No (Ref)	-	-
	Yes	0.69 (0.54–0.88)	0.0025
Aggression toward animals	No (Ref)	-	-
	Yes	0.24 (0.20–0.29)	<0.0001
Outdoor access	Both indoor (Ref)	-	-
	Both outdoor	0.72 (0.60–0.86)	0.0004
	One indoor, one outdoor	0.60 (0.46–0.78)	0.0002

*Tukey adjusted p-value and adjusted confidence interval used.

at home. It should be noted that other factors such as age of weaning, socialization experiences, and how cats are introduced, likely impact the complex relationship between cat dyads in the home. As well, animal shelters typically place cats into a home with another cat if the shelter cat has a history of living with other cats, and if they display more social behaviors in the shelter or foster home such as playing, compared to fearful or avoidant behaviors (51).

Age also impacted owner ratings of their cats' relationship, with younger (1–3 years old) cat dyads less likely to be rated negatively, compared to all other age group combinations. In addition, dyads consisting of a young and adult cat (4–6 years old) were less likely to have a negative relationship compared to mature-cat combinations. As well, pairs of mature cats (7+ years old) were more likely to have a negatively perceived relationship compared to pairs of adult cats. This suggests that cat owners perceive younger cats as getting along better with other young or adult cats, compared to mature cat combinations. Thus, when pairing cats, such as during the adoption process, it may be beneficial to pair younger cats together and avoid mature-cat combinations. Other research examining age-related impacts on the multi-cat relationship suggests that younger cats display chasing and fleeing behaviors, which the authors categorized as conflict-related, more frequently than older cats (34). However, chasing and fleeing behaviors are also seen during play (52), and thus may indicate increased play and not conflict, in younger vs. older cats. Another study examining the impact of conflict behaviors in households following the introduction of a new cat did not find an age effect on the cat-cat relationship (12). Overall, more research is needed to establish stronger links between cat dyad age combinations and the cat-cat relationship. For example, a prospective cohort study with direct behavioral observations of cat dyads of various age combinations in two-cat households would be beneficial.

Cats' relatedness was a factor that impacted participant ratings of their cats' relationship. Cats that were not related were more likely to be rated as having a negative relationship compared to cats that were siblings or placed into the "other" category. Participants that selected "other" had cats that were parent and child or that were bonded before adoption. This finding is not unexpected given the natural history of cats. For example, in free ranging cat colonies, individuals choose to socialize with preferred conspecifics and related females typically interact and may even form small colonies with other females from their lineage and their offspring (3, 11). Similarly in a private colony of neutered cats, Curtis and colleagues (42) found related cats were significantly more likely to be within 1 m of each other and display allogrooming, an affiliative inter-cat behavior. In shelter environments, littermates show more physical contact and allogrooming behavior than unrelated cats from the same household (43). Thus, related cats may be more likely to get along due to the strong bonds formed early in life (11, 43). It is important to educate owners on the importance of relatedness and early social bonds when they are adopting. If there is an opportunity to adopt related cats, owners should be educated on the positive influence it may have on the cats' relationship and the possible consequences of introducing an unrelated cat later on. Future studies should investigate the motivations of cat owners seeking additional cats into their households. Further, research is needed to provide evidence-based recommendations for introducing an unknown cat into a household with existing cat(s).

Outdoor access (either supervised or unsupervised), was another factor that impacted participant ratings of the cat-cat relationship in 2-cat households; those with outdoor access were more likely to have a reported negative relationship than pairs kept indoors-only. Other cross-sectional cat-owner survey research examining multi-cat households have found similar results, with outdoor access associated with increased aggression toward other household cats (18), outdoor access associated with increased fighting during the period of time when cats are being introduced (12), and a negative correlation between outdoor access and inter-cat affiliative behaviors (34). It is possible that cats with outdoor access may bring new and unfamiliar odors into the home which may initiate cat-cat conflict, however no research supports this. Another possibility is that cat owners may be more likely to let their cats outdoors when they do not get along in the home. Given our survey had a cross-sectional design, we were not able to assess temporality of factors associated with a negative cat-cat relationship, which induces uncertainty about causation (53). Future research should use a study design that allows for temporal investigation such as a longitudinal study where cats in the home can be followed over time. This type of study design would also help reduce recall bias which may exist in cross-sectional research.

A high proportion of participants reported that at least one of their cats have had, or currently has, a health problem (59.9%). Although this is concerning, it is comparable to other studies. For example, O'Neill et al. (54) found 68% (2,449/3,584) of cats seen by veterinarians in England have at least one health disorder. Moreover, 48% of US and Canadian cat owners (580/1,208) reported a health disorder in their own cat(s) (55). The most commonly reported health problems in the current study were obesity (25.2%) and dental disease (23.4%, Table 5) and other studies have reported similar prevalence of these health issues. Roberts and colleagues (17) found 19.9% (150/755) of UK owners reported their cats as overweight or obese. In the US, the prevalence of obesity in cats seen by veterinarians during 1995 ($N = 8,159$) was 35% (56), while more recently, Dodd and colleagues (55) found 33% (405/1,233) of US and Canadian cat owners rated their cat's body condition as overweight. Veterinary practices in the US ($N = 15,226$) report cat patients are most commonly diagnosed for dental calculus (24.2%) and gingivitis [13.1%; (56)]. Similarly, O'Neill et al. (54) report that periodontal disease was the most prevalent disease (13.9%, $N = 499/3584$) in cats of UK veterinary clinics. While the current study did not find any health issues to significantly impact the cat-cat relationship as perceived by the owner, future studies should assess if symptoms of health issues (i.e. pain, fatigue) would affect the latter.

A large portion of cat owners (78.5%) also reported that at least one of their cats has a current or previous behavior problem, with fears/phobias (45.7%), unwanted behaviors (45.2%) and destructive behaviors (40.6%) most commonly reported. However, we did not require these to be diagnosed by a veterinarian or animal behaviorist. One survey of US cat owners ($N = 547$), state that 47% of participants answered "yes" when asked if their cat(s) ever misbehave (9), and they found similar prevalence for anxiety/fear (59.4%) and destructive behaviors (49.7%) as the current study. Another survey of US and Canadian cat owners ($N = 2465$) found that 58% reported inappropriate scratching (57), which is similar in prevalence to destructive and unwanted behaviors in the current study. It is possible some participants selected a behavior problem because they have seen it in their cat(s) (i.e. excessive night time activity, unwanted behaviors, fear/phobias, etc.), but it may not be displayed to the intensity and frequency where it would constitute as a behavior problem (58).

Households with at least one cat that has shown animal or human-directed aggression were associated with owners rating their cats' relationship negatively. Aggression toward people and other animals can vary from subtle agonistic displays to more obvious displays that may lead to serious injuries. Inter-cat aggression is a major stressor for cats, and may lead to further behavioral problems such as house soiling (5, 6, 57), which may increase the risk of relinquishment (25–27). Aggression toward people and other animals may be affected by many factors such as socialization experiences, management of the home environment, and interactions with people and other animals in the home (58). It is important for the type of aggression to be identified (i.e., fear-related, territorial, play-related, petting-induced, redirected, social stress, pain-induced), as well as sources or triggers that may lead to an aggressive event (58). Research suggests cats reported to show human and/or animal-related aggression may involve redirected aggression, which is commonly enticed by inter-cat conflict and loud noises (59). However, the current study did not assess causes of aggression-related behavior problems given this is not possible with a cross-sectional survey design. Cat owners may benefit from addressing aggression through early management of the problem, to minimize the risk of stress, injuries, and further behavioral or health problems.

We also found that provision of resources in the home is associated with owner perceptions of a negative cat-cat relationship. Owners perceiving their cats' relationship as negative was associated with households with multiple litter boxes and feeding areas. These findings were not in line with our predictions; however, our survey design could not assess the temporality of these associations. Thus, it is possible that cat owners choose to provide multiple resources as a solution when conflict becomes present in the home rather than as a preventative measure. The American Association of Feline Practitioners recommends that multi-cat households should have multiple, easily accessible resources to meet cat behavior needs (60). Multi-cat households have been identified as a risk factor for behavior problems in the home (20, 22) such as inappropriate elimination (61–63), is a common reason for relinquishment (26). While providing multiple litter box areas may not solely prevent house soiling, it is an important consideration. In addition, providing multiple separate food areas in multi-cat households is recommended to help reduce agonistic interactions such as resource guarding, which may be present when one cat is more dominant and assertive over another more timid cat (60). Resource guarding around limited food areas may lead to rapid ingestion of food or inadequate nutritional intake, and may increase the risk of health issues overtime (64). Although the recommendation of multiple food areas is not based on scientific evidence, cats are naturally solitary hunters. Thus, feedings areas that are physically separate may reduce the potential of threat and may better mimic "solitary" eating (65, 66). Overall, there is little experimental evidence about the impact of resource distribution in the home on cat-cat interactions, and more research is needed.

Our survey results show that the cat-cat relationship in two-cat households is complex and impacted by many factors such as, cat sex, age, relatedness, outdoor access, resource provision in the home, and aggression directed toward other people and animals in the home. The complex interplay and directionality of these factors requires further investigation for a full understanding of how to improve the cat-cat relationship in the two-cat households. More research is also needed to provide cat owners with evidence-based recommendations for providing adequate resources in two-cat households. Cat owners may also benefit from information on factors to consider before acquiring a second cat to foster a stronger connection between their cats, as well as scientifically supported guidelines for introducing their cats.

4.1. Limitations

Our research survey was cross-sectional and limits our ability to understand the temporality of factors associated with participants' perceptions of their cats' relationship, thus limiting interpretations of the study results. In addition, the data may be impacted by participant recall bias and the responses received may be more indicative of their cats' current relationship. The results of this study are also reliant on the cat owner's ability to accurately assess their cats' relationship. The second part of the survey (results not published here) examines cat owner's knowledge of cat behavior and cat-cat interactions, and examines this in more detail.

The majority of the survey participants were female, middle aged (30–50 years old), had no dogs or children, and indicated they keep their cats indoor-only. A larger proportion of female participants is common in online survey studies (67) and a noted limitation. A large proportion of participants also had no children or dogs, which may be a limitation and reflection of the type of cat owner that participates in cat-related research surveys. Previous studies of cat owners also found the majority of participants do not have children (9, 18, 68, 69) and that approximately half (9) or the majority do not have dogs (18). Furthermore, it is possible our study attracted cat owners with a special interest in cat-related topics or research, which may not be representative of the average cat owner.

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 studies involving human participants were reviewed and approved by UC Davis Institutional Research Ethics Board. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

Author contributions

SK wrote the manuscript. CM edited the manuscript. All authors established the study question, devised the study methods, and questionnaire. 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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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fvets.2023.1128757/full#supplementary-material

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Attitudes and practices toward feral cats of male and female dog or cat owners and non-owners in Seoul, South Korea

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The number of pet cats in South Korea has sharply increased since 2010. Problems have arisen with feral or stray cats, creating conflict among residents, to such an extent that the government provides some sites for people to offer feeding stations for the stray cats. This study investigated hypotheses on people's attitudes toward feral cats in Seoul, South Korea: (i) dog and cat owners would show more positive attitudes than non-owners toward feral cats; (ii) females would have more positive attitudes toward feral cats than males; (iii) the number of Seoul-provided feeding stations by district would be correlated with people's positive attitudes toward feral cats. Responses from 7,394 participants were used for the final analyses with 3,179 males, 3,607 females, and 599 others (includes "decline to state"). Cat owners reported more extremely positive attitudes toward feral cats than people who had no cats. Females more often had cats than males, and they were more extremely positive toward pet and feral cats than males, and strongly opposed to culling as a management strategy. The attitudes toward feral cats of people with only dogs were intermediate between people with cats and people without pets, more resembling those of people without pets. There was a correlation between the number of city-provided feeding stations and people's attitudes toward feral cats, but only in the areas with at least 40 feeder stations; having many city-provided feeding stations was associated with very negative attitudes to feral cats. Whether the very large number of feeding stations were provided in the two neighborhoods due to a previously excessive number of feral cats in those neighborhoods, vs. those feeding stations attracting or provisioning an ever-growing number of feral cats, is unknown. These results show sharp differences in attitudes between cat owners and non-owners, and between males and females. Results resemble findings in other studies, perhaps with more extreme differences between sub-groups. The study revealed that attitudes toward pet and feral cats in Seoul were complex and varied with pet ownership, with sex, and with neighborhood context.

KEYWORDS

neutering, human-animal interactions, Trap-Neuter-Return, felines, canines

Introduction

Genetic and archeological evidence suggests that the domestication of cats began as early as 10,000 years ago when agriculture was advancing (1). Throughout their long history with cats, people have held attitudes and beliefs toward cats that differ significantly across cultures and religions (2). In Egypt, cats were considered sacred and were worshiped as deities (2), whereas some other cultures and religions considered cats to be associated with bad luck and bad spirits, as in old folklore of Korea (3). Both extremely positive and negative feelings about cats are reported in Brazil (2). In modern society, regardless of culture or religion, people's attitudes toward cats vary drastically, from those who love cats to those who despise them. These conflicting attitudes play out differently in various locations. Increasingly, with the emphasis on no-kill and the intrinsic value of animals (4), eradication may be viewed as an infeasible policy, even on small islands (5); Trap-Neuter-Return (TNR) and similar approaches often become primary strategies. At the same time, wildlife professionals highlight that cats are an invasive species and recommend preventing outdoor feeding of cats and not allowing them to roam freely (6). Serious efforts have been made to bridge the values conflicts, with wildlife advocates perceiving stray cats as an invasive species and cat advocates viewing them as homeless pets. A 2020 paper by Leong et al. provided explanatory diagrams clarifying the complexity of these issues and conflicts (7). One diagram depicts how human sources of outdoor cats are enhanced by human provisioning of the cats, leading to a general outdoor cat problem, then resulting in many specific problems that groups want to address. A second diagram shows the many different measures required to mitigate the problems, starting with keeping pet cats indoors and stopping abandonment.

Problems with cats have accelerated in South Korea with the recent surge in cat ownership. An estimated 1.54 million households among a total of 21.5–23.4 million households were reported to have 2.6 million cats in 2020: a noticeable increase from the 0.6 million cats in 2010 with 17.5 million households, and 1.9 million reported in 2015 with 19.6 million households (8–11). Despite the growing popularity of pet cats, stray or feral cats have become a focus of national conflict in South Korea (12). Stray cats are defined as pets that were once raised and socialized by humans. Feral cats, in contrast, have had little to no human contact in their lives and are essentially wild. In an urban environment, it is difficult to differentiate stray cats from feral cats, thus, the term feral cats will be used in this paper.

Common complaints against feral cats in South Korea resemble those in other countries such as the United States or Japan, where conflicts focus on cats' excrement deposition, scavenging for food in the trash, and cries made during territorial disputes among feral cats and during mating (13, 14). These complaints are especially impactful in urban settings. Studies in Guelph, Canada, clarified how complicated the issues are, especially with urban feral cat colonies (15). Cat owners often are reported as more favorable to feral cats than non-owners, as with an example in California (16). The research in Canada reported that cat owners had more favorable attitudes to feral cats than non-owners; non-owners favored euthanasia of the feral cats more often than owners (17). This group recommended using community-wide approaches (18).

Additionally, females have been reported as more sympathetic to feral cats than males and less willing to consider lethal options when dealing with feral cats. In a study in Bulgaria, 33% of females fed stray cats, and only 20% of males (19). A study in Australia found that males were more willing than females to use all control methods, including poison and methods that may be inhumane; females also were more reluctant to use methods that were unfamiliar or unknown to them (20). Another study in Australia also reported that males were more accepting of lethal methods than females (21). A large study in Belgium found numerous differences in attitudes of males and females toward managing cats, leading the authors to conclude that customized approaches were needed for varied sub-groups (22).

Opinions differ on how best to address problems with feral cats. Studies in Hawaii by Lohr and colleagues have found high acceptance of lethal traps as the best technique for dealing with feral cats, and TNR as the worst technique, reflecting the costs and benefits; however, respondents felt that avoiding abandonment of cats would be even better (23). These results differ from a general preference for non-lethal methods of dealing with feral cats (4). While recreating their study in Australia, Lohr's group found it challenging to monitor feral cats at a vast landscape scale (24). Several recent studies describe the advantages of neutering feral cats. One highlights that the smaller territories of cats in protected island settings are better for wildlife (25). Others report that smaller territories result in less aggression (26) and result in fewer injuries for males (27). Those in South Korea who despise feral cats have demanded that feeding and caring for the cats be stopped and some have advocated for the culling of feral cats. Some have even resorted to violence and hate crimes against both advocates and animals.

Some committed animal advocates work for the welfare of feral cats, such as by providing feeding stations, food, shelter, and medical help to feral cats. Such animal advocates are sometimes described as "semi-owners" (28). Feeding stations are designated patches of space around neighborhoods where dedicated volunteers create and supply a small shelter with food and water. These volunteers also keep tabs on the well-being of cats and provide medical attention and TNR services to the cats in need. Previous studies have also found that providing and managing feeding stations for feral cats makes it easier to estimate the population size, identify immigrant cats, provide medical attention to feral cats, and conserve wildlife (29, 30). Helback's study demonstrated feral cat population densities correlated with providing feeding stations, so potentially feral cat habitats can be maintained and the cat populations successfully managed in designated areas (30).

After considering the advantages of feeding stations and to alleviate human conflicts caused by feral cats, the Seoul Metropolitan City Government began employing cat feeding stations in 2013. This involves providing designated spaces on government property where people can provide food and water for cats. These stations facilitate the efforts of volunteer programs that aim to spay and neuter feral cats using the feeding stations. During this survey there were 346 feeding stations in 25 districts in Seoul. However, no reports have been presented on whether and how feeding stations relate to people's attitudes toward feral cats.

The aim of this study was to investigate people's attitudes toward feral cats in Seoul, South Korea, a city where petkeeping is not a longstanding tradition. We had three hypotheses: (i) people who had a pet would show more positive attitudes than non-owners toward feral cats; (ii) females would have more positive attitudes toward feral cats than males; (iii) there would be a correlation between the number of city-provided feeding stations and people's positive attitudes toward feral cats. Considering the social conflict among residents in Seoul concerning feral cats, we sought to clarify the characteristics and attitudes of people supporting feral cats as compared with those opposed to feral cats.

Methods

Study design overview

The Institutional Review Board (IRB) of the University of California, Davis, ruled this study as exempt (IRB approval number: FWA No: 00004557). A web-based survey was conducted via an online survey site (Qualtrics), between August 2021 and January 2022 in South Korea; recruitments and responses were primarily from Seoul. It was distributed via social media (Facebook, YouTube, Instagram), in the Korean language. Responses were gathered from throughout South Korea and included in the general analyses. For the assessment of feeding stations in districts of Seoul, only responses from people residing in Seoul (69% of respondents) were included.

The survey consisted of a total of 24 questions, eight questions concerning general information on the respondents and their pet ownership history, eight questions regarding their attitudes toward feral cats, two questions for respondents' preferences for the management of cats, and six questions about their experiences related to providing feeding stations and shelter. The full survey is available in Figshare. Questions for the survey were written in English by all authors, and the survey was translated into Korean by two veterinarians using a forward–backward translation procedure (31). The inclusion criteria for participants in the study included adult residents in Korea who are over the age of 18 years.

Statistical analyses

A total of 24 items in the questionnaire included three binary (yes or no), seven categorical (e.g., gender, species of the participants' first pet), 10 ordinal (e.g., attitudes toward pet cats or feral cats), three numerical (e.g., current age, age when the participant got their first pet), and one open-ended questions (i.e., describe any experiences related to animal shelters in Korea). Three categorical questions (i.e., options that the participants support for managing feral cat populations, species of their current pets, and characteristics that the participants find most important to be a good cat owner) allowed the participants to select all options that applied.

All the analyses were done in R (version 4.2.0). Descriptive statistics were used to summarize the survey results. Binary, categorical, or ordinal data were summarized as counts and percentages, and the percentages were calculated after excluding not-responded data for each question. For the question about gender, "Non-binary," "Gender fluid," "Other," and "Prefer not to say" were re-categorized as a single item ("Others"); overall, fewer than 10% of respondents declined to provide a binary response. For ordinal data, "very negative," "negative," "neither positive nor negative," "positive," and "very positive" were converted into ordinal values "1–5," respectively. Numerical data were summarized as means and standard deviations in each categorical group. To test for statistical differences in attitudes among four groups of animal owners (dog, cat, dog and cat owners, and no pet owners) and gender, the Kruskal-Wallis test was used with ordinal data. To examine the correlations between the respondents' answers to attitudes toward pet cats and feral cats in the same owner or gender group, Spearman's rank correlation coefficient was used. When results were significant ($p < 0.05$), pairwise comparisons were conducted using the Wilcoxon rank sum test. To assess attitudes toward feral and pet cats by the species of animal kept as a pet after adjusting for gender effect (male vs. female), logistic regression was used after re-categorizing the ordinal data ("very negative," "negative," "neither positive nor negative," "positive," and "very positive") into binary data as "negative" including "very negative," "negative," and "neither positive nor negative" and "positive" including "positive," and "very positive."

Results

The total number of respondents was 11,240. For inclusion, participants were required to answer over 95% of all the questions and to own only a cat and/or a dog, or not own any pet. Participants under 19 years old were excluded. Data for participants who reported a lower "current age" than "the age when they first got a cat" were excluded. Thus, reflecting these inclusion and exclusion criteria, the total number of participants whose data were used in the statistical analysis was 7,394. The general demographics of the participants and characteristics toward feral cats and management are summarized in Table 1.

Overall, as shown in Figure 1A, participants' attitudes toward pet cats were more positive than toward feral cats, regardless of the species of animals they kept as pets. Cat owners were the most positive toward pet cats (84%, very positive), and cat and dog owners were the most positive toward feral cats (55%, very positive). However, 41% of dog owners and 43% of people who did not have pets evaluated their attitudes toward feral cats as "very negative." As a result, for both pet cats and feral cats, significant differences among the owner groups were observed ($p < 0.001$). All the other pairwise comparisons were significant as well, except for the comparisons between cat owners and cat and dog owners in attitudes toward both pet cats ($p = 0.16$) and feral cats ($p = 0.55$); cat owners and cat and dog owners were similar in their attitudes toward pet cats and feral cats. Within each category group of ownership, the correlations between the answers to attitudes toward pet cats and feral cats were moderately correlated in owners of cat or cat and dog owners (dog: $r = 0.36$; cat: $r = 0.41$; cat and dog: $r = 0.47$; no pet: $r = 0.22$; $p < 0.001$).

Figure 1B shows the attitudes toward pet cats and feral cats depending on the participants' gender; 54% of females answered "very positive" toward feral cats but less than 10% of males and the other group answered "very positive" toward feral cats. Interestingly, investigating the correlations between the answers to attitudes toward pet cats and feral cats within the same gender group, they were very weak in male ($r = 0.18$) and other ($r = 0.18$) groups, whereas the female group ($r = 0.54$) showed a moderate correlation, which means that the answers to the questions between pet cats and feral cats in male and other gender group were very inconsistent.

However, as in Table 1, the species of animal kept as pets were significantly associated with person's gender group ($p < 0.001$); 52% of male participants were dog owners, and 74% of female participants were cat owners. Thus, Table 2 summarized the attitudes toward feral and pet cats by the species of animal within each female and male group. Male cat owners still had negative attitudes toward feral cats (negative – 20.3%, very negative – 31.7%), but their attitudes were less negative than those of male dog owners (negative – 31.3%, very negative – 53.6%), or

TABLE 1 Characteristics of the participants grouped by species of their current pet ($n = 7{,}394$).

Characteristics count (percentage)		Cat (n = 2,831)	Cat and dog (n = 446)	Dog (n = 941)	No pet (n = 3,176)	Total (n = 7,394)
Gender	Male	567 (20.0%)	91 (20.4%)	489 (52.0%)	2,034 (64.0%)	3,179 (43.0%)
	Female	2,095 (74.0%)	332 (74.4%)	366 (38.9%)	814 (25.6%)	3,607 (48.8%)
	Others	164 (5.8%)	21 (4.7%)	85 (9.0%)	329 (10.4%)	599 (8.1%)
Age in years *Mean (SD)*		34.5 (10.1)	36.9 (11.7)	31.5 (9.6)	30.6 (8.5)	32.5 (9.7)
Age when owners got their first pet (including all species of animals) *Mean (SD)*		18.0 (11.4)	16.3 (10.4)	15.3 (9.0)	10.4 (7.1)	14.3 (10.0)
Owners' attitudes toward intense feeding of cat colonies/management	Strongly disagree	643 (22.7)	101 (22.6)	549 (58.4)	2,185 (68.8)	3,478 (47.0)
	Disagree	118 (4.2)	22 (4.9)	83 (8.8)	415 (13.1)	638 (8.6)
	Neither agree nor disagree	154 (5.4)	24 (5.4)	30 (3.2)	165 (5.2)	373 (5.0)
	Agree	484 (17.1)	42 (9.4)	65 (6.9)	133 (4.2)	724 (9.8)
	Strongly agree	1,430 (50.5)	256 (57.4)	214 (22.8)	278 (8.7)	2,178 (29.5)
Whether owners were involved in the management of feral cats	Yes	1,000 (35.3)	212 (47.5)	131 (13.9)	184 (5.8)	1,527 (20.6)
	No	1,830 (64.6)	234 (52.4)	810 (86.1)	2,992 (94.2)	5,866 (79.3)
Three characteristics that owners find the most important to be a good cat owner*	Responsibility	2,481 (87.6)	410 (91.9)	820 (87.1)	2,767 (87.1)	6,478 (87.6)
	Knowledge about cat health	1,417 (50.1)	245 (54.9)	282 (30.0)	900 (28.3)	2,844 (38.5)
	Knowledge about cat behavior	1,321 (46.7)	238 (53.4)	316 (33.6)	964 (30.3)	2,839 (38.4)
Whether owners have seen cats in animal shelters in Korea	Yes	1,203 (42.5)	224 (50.2)	353 (37.5)	774 (24.4)	2,554 (34.5)
	No	1,627 (57.5)	222 (49.8)	587 (62.4)	2,401 (75.6)	4,837 (65.4)
Respondents living in certain districts of Seoul with greatest number responding**		Gangnam 149 (5.3) Gwanak 111 (3.9) Songpa 93 (3.3)	Gangnam 22 (4.9) Eunpyeong 14 (3.1) Songpa 14 (3.1)	Gangnam 46 (4.9) Gwanak 37 (3.9) Gangseo 37 (3.9)	Gangnam 161 (5.1) Gwanak 134 (4.2) Seongbuk 123 (3.9)	Gangnam 378 (5.1) Gwanak 295 (4.0) Seongbuk 227 (3.1)

*On this question, all items that applied could be selected. **31% of the respondents were living outside of Seoul and could not specify their regions. Nine of the 25 districts of Seoul had government-sponsored feeding stations. Data are shown for the three of these districts having the most respondents for each category of pet ownership.

non-owners (negative – 31.7%, very negative – 47.4%). In the final logistic regression model to assess attitudes toward feral and pet cats by the species of animal kept as a pet after adding gender effect (male, female), results showed that the odds of being positive toward feral cats were 93% lower in males than in females, although that of being positive toward pet cats was only 44% lower in the male than in the female group (Table 3). The odds of being positive toward feral or pet cats were significantly lower in dog owners or non-owners compared to the cat owner group, even after adjusting for the gender effect.

Overall, as shown in Figure 2A, participants reported their current attitudes toward pet cats compared with 5 years ago as more positive than toward feral cats, regardless of the species of animals that they currently kept as pets. Especially, 55% of dog owners and 61% of people without pets evaluated their current attitudes toward feral cats compared with 5 years ago as "very negative"; compared to Figure 1A, the negative values were increased. Similarly, when seeing the answers by gender groups in Figure 2B, 65% of the male group and 72% of the other group evaluated their current attitudes toward feral cats compared with 5 years ago as "very negative," reflected in increased values compared to Figure 1B. Current attitudes toward pet cats and feral cats compared with 5 years ago also showed significant differences among the owners and gender ($p < 0.001$). Also, all the other pairwise comparisons between owner groups were significant, except for the non-significant comparisons between cat owners and cat and dog owners for both their attitudes toward pet cats and feral cats; again, cat owners and cat and dog owners were similar in their attitudes. No significant differences in attitudes toward pet cats and feral cats between males and the other gender group were observed, but females showed significantly different attitudes compared to the two other gender groups ($p < 0.001$). The correlations between the answers to attitudes toward pet cats and feral cats within cat or cat and dog owners were moderately correlated (dog; $r = 0.39$, cat; $r = 0.41$, cat and dog; $r = 0.45$, no pet; $r = 0.18$; $p < 0.001$). As in Figure 1B, the males ($r = 0.12$) and the other ($r = 0.11$) gender group showed inconsistent weak associations between answers to pet cats and feral cats in Figure 2B. When comparing the attitudes toward feral and pet cats compared with 5 years ago by the species of animal within each female and male group, the results were similar to Table 2, but the answers were more polarized. Women had become more extremely positive, and men had become more extremely negative toward feral cats in all categories of owners, when they assessed themselves compared to 5 years ago.

Cat owners and cat and dog owners selected the single most effective way to manage the feral cat population as "Increase TNR funding/availability" (43, 39%), as shown in Figure 3A. However, for the same question, dog owners and people who did not have a pet selected "Feral cat culling" (52, 64%). When investigating the answers by gender group, shown in Figure 3B, males and the other gender group selected "Feral cat culling" as the most effective way as well (67, 73%). Male cat owners also selected "Feral cat culling" (261/567, 46%) as the most effective way to manage the feral cat population, whereas female cat owners answered "Increase TNR funding/availability" (1,070/2,095, 51%).

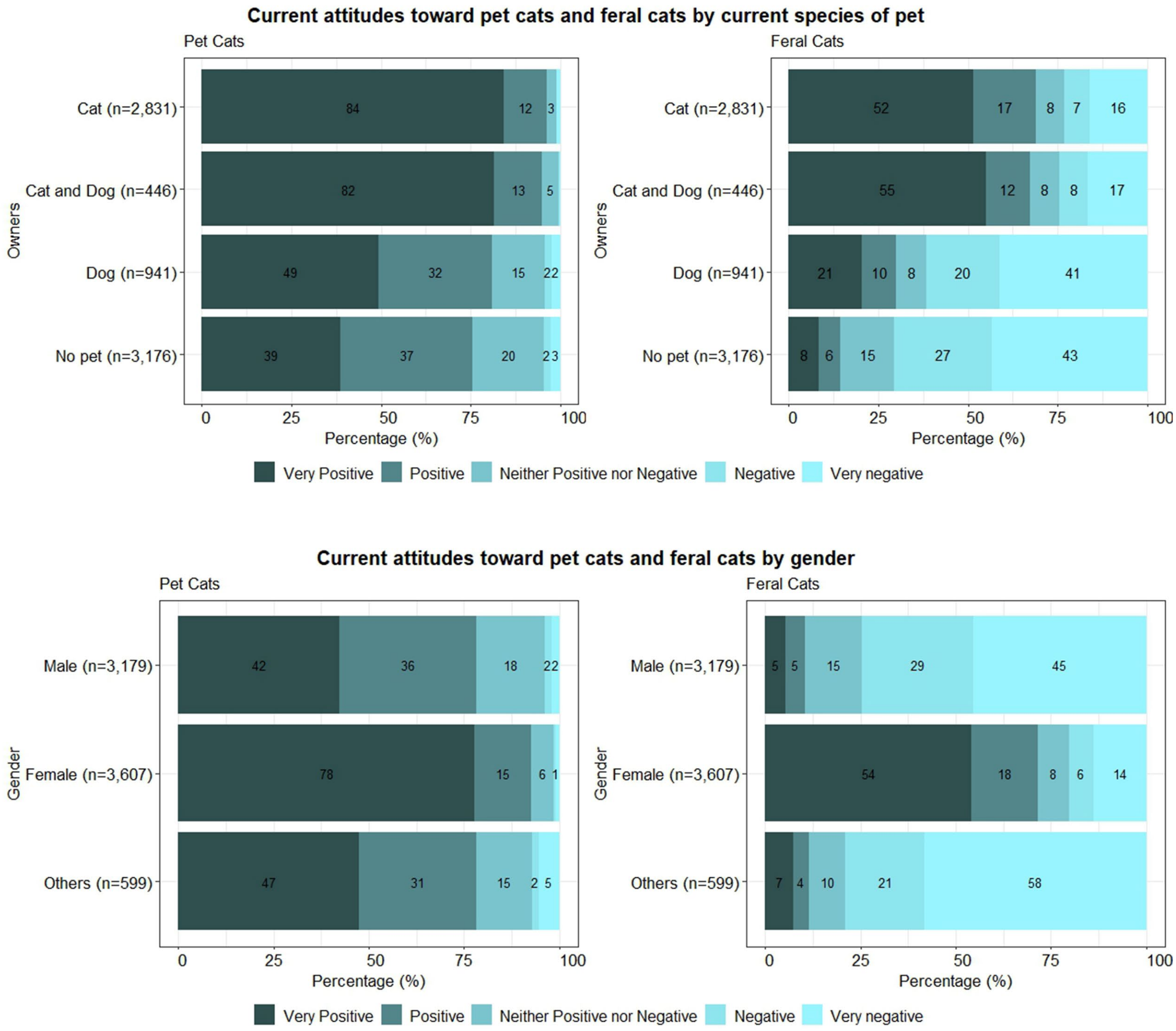

FIGURE 1
(A) Participants' current attitudes toward pet cats and feral cats grouped by their current species of pets. **(B)** Participants' current attitudes toward pet cats and feral cats grouped by gender.

Cat feeders who answered that they had experienced government or private feeder stations for feral cats at least once, strongly favored "Increase TNR funding/availability" (832/1,567, 53%), shown in Figure 3C. They supported "Increase the number of government-provided feeder stations" (304/1,567,19.5%) and "More government facilities" (174/1,567, 11.1%) relatively more often than other pet owners.

According to the information provided by the Animal and Plant Quarantine Agency in Korea, at least 40 feral cat feeder stations were installed in 2 of 25 districts (Gangdong-gu and Gangnam-gu) in Seoul. Seven other districts (Dongdaemun-gu, Gwanak-gu, Jongno-gu, Jung-gu, Mapo-gu, Seocho-gu, and Seodaemun-gu) had 20–29 feral cat feeder stations. The other 16 districts had no feeder stations currently operating. After recategorizing the districts as three groups (no feeder station, feeder stations ≥20–39, feeder stations ≥40), participants' attitudes toward pet cats and feral cats are shown in Figure 4, for the three categories of districts. Participants from the districts with at least 40 feeder stations had the highest percentage (48%) of answers as "very negative" toward feral cats. Current attitudes toward pet cats and feral cats showed significant differences among the three district groups (pet cats: $p = 0.015$; feral cats: $p < 0.001$). However, with pair-wise comparisons, the participants' answers between districts with no feeder stations and districts with at least 20 feeding stations showed no significant differences in attitudes toward both pet cats ($p = 0.4$) and feral cats ($p = 0.28$).

For the open-ended question inquiring whether participants had experiences adopting cats in animal shelters in Korea, 74% (440/595) of the participants who answered "yes" to that question wrote their opinions in words. Most of the answers were about when and from which animal shelters they adopted the cats. They often mentioned the cats they adopted were babies so they could not leave them in the shelters. In addition, many of them said they decided to adopt the cats after hearing that the abandoned cats in the animal shelters would be euthanized after the certain amount of time if not adopted by anyone.

TABLE 2 Current attitudes toward feral cats and pet cats by person's gender and species of the participants' pets.

Current attitudes toward feral cats							
Females ($n = 3,607$)				Males ($n = 3,179$)			
Cat (2,095)	Very Positive	1,324	63.2%	Cat (576)	Very Positive	106	18.7%
	Positive	400	19.1%		Positive	74	13.1%
	Neutral	124	5.9%		Neutral	92	16.2%
	Negative	53	2.5%		Negative	115	20.3%
	Very Negative	194	9.3%		Very Negative	180	31.7%
Cat and dog (332)	Very Positive	223	67.2%	Cat and dog (91)	Very Positive	16	17.6%
	Positive	49	14.8%		Positive	5	5.5%
	Neutral	21	6.3%		Neutral	14	15.4%
	Negative	8	2.4%		Negative	21	23.1%
	Very Negative	31	9.3%		Very Negative	35	38.5%
Dog (366)	Very Positive	176	48.1%	Dog (489)	Very Positive	10	2.0%
	Positive	70	19.1%		Positive	18	3.7%
	Neutral	25	6.8%		Neutral	46	9.4%
	Negative	27	7.4%		Negative	153	31.3%
	Very Negative	68	18.6%		Very Negative	262	53.6%
No Pet (814)	Very Positive	226	27.8%	No Pet (2,032)	Very Positive	36	1.8%
	Positive	117	14.4%		Positive	67	3.3%
	Neutral	124	15.2%		Neutral	320	15.7%
	Negative	141	17.3%		Negative	645	31.7%
	Very Negative	206	25.3%		Very Negative	964	47.4%
Current attitudes toward pet cats							
Female ($n = 3,607$)				Male ($n = 3,179$)			
Cat (2,095)	Very Positive	1,858	88.7%	Cat (576)	Very Positive	413	72.8%
	Positive	184	8.8%		Positive	118	20.8%
	Neutral	37	1.8%		Neutral	30	5.3%
	Negative	1	<0.1%		Negative	3	0.5%
	Very Negative	15	0.7%		Very Negative	3	0.5%
Cat and dog (332)	Very Positive	288	86.7%	Cat and dog (91)	Very Positive	59	64.8%
	Positive	37	11.1%		Positive	21	23.1%
	Neutral	7	2.1%		Neutral	10	11.0%
	Negative	–	–		Negative	1	1.1%
	Very Negative	–	–		Very Negative	–	–
Dog (366)	Very Positive	234	64.0%	Dog (489)	Very Positive	193	39.5%
	Positive	78	21.3%		Positive	195	40.0%
	Neutral	41	11.2%		Neutral	80	16.4%
	Negative	8	2.2%		Negative	8	1.6%
	Very Negative	5	1.4%		Very Negative	13	2.7%
No Pet (814)	Very Positive	426	52.3%	No Pet (2,032)	Very Positive	681	33.5%
	Positive	239	29.4%		Positive	811	40.0%
	Neutral	123	15.1%		Neutral	448	22.0%
	Negative	9	1.1%		Negative	42	2.1%
	Very Negative	17	2.1%		Very Negative	50	2.5%

TABLE 3 Logistic regression results of the attitudes toward feral and pet cats associated with the person's gender and species of animal kept as a pet.

Attitudes toward feral cats			
Variable	Odds Ratio	95% CI	*p* value
Gender			
Female	Ref		
Male	0.07	0.06 - 0.08	<0.001
Species of animal kept as pet			
Cat	Ref		
Cat and dog	0.87	0.64 - 1.13	0.3
Dog	0.31	0.25 - 0.37	<0.001
No Pet	0.14	0.12 - 0.17	<0.001
Attitudes toward pet cats			
Variable	Odds Ratio	95% CI	P value
Gender			
Female	Ref		
Male	0.56	0.48 - 0.67	<0.001
Species of animal kept as pet			
Cat	Ref		
Cat and dog	0.78	0.48 - 1.34	0.34
Dog	0.19	0.14 - 0.25	<0.001
No Pet	0.14	0.11 - 0.18	<0.001

Discussion

In this research, people who had at least one cat reported more positive attitudes toward feral cats than people who had no cats. The attitudes toward feral cats of people with only dogs were intermediate between people with cats and people with not pets, more resembling those of people without pets; attitudes of people with only dogs were less positive to cats than our hypothesis had predicted. A larger proportion of females than males kept cats, and the females were extremely more supportive of TNR and opposed to culling and other less humane methods than the males. In addition, there was a correlation between the number of city-provided feeding stations and people's attitudes toward feral cats, but only in the areas with at least 40 feeder stations. Contrary to our hypothesis, people living in areas with many city-provided feeding stations had very negative attitudes to feral cats. More investigation would be required to assess whether the extremely negative attitudes had preceded or been increasing since adding the feeding stations.

Many other studies have investigated attitudes toward animals, and among them, some early studies focused specifically on attitudes to feral cats. In rural and non-rural Victoria, Australia, 22% of randomly selected respondents engaged in some type of semi-ownership behaviors with cats, primarily feeding (28). A survey of randomly selected households in the southeastern U.S. found that cat sanctuaries were most highly endorsed (56%) as a method to reduce feral cat populations, while TNR was supported almost as much (49%), and capture with euthanasia also had some substantial support (44%: 33). Cat owners more often opposed cat licensing and impounding stray cats, supported TNR, and were less concerned about water pollution. Working in Tel Aviv, Israel, Finkler and Terkel focused on the behaviors of cat owners that may contribute to cat overpopulation; education, income, gender, and age all were significant: less educated, older women being more likely to feed stray cats (32). Persons who did not neuter their cats also let their female cats give birth and allowed their non-neutered cats to roam: also abandoning non-neutered cats more frequently. Most of these cat-owning respondents also fed stray cats, and most of these cat owners did not neuter the strays. These authors in Israel proposed several measures to improve the level of knowledge and awareness among cat owners regarding cat overpopulation issues. A California study estimated comparisons of feces produced by outdoor pet cats vs. feral cats, finding that owned cats were responsible for 72% of the outdoor fecal deposition (23). Cat owners, more often than non-owners, opposed cat licensing and impounding stray cats and supported TNR. Studies in Brooklyn, New York, and Rome, Italy suggest that semi-owners, feral cat feeders, who intentionally provide food or other benevolent actions for the health and fitness of cats, contribute toward the overpopulation of cats in urban environments (33, 34). A similar conclusion was put forward in a recent study in Tennessee, where authors concluded that the people feeding the cats needed to be persuaded to provide less food, otherwise some cats would need to be euthanized (35).

Some community efforts have had positive effects. People managing the colonies of feral cats studied in Rome, Italy, compared with 20 years earlier, had improved their methods to assure hygiene, including removal of rubbish and neutering of cats, resulting in stable feral cat colony sizes; this reflected a somewhat increased cooperation between cat lovers and the public veterinary services (34). Unified efforts within UK communities resulted in better cooperation, with

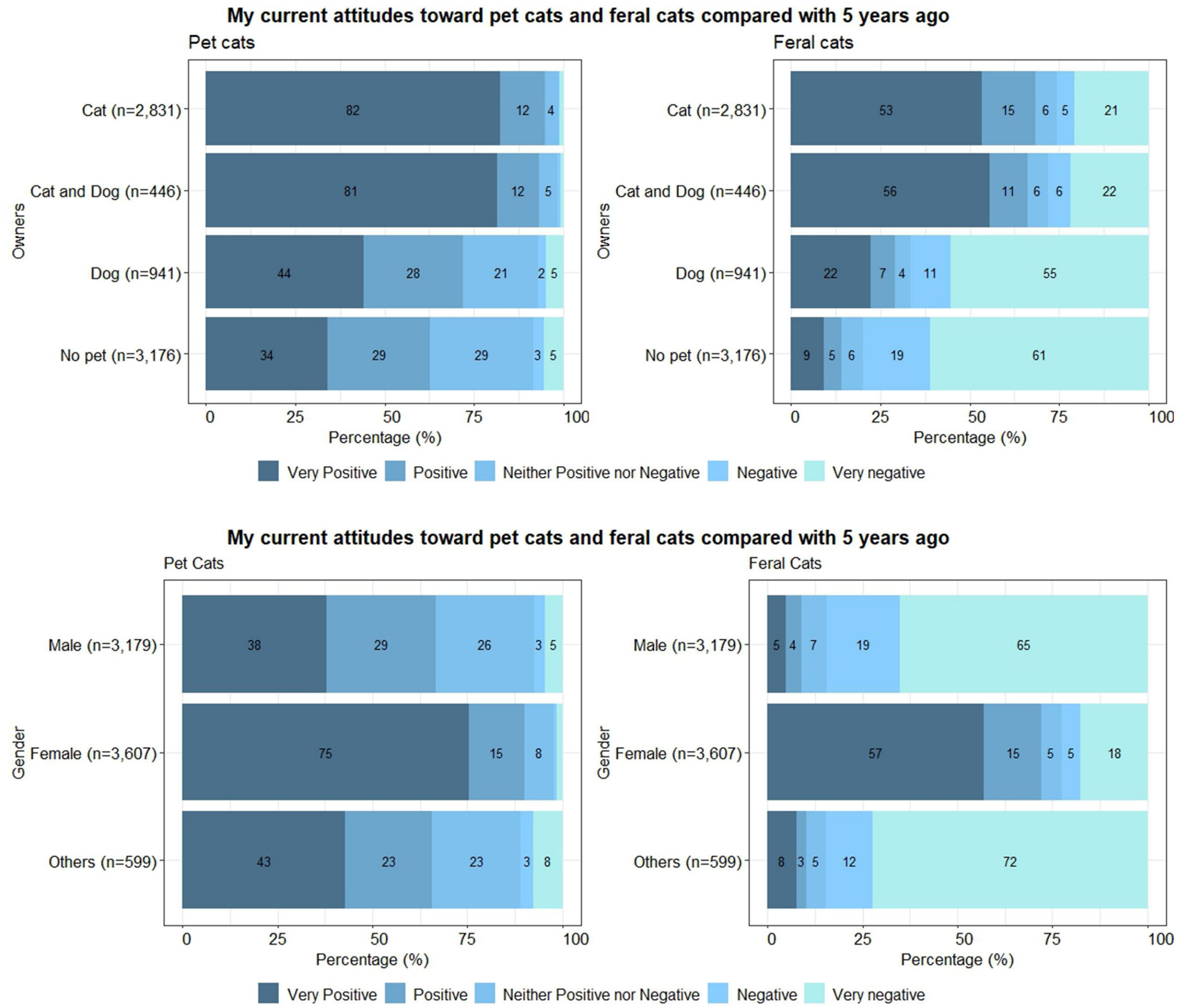

FIGURE 2
(A) Participants' current attitudes toward pet cats and feral cats compared with 5years ago grouped by their current species of pets. **(B)** Participants' current attitudes toward pet cats and feral cats compared with 5years ago grouped by gender.

residents assisting in locating unowned cats and making progress with neutering them; the program enhanced the confidence and self-esteem of participants (36). The Amsterdam Stray Cat Foundation furthers the concept of supporting stray cats and their humans; their view is that humans provide care for the cats and cats also take care of humans, providing significant responsibility for the volunteers involved (37). A cautionary note is that stray cats in Japan, cared for as community cats with high welfare standards, still had numerous health problems, including one-sixth of the cats being FIV-positive (38). Yet, it seems that urban communities need to address the reality of public opinion, which is overwhelmingly in favor of "no-kill" shelters (39).

The opinions on feral cats for people living in very obviously environmentally vulnerable environments, where the lives of wild animals are jeopardized, are likely to differ from those of people living in urban centers (40). Feeders of feral cats in an early study in Oahu, Hawaii, were generally pet owners– more specifically middle-aged women living with their spouses, who had been feeding the feral cats for 2 to 4 years and sought to get them neutered (41). Crawford argued that TNR is not ethical for the welfare of wildlife in Australia; rather, strategies such as targeted adoption, early-age desexing, community education initiatives, and responsible pet ownership have greater promise (42).

In our study, we focused on relationships between pet ownership and attitudes toward feral cats. A study of young pet owners aged 9–19 years in an earlier study in Chicago also reported higher empathy and more favorable attitudes toward cats than non-owners; these young pet owners also reported lower delinquency (43). The relationship between cat ownership and positive attitudes to feral cats was generally supported by our study, that is, cat owners were more positive toward feral cats than non-cat owners.

Some semi-owners in this study managed private cat feeding stations, and the city of Seoul also provides feeding stations to manage feral cats and reduce conflict among feral cats, people who dislike feral cats, and people who like feral cats. In this study, the number of city-provided feeding stations in districts and the attitudes of people living in the districts toward feral cats were compared. In districts with more than 40 feeding stations, people showed more negative attitudes toward feral cats. As mentioned, It is unclear

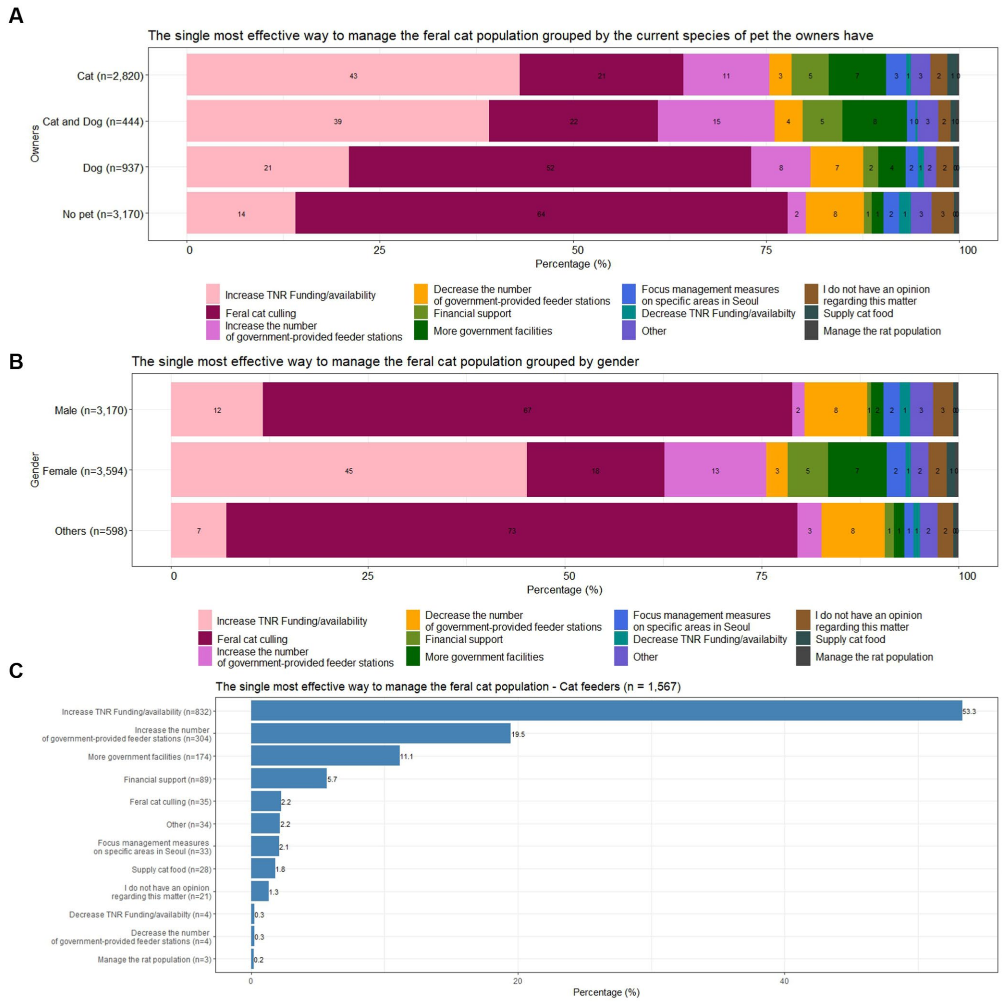

FIGURE 3
(A) The single most effective way to manage the feral cat population grouped by species of pet. **(B)** The single most effective way to manage the feral cat population grouped by gender. **(C)** The single most effective way to manage the feral cat population according to cat feeders.

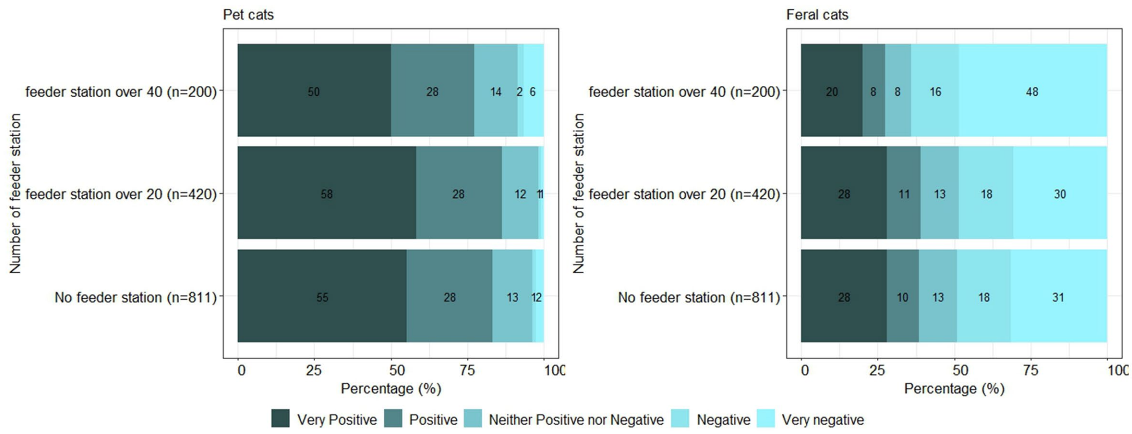

FIGURE 4
Attitudes toward pet cats and feral cats depending on the number of public feeder stations (n = 1,431).

whether the extremely negative views preceded or followed the introduction of so many feeding stations. Gaining consensus on the management of outdoor cats also was found to be difficult in a study on a Japanese island (44). Increasing numbers of feral cats perhaps are likely in the future as more people get pet cats; in the United States, an early study concluded that there were almost as many feral cats as pet cats (45). But in contrast, a recent estimate of the number of unowned cats in the United Kingdom was almost 250,000, whereas pet cats were thought to be more than two million (46). A more substantial effort to estimate the number of domestic cats in an urban area was conducted by the Washington DC Cat Count: a collaboration of animal welfare organizations and wildlife scientists with extensive methodologies (47). Analyses of these extensive data showed that only 3% of the cats were feral, living outside fulltime, and the total number of cats was far higher than a previous estimate (48).

In this study, the four categories of people (cat only, cat and dog, dog only, and no pet) reported different opinions about the single most effective way to manage the feral cat population. Those who had at least one cat favored increasing TNR funding/availability, but those who did not have a cat most often preferred culling as the solution. A recent study of over 4,000 respondents, in Flanders, Belgium, differed from the results here in finding no effect of cat ownership on these opinions but instead, found that the attitudes toward cats, residence, and gender affected their preferences for managing stray cats (27). A strong majority of these Belgian respondents supported responsible household cat ownership and converting stray cats to "community cats"; these preferences were given especially by females, cat-lovers, and families without children. Killing stray cats and taking no action were least supported. These recent results are consistent with earlier research showing that caregivers have a strong bond with their feral cats (49). As also found in a study in Georgia where most people preferred sanctuaries over TNR, people's attitudes are more important than experiences or knowledge for their ideas about managing stray cats (50).

Limitations

This study has some limitations in terms of recruiting the survey participants and analyzing the data related to classifying the districts by the number of feeding stations. Since the present study recruited the participants mainly thorough social media outlets, participation bias may be present. Cat owners that had easy access to the social media would be more likely to answer the questions so the answers may not reflect the views of all pet and non-owners in Seoul. In addition, classifying the districts by the density of pet or feral cats would be more appropriate to reflect the attitudes on pet and feral cats. However, Korea only started to recommend that cat owners register their pet cats in 2018. Although registration of dogs is required, registering cats currently is elective, so obtaining the data regarding the density of cats in districts was not possible.

Conclusion

Our study may contribute to understanding the relationships between feral cats and humans and resolving conflicts in the future. The results reveal the complexity of factors influencing people's attitudes to pet and feral cats, with pronounced differences associated with pet ownership status, sex of the respondent, and characteristics of the neighborhood. Despite the recency of extensive petkeeping in South Korea and the density of housing in Seoul, these results generally are consistent with findings in other parts of the world where petkeeping is a longstanding practice. Females who own cats are most sympathetic to feral cats and could be prospects for participating in TNR programs. Further prospective studies could reveal details on when feeding stations are beneficial in neighborhoods and when they may increase problems with feral cats.

Data availability statement

The original contributions presented in the study are publicly available. This data can be found here: https://figshare.com/articles/dataset/_strong_strong_Attitudes_and_practices_toward_feral_cats_of_male_and_female_dog_or_cat_owners_and_non-owners_in_Seoul_South_Korea/23646750/1.

Author contributions

CK and LH initially conceived and designed the study, with bibliographic assistance from JL. CK collected the data. S-AK and SC compiled and analyzed the data. SC performed the statistical analyses provided ongoing edits for all manuscript drafts. JL surveyed relevant Korean resources. S-AK and LH drafted the initial manuscript. All authors then edited the manuscript. 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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