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Cats are (almost) liquid!—Cats selectively rely on body size awareness when negotiating short openings

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Highlights

Cats were tested for their body-awareness with incrementally decreasing openings

Cats did not make *a priori* decisions when they approached tall, narrow openings

However, cats hesitated to approach and enter uncomfortably short apertures

Trial-and-error or body-awareness are both ecologically valid strategies for cats

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Cats are (almost) liquid!—Cats selectively rely on body size awareness when negotiating short openings

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SUMMARY

Various animal species can make *a priori* decisions about the passability of openings, based on their own size knowledge. So far no one has tested the ability for self-representation in cats. We hypothesized that cats may rely on their size awareness when they have to negotiate small openings. Companion cats (*N* = 30) were tested with incrementally decreasing sized openings, which were either the same height, or the same width. Cats approached and entered even the narrowest openings, but they slowed down before reaching, and while passing through the shortest ones. Because of their specific anatomical features and cautious locomotory strategy, cats readily opt for the trial-and-error method to negotiate narrow apertures, but they seemingly rely on their body-size representing capacity in the case of uncomfortably short openings. Ecologically valid methodologies can provide answers in the future as to whether cats would rely on their body awareness in other challenging spatial tasks.

INTRODUCTION

The classic concept of self-representation suggests an "all or nothing" approach,[1] where animals were considered to be capable of representing themselves in their mental model only if they "passed" the mirror mark test.[2] This paradigm has been the hallmark method for the detection of full-blown self-awareness in human children,[3] and subsequently in nonhuman animals by comparative psychologists.[4,5] The more recently introduced modular theory of self-representation,[6] states that components of the self-representation complex can appear and develop independently from each other, depending on the unique evolutionary past and ecological environment of a given species.[7] Therefore, this paradigm is especially suitable for designing ecologically valid experiments to test animal self-representation, as researchers can create hypotheses, where they target particular behavioral manifestations of self-representation with a direct consideration of its adaptivity for the species.

The cat (*Felis catus*) is a species that retained its original hunting skills as a domesticated mesopredator,[8] however, it also widely shares the anthropogenic niche with humans as one of the most successful companion animals.[9] There is accumulating evidence about cats' capacity for complex cognition, for example, they performed successfully in the so-called "Kanizsa-square" paradigm[10]; and cats were also capable of spontaneous quantity-discrimination (adult cats,[11] kittens[12]). Moreover, perhaps as a sign of evolutionary adaptation to their new social environment, cats show remarkable performance in many tasks involving social cognition: they can follow human visual signals, such as gazing,[13] respond to ostensive cues,[14] and prefer cat-directed speech patterns.[15] However, with the exception of Saito et al.,[16] who found that cats are sensitive to their own name, we are not aware of any empirical studies that attempted to test whether cats would possess or use such skills that require other modules of self-representation. Cats, as highly agile ambush predators within the Felidae family, are especially well-adapted to negotiate difficult obstacles and spatial challenges in the physical environment,[17,18] therefore, in our opinion, body awareness would be a part of the self-representation complex that would bear high biological relevance for them.

To avoid accidents caused by colliding with obstacles in the environment, falling down from elevated locations, or getting stuck within too small apertures, animals that are capable of active locomotion should make the right decisions. Body awareness is a capacity where an individual represents some of its physical attributes in its own mental model,[19] and uses it for making decisions whether to use or not some of the affordances that its environment provides.[20,21] The decision, whether an animal would attempt to pass through an opening or not, can be made with the help of other cognitive mechanisms that do not involve body awareness (e.g., learning the passability of all the obstacles in the environment—the so-called "snapshot method"[22]; or rely on trial-and-error in each case). However, the knowledge of one's own size (and shape) could provide a highly flexible capacity of negotiating novel spatial problems during encounters with them.[6,23] The development of body size representation requires experience (usually throughout ontogeny), and its incorporation to the mental model of the

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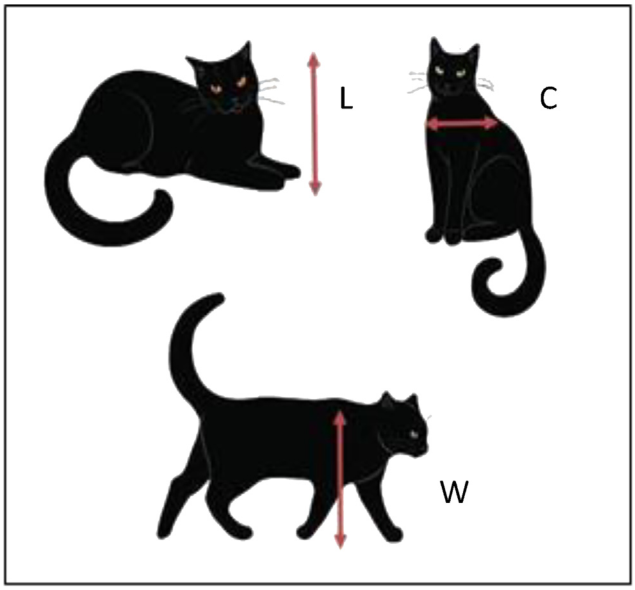

Figure 1. The illustration in the survey to help measure some of the cat's size parameters
See Table 1 for the average cat sizes according to our preliminary survey.
L, height in laying ("Sphynx") posture; C, width of the chest; W, height at the withers.

individual.[24] Therefore, it is evident that testing for body size awareness would offer an excellent opportunity for designing biologically meaningful experiments about animal self-representation. There is a rather small, but growing number of positive examples where nonhuman species were capable of negotiating suitable sized apertures by making *a priori* decisions when approaching them, based on their own body size. The scope of these animals ranges from species with relatively small brain sizes such as the bumblebee,[23] terrestrial hermit crabs (*Coenobita* spp.),[25,26] and snakes,[27] to highly cognitive birds, such as hooded crows[28]; and mammalian predators such as ferrets[29] and dogs.[30,31] In our current study we wanted to know whether cats would make a decision based on their own body size, before they decide to use a narrow gap for passing through.

Recently we tested dogs in various settings, where they had to make shortcuts through apertures that were comfortably large, or too small for them to fit through easily. We found that dogs, depending on the relationship between their own body height (at the withers) and the size of the opening, opted for approach without hesitation ("suitable size opening"), or arrived at the opening with longer latencies ("too small opening"[30]). If the opportunity was given to them, dogs opted for a detour in the case of uncomfortably small apertures.[31] Dogs belong to a group of fast moving, pursuit-type predators, where collisions, or getting stuck within too narrow openings, would have serious consequences—therefore in their case, a well-working, body size awareness-based avoidance system, is of high relevance. Dogs also live in an unusually complex and dynamic anthropogenic environment where they can readily benefit from their capacity for performing well in various modules of self-representation (episodic-like memory[32]; body awareness[6]). But what about cats? Similar to dogs, most cats share a complex and changing environment with humans,[33] and companion cats also engage in various social activities with their owners[34,35]. In addition to the aforementioned *ecological enablers*, by taking in consideration the well-developed (socio-) cognitive capacities of cats,[36] one could hypothesize that these animals will likely show evidence of size-awareness. However, cats are ambush predators that mostly move slow and careful, and they often use elevated vantage points.[37] Their anatomy is highly specialized for climbing, jumping, and even for avoiding the fatal consequences of falling from considerable heights.[38] As they do not have functional collarbones, they show remarkable adaptation for squeezing through narrow gaps.[39] Therefore, we hypothesized that cats would behave differently than dogs when they encounter such

Table 1. Preliminary survey—the questions about the size parameters of the cats, and the calculated means (in cm), and standard deviation values of these

Questions of the survey	Mean; (SD)
What is the total height of the cat? (cm)—from the feet to the ear tips in standing position	37.12; (5.8)
What is the chest width of the cat? (cm)	11.48; (2.56)
What is the height of the cat in laying ("Sphynx") posture? (cm)	19.61; (3.96)
What is the cat's height at the withers? (cm)	27.97; (4.49)
What is the maximum width of the cat's head? (cm)	10.14; (1.61)

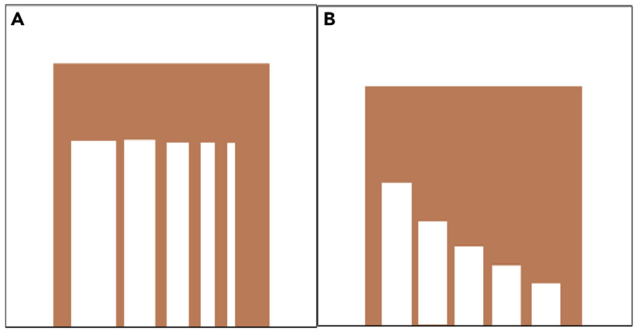

Figure 2. Two variants of the incrementally decreasing size openings

Schematic outlay of the "same height" (A) and the "same width" (B) equipment.

apertures that are seemingly too small for them (Figures 1 and 2). We predicted that instead of hesitating while they approach the opening, cats will try entering the gap, and only decide to go through or not, when they experience its actual size (Figure 3). In other words, we expected that cats will not capitalize their body awareness in such tasks (going through a hole), which in their case, can be solved via other, biologically relevant ways.

RESULTS

Although we run the statistical tests on the composite behavioral variables, some of the original behaviors are worthy to report also as descriptive results. In the case of the "same height" openings (Table 2), two cats opted for jumping over the panel, both in trial 4. In the case of the "same width" openings (Table 3), one cat jumped over the panel in each trial, three cats jumped over the panel in trial 4, one cat jumped over in trials 4–5, one cat jumped over in trial 5, and one cat jumped over only in trials 1–2. "Jumping over" can be considered as cats' refusal to use the opening. Compared to the total number of subjects and trials, these were still sporadic events, however, we can probably conclude that cats tend to avoid more the small, short holes than the tall openings, even if those were narrow.

Same height openings

Neither the repeated trials, nor the measurements of the cats had significant association with the behavioral categories (Table 4). "Hesitate approach" (Trial: $\chi2\ (4) = 8.428$; $p = 0.077$; Chest: $\chi2\ (1) = 0.151$; $p = 0.698$; Withers: $\chi2\ (1) = 0.138$; $p = 0.710$); "hesitate opening" (Trial: $\chi2\ (4) = 9.09$; $p = 0.042$; Chest: $\chi2\ (1) = 0.002$; $p = 0.965$; Withers: $\chi2\ (1) = 0.002$; $p = 0.966$); "alternative solution" (Trial: $\chi2\ (4) = 7.495$; $p = 0.112$; Chest: $\chi2\ (1) = 0.003$; $p = 0.956$; Withers: $\chi2\ (1) = 0.476$; $p = 0.490$). Although cats seemingly hesitated more while they crossed the narrower openings toward the end of the trials, this result was only a non-significant trend.

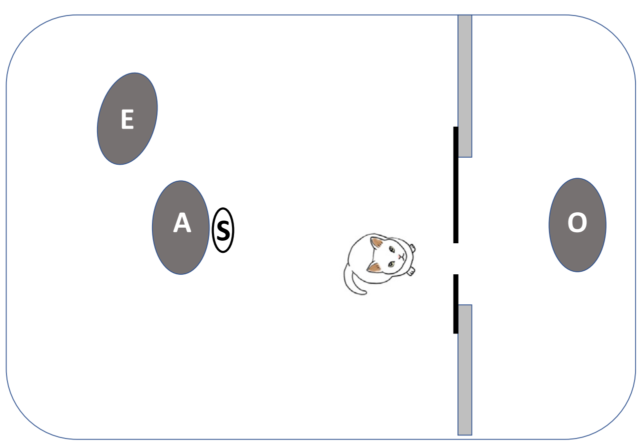

Figure 3. Schematic overhead drawing of a typical testing scene

The cat is depicted in front of an opening of the cardboard panel (black), which is attached to a doorframe in the owner's home. O = owner (behind the panel); S = start point; A = assistant (a family member, who was asked to position the cat, and release it from the start point); E = experimenter (who recorded the trials with her mobile phone camera). In some cases, when there was no assistant, the experimenter held the cat at the start point, and the camera was placed to a piece furniture, 1–1.2 m above the floor.

Table 2. The parameters of the "same height" equipment

"Same height"	Opening 1	Opening 2	Opening 3	Opening 4	Opening 5
Height (cm)	50	50	50	50	50
Width (cm)	13	11	9	7	5

Same width openings

We found a significant effect of the repeated trials on cats' behavior while they approached the incrementally shorter openings on the panel. The size and withers of the subjects did not show significant association with this behavioral parameter. "Hesitate approach" (Trial: $\chi2$ (4) = 38.815; $p < 0.001$; Chest: $\chi2$ (1) = 1.089; $p = 0.297$; Withers: $\chi2$ (1) = 1.097; $p = 0.295$). Cats hesitated more when they approached the shortest opening than in the case of the tallest ones (Figure 4).

We found a significant effect of trials on the "hesitate opening" parameter, too ($\chi2$ (4) = 36.054; $p < 0.001$). Again, the effect of chest width ($\chi2$ (1) = 1.017; $p = 0.313$) and height at the withers ($\chi2$ (1) = 2.499; $p = 0.114$) was non-significant. In the case of the trials, cats hesitated more when they walked through the two shortest openings in trials 4 and 5 (Figure 5).

In the case of the "alternative solution" variable, the repeated trials ($\chi2$ (4) = 12.527; $p = 0.006$) and the cats' height at the withers had a significant effect ($\chi2$ (1) = 7.771; $p = 0.005$). Cats looked for alternative solutions instead of going through the opening more likely in trials 4–5 than in the case of the larger openings in the first three trials (Figure 6); and taller cats significantly more likely opted for alternative solutions than shorter ones. The width of the chest did not have significant association with this behavioral parameter ($\chi2$ (1) = 3.274; $p = 0.070$).

DISCUSSION

In this experiment we tested body size representation of companion cats with a similar setup to the one that was recently used in companion dogs.[30] While dogs slowed down and hesitated before they attempted to use an uncomfortably small opening, in the case of cats, we did not detect this change in their behavior before their attempt to go through even the narrowest openings. However, remarkably, cats showed hesitation both before they attempted to penetrate the shortest openings, and while they moved through it. This "aperture test" requires a decisive response from the participant *before* it would make contact with the opening as proof of its reliance on its mental representation of their own size and/or shape[40]. Based on this, we provided evidence that cats probably did not make detectable *a priori* own size-based decisions when they approach narrow but comfortably tall openings, even if these were narrower, than the chest width of the cat. At the same time, when the openings became shorter than the cats' height at the withers, they hesitated approaching them, and even tried to find alternative solutions to negotiate the panel. Remarkably, taller cats opted for this solution more often than the shorter subjects. This indicates that for cats, the vertical and horizontal dimensions of an aperture represent different importance. The passable, but uncomfortably short openings elicited noticeable hesitation in their approaching, thus indicates a reliance on body size representation in the cat. This result immediately raises further questions: (1) why did the cats choose a trial-and-error strategy for the tall but narrow apertures; and (2) why did the cats seemingly rely on their body-size awareness capacity in the case of the shortest openings?

Regarding the first question, we should see that some of those animals that recently provided positive evidence for their body size awareness, have a shared benefit of a cautious approach to a small aperture. Budgerigars[40] and bumblebees[23] were tested in such conditions where they had to fly through holes—where collisions during flight holds risk of injury. Therefore, in the case of these animals, the careful *a-priori* examination of the holes and the evasive posture while flying through were adaptive responses, most likely based on the representation of their own size and shape. With regard to dogs, as they usually move at a fast pace, and their body is less flexible than it is in cats, their response of slowing down[30] and looking for alternative solutions[31] before arriving to a too small opening, can also be regarded as a biologically relevant strategy, aided by body size awareness. However, such precautions would probably be superfluous for a cat, because of their specific features of locomotion, anatomy and space usage. Cats prefer environments with a complex structure (plenty of hiding places, vantage points, in other words: "obstacles"), where they usually move slowly and with great agility.[41] More importantly, their anatomy supports flexibility[42] and their free-floating, diminutive collarbones[43] allow them to squeeze themselves through very narrow gaps. We assume that this was the main reason why did cats readily approach the very narrow openings without apparent hesitation: for those narrow but tall openings represent no relevant trouble to negotiate, thus (probably aided by experience, i.e., body awareness) for them the uninterrupted approach was the biologically meaningful solution. Interestingly, very similar results were found by Khvatov et al.[28] who tested the body awareness in hooded crows. These birds preferred the tallest aperture when they had to choose from apertures of different height; however, they did not show preference for the largest hole when the three options differed only in their width. Khvatov and colleagues[28] also concluded that the anatomy of crows probably allows these birds to negotiate easier the tall-but-narrow than the wide-but-short openings. Cats are also aided by

Table 3. The parameters of the "same width" equipment

"Same width"	Opening 1	Opening 2	Opening 3	Opening 4	Opening 5
Height (cm)	43	37	28	20	15
Width (cm)	15	15	15	15	15

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Table 4. The list of behavioral units coded from the video footage ("original behavior"), and the resulting complex categories ("composite behavior") after combining them for the statistical analysis

Original behavior	Composite behavior (for analysis)
Stops before panel	
Sits before panel	Hesitation before arrival
Slows down before panel	
Stops during passing through	
Sits during passing through	Hesitation during passing through
Turns back during passing through	
Sniffing panel	
Looking for alternative solution	Alternative solutions
Attempts to jump over	
Jumps over panel	

their large and sensitive vibrissae, which are positioned on such locations of their head that the cat can detect nearby obstacles in closer encounters. Vibrissal sensation can compensate for the somewhat weaker vision in cats from closer distances or in poorly illuminated environments.[44,45] Therefore, it is possible that cats approached the narrow openings in our experiment without differential hesitation, and they could use their vibrissae to assess the suitability of the apertures before penetrating them. All in all, for cats, the adaptive response to a narrow opening would most probably be to approach it without hesitation. The next step is to actively try it, to see whether they can actually get through.

Regarding the second question, it is an interesting opportunity to compare the freshly obtained results of cats with the ones from ferrets—a burrow-dweller predator that often hunts also underground, thus for them penetrating holes can also be considered as an ecologically valid task.[29] In a series of cleverly designed experiments, Khvatov and colleagues[29] found that although ferrets always preferred the shortest route to the target (independently of how "comfortably sized" was the hole), in another scenario these animals showed a clear preference for the "passable" opening and disregarded the unsuitably narrow or short ones. As the apertures that the ferrets avoided had larger surface than the "passable" one did, one can argue that ferrets used some sort of knowledge about their own size (or shape) when they choose from among the possibilities. In the case of the cats, although they readily approached the tall and narrow openings, they showed more hesitation while approaching and during penetrating the shortest (but wide enough) openings. While the ferrets are elongated animals with relatively short legs, cats have longer legs, and their chest is rather narrow. The fact that cats showed no hesitation when they approached and penetrated the seemingly too narrow (but tall enough) openings may indicate that animals more easily consider an opening as passable if it fits to the given species' body proportions (i.e., ferrets: square or round hole; cats: upright rectangular opening). In the case of cats, their physical agility also

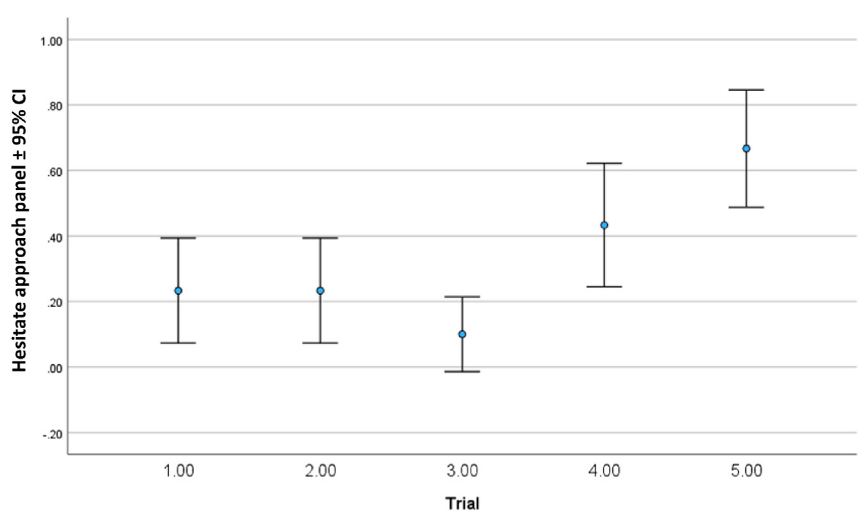

Figure 4. The combined hesitation variable consists of behaviors where the cats slowed down, stopped or sat, while they walked toward the opening of the panel

The openings were the same width, but incrementally became shorter across the trials. Hesitation was significantly affected by the decrease in opening height in trial 5. Error bars represent ±95% Confidence Interval (CI).

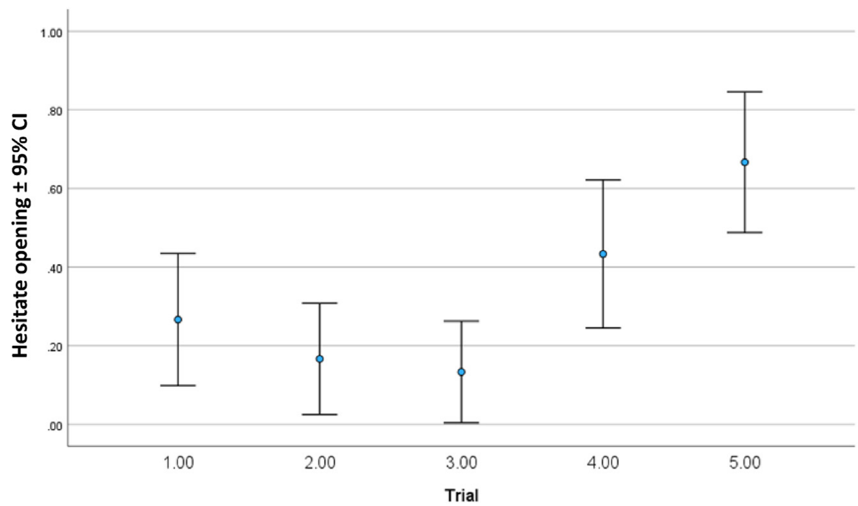

Figure 5. The combined hesitation variable consists of behaviors where the cats slowed down, stopped, sat, or turned back after they started to walk through the opening of the obstacle

The openings were the same width, but incrementally became shorter across the trials. Hesitation was significantly affected by the decrease in opening height in trials 4–5. Error bars represent ±95% Confidence Interval (CI).

can be used in their favor: they not only hesitated to approach the shortest openings, but also tried to avoid them by seeking out alternative solutions (i.e., jumping over the obstacle). As this behavior was shown by the taller cats more often, this can also be a sign that body size awareness plays a role in this case. Alternatively, larger cats may habitually opt for negotiating barriers by jumping.

In the case of the aperture tests, besides hesitation while approaching, *a priori* posture changes can also be the sign of body awareness-based decision making. It was found that human participants preemptively turn their shoulders, when they consider a door as being too narrow for walking through in a normal forward-facing posture.[24] In the case of cats, postural changes were not detected during their approach to the tall and narrow openings, the subjects tried to squeeze through immediately after their arrival to the cardboard panel. However, in the case of the shortest openings, the more frequent attempts to find alternative solutions can be considered as an analogy to postural changes, especially because otherwise the openings were still large enough to pass for the subjects.

Although cats approached and negotiated the tall and narrow openings without hesitation, they slowed down and hesitated when they went through the shortest openings. As these were always the last two in the series of five "same width" apertures, one could assume that

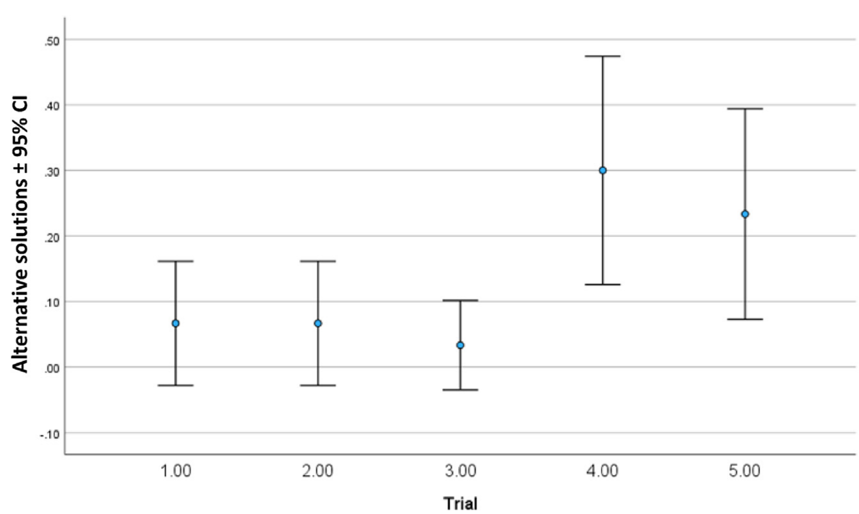

Figure 6. The combined "alternative solutions" variable consists of behaviors where the cats sniffed and examined the panel, or they attempted or managed to jump over it

The openings were the same width, but incrementally became shorter across the trials. Cats significantly more likely opted for alternative solutions in trials 4–5, where the openings were the shortest. Error bars represent ±95% Confidence Interval (CI).

maybe cats lost their motivation along the test trials. However, as we alternated the two testing conditions, and we haven't found similar hesitation in the case of the "same height" openings, fatigue/decreased motivation can be excluded from the explanations. The results indicate that cats may find it more difficult to crawl through a short opening than squeezing themselves through a tall but narrow one. Their specific anatomical features support this theory. Additionally, cats could behave more cautiously when they have to lower their posture in a very short opening, because they might feel more vulnerable in this situation.

Ecological validity ought to be considered as the gold standard in ethological research.[46] The modular concept of self-representation in nonhuman animal species has led to several discoveries where researchers showed that particular components of representing the self can provide advantages to various animals in specific contexts (e.g., mirror self-recognition in cleaning fish[47]; "body as an obstacle" in elephants[48]; body size awareness in bumblebees[23]). The results of this study have shown that cats did not react with *a priori* hesitation when they approached very narrow apertures that were smaller than the cat's corresponding chest width. Compared to dogs' reactions,[30,31] this implies that for cats, body size awareness could have smaller relevance as a mental mechanism when they solve specific aperture tasks. This "negative result" actually strengthens the assumption that particular modules of self-representation would evolve, if in the given species this mechanism would provide an advantage for adaptation[6,7]. Cats have evolved such anatomical features, and they move in their environment with such skills, which might favor the ad hoc trial-and-error methods over the *a priori* decision making. On the other hand, cats reacted with *a priori* hesitation and subsequent looking for alternative solutions when they found the openings as uncomfortably short. This indicates that for cats, the aperture dimensions are also relevant when they opt for relying on their body size awareness, most probably from anatomical and ecological (predator avoidance) reasons. Cats are mammals with well-developed complex cognition,[8,49] who have to negotiate various and often dynamic obstacles in their three-dimensional spatial environment. This strengthens the likelihood that cats should possess probably even multiple forms of body awareness (size, shape, and weight). In the future, we plan to conduct further biologically meaningful experiments on various aspects of cats' body awareness capacity in different challenging environments.

Limitations of the study

The results showed that cats without hesitation approached and negotiated small openings even half as wide as their chest. One may conclude that in the case of cats using the principally same experimental paradigm as we did earlier in dogs [30] was not a good choice because of the differences in the anatomy and spatial ecology of the two species. However, without even trying the aperture test in cats, we would not be able to tell whether cats truly behave differently compared to dogs in this context, or they rather rely similarly on their body-size awareness as dogs do. Based on our current findings, it is possible that for cats, the aperture test where the openings are tall but very narrow, is unsuitable for eliciting *a priori* decision making *against approaching* an opening. It can be because cats may not develop a representation of how wide they are (probably from ecological/anatomical reasons). It also can be that cats more readily use body weight representation (similarly to the brachiator orangutans,[21] when they negotiate thin branches in the canopy of trees.

Another limitation of the study was that unlike in the case of our previous experiment with dogs that has been run in standard laboratory environment, [30] cats had to be tested at their owner's home, where we had to compromise with the unique local conditions. Importantly, we could not set up a uniform starting distance between the start point and the openings on the cardboard panel. Because of this, we could not use latency of approach in the analysis.

RESOURCE AVAILABILITY

Lead contact

Further information and requests for resources should be directed to and will be fulfilled by the lead contact, Péter Pongrácz (peter.pongracz@ttk.elte.hu).

Materials availability

This study did not generate any new materials.

Data and code availability

- All behavioral data and descriptives of the participating cats that were used for the statistical analysis are included in a data file to the supplementary material (Table S1). These data are publicly available as of the date of publication.
- This paper does not report original code.
- Any additional information required to reanalyze the data reported in this paper is available from the lead contact upon request.

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AUTHOR CONTRIBUTIONS

Conceptualization, P.P.; methodology, P.P.; data curation, P.P.; formal analysis, P.P.; visualization, P.P.; writing—original draft, P.P.; writing—review and editing, P.P.; supervision, P.P.

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DECLARATION OF INTERESTS

The author declares no competing interests.

STAR★METHODS

Detailed methods are provided in the online version of this paper and include the following:

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SUPPLEMENTAL INFORMATION

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STAR★METHODS

KEY RESOURCES TABLE

REAGENT or RESOURCE	SOURCE	IDENTIFIER
Deposited data		
Raw behavioral data	This paper	Table S1
Software and algorithms		
IBM SPSS Statistics	IBM Corp.	Version 29.0
Solomon Coder	©Péter András	https://solomon.andraspeter.com/

EXPERIMENTAL MODEL AND STUDY PARTICIPANT DETAILS

Animal subjects

Cats were privately owned companion animals, recruited through advertisements on social media platforms. No incentive of any form was offered for participation. We initially included any cat to the test, regardless of their sex or breed, with the exception of large bodied breeds (such as Maine Coons) and obese cats. Cats had to be older than 8 months. We measured the following parameters in the case of each cat: height at the withers; width of the chest. We calculated the median value for the measurements (height = 28 cm; width = 11 cm), and in the case of each body measurement, we sorted the cats into two categories: small (lower values than the median) and large (equal or larger values than the median). We tested N = 38 cats at their owners' home. We had to exclude eight subjects, because they lost their motivation, or left the room where we conducted the experiment, or the owners did not follow the instructions. We included to the statistical analysis the data from N = 30 subjects. (27 domestic cats, 2 half-Persians, 1 Sphynx; Male/Female = 13/17; Mean age $\pm$SD = 3.51 $\pm$ 2.39 years, minimum 8 months, maximum 11 years).

Ethical approval

The applied procedure was fully non-invasive and reward-based. The study was approved by the Institutional Animal Welfare Committee (Eötvös Loránd University, Budapest), who checked and accepted the experimental method (Ref. no.: ELTE-AWC-016/2023). All tests were performed in accordance with the Hungarian regulations on animal experimentation and the Guidelines for the use of animals in research described by the Association for the Study of Animal Behavior (ASAB). The research did not involve human experimentation or the collection of sensitive data from the owners, thus human ethical approval was not necessary to be obtained in Hungary. We collected a written informed consent from every cat owner, who voluntarily participated with their cats in our test. Before the test, cat owners were informed about the use of data, and the aim of the experiment, the procedure, and the possibility that they could stop the test any time they felt that their cat would experience any sort of unacceptable stress.

METHOD DETAILS

Preliminary survey about the 'average cat size'

To make appropriate plans for the sizing of the openings in the experimental device, we ran a preliminary body size data collecting survey among owners of the targeted companion cat population. As domestic cats (especially moggies) show negligible size variability compared to dogs,[50] we assumed that averaging the collected size dimensions would allow us to design a device that would be applicable for each subject. We ran an online survey, where we requested the responding cat enthusiasts to measure and provide five different size parameters of their cats (Table 1). The dimensions were requested in centimeters, and we included a drawing to the questionnaire, which explained to the cat owners, how and which parameters should be measured (Figure 1). The only inclusion criterion was that the cats should be more than 8 months old. Forty participants completed the questionnaire. We excluded the data of obese cats and Maine Coons due to their disproportionally large dimensions compared to other cats. Thus, we could use the parameters of 32 cats, 17 males and 15 females. Except for two cats, each was spayed or neutered, and all of them were kept indoors only. We received data from 26 European shorthair (domestic) cats, 4 Siamese cats, 1 half-Persian and 1 Sphynx cat. We calculated the mean values of each of the five measurements, and based on these we designed the experimental equipment (Table 1).

Equipment

We created two types of equipment, each of them had a series of five openings of incrementally decreasing size for the cats to go through. Both versions of the equipment consisted of a large piece of strong (1 cm thick) cardboard, which was long enough to block a regular doorway in an apartment. The cardboard was strong enough that the passing through cats did not damage the structure. The two cardboard panels were 75 cm tall. The size of the openings was based on the average cat-sizes we calculated according to the preliminary survey. On one of the cardboard panels the width of the openings was the same size ('Same Width'), while on the other, the height of the openings was kept constant ('Same Height'). The height and width of the first (largest) opening in both cases was large enough for any of our subjects to walk through comfortably (i.e., the height was taller than the cat's height in standing position, measured to its ear tips; the width of the largest opening was broader than the chest of the cats). Beginning from the largest opening, the following four openings became either shorter or narrower. The last opening of the 'Same Width' panel was shorter than the cats' height in an upright laying position, measured to the ear tips; and the last two openings of the 'Same Height' panel were narrower than the width of the cats' head. The parameters of the openings on the two cardboard panels can be seen on Tables 2 and 3. Figures 2A and 2B show the outlay of the two types of equipment. During testing, only one opening was left open for the cats in a given trial. The other openings were covered with additional sheets of cardboard. The tests were recorded with a mobile phone camera (Samsung Galaxy A).

Testing method

The tests always took place indoors, at the cat owners' home. In this way, the cats were familiar with the environment, which is important as companion cats are notoriously hard to test away from their home.[14,51,52] Upon arrival to the cat owners' home, the experimenter attempted to establish friendly contact with the cat. Cats were only tested if they approached the experimenter, allowed her to pet them and took an offered treat from her. We requested the cats' owners not to feed their cats for at least 3 h before the test to enhance food motivation in the subjects. The general outlay of a testing scene can be seen on Figure 3. Before the tests began, we selected a suitable doorway in the flat where the equipment (cardboard with the openings) could be securely attached to the doorframe (with tape). Additionally, we needed at least 1.5 m clear distance on one side of the doorway, where the cat would be positioned on the starting point. The owner of the cat was positioned on the other side of the doorway, behind the cardboard. The experimenter stayed on the cat's side of the cardboard, and handled the camera. If it was possible, another member of the owner's family was asked to assist with the testing. Their task was to keep the cat at the starting point and then releasing the subject when the experimenter indicated it. If there was no assisting family member available, the experimenter handled the cat at the starting point. In this case the mobile phone with the camera was positioned on a suitable nearby furniture, approximately 1–1.2 m high, aimed at the panel in the doorframe and being able to record the cat's approach to it.

Each cat was tested with both types of cardboard panels ('Same Width' and 'Same Height'), 5-5 trials each, so altogether 10 trials. We tested half of the subjects with the constant height openings first, and the other half were tested with the constant width openings first. We allowed a 5-min break between the two conditions for the subjects (this time was suitable for swapping the cardboard panels in the doorway). We also had a 2-min break between the trials within the five-trial series, which was needed to reset the openings and return the cat to the starting point.

The cardboard was always placed to the bottom of the doorframe in such a way that the cat could only pass by going through the opening we left uncovered, or (rarely) by jumping over the cardboard. In each trial, only one opening was freely passable. Based on the method used by Lenkei et al.[30] with dogs, we always started with the largest opening on the given cardboard in trial 1, then we continued with the next size smaller, until in trial 5, the smallest opening was offered to the cat.

Each cat always started from the same place, which was, depending on the circumstances of the owner's home 1–1.5 m from the opening on the cardboard panel. The assisting family member (or in a few cases, the experimenter) gently restrained the cat at the start point, while the owner waited for the cat beyond the opening, 50 cm away from the cardboard. The owners motivated their cats with food or toy (depending of the cat's preference), and they were also instructed to call their cats, encouraging the subject to negotiate the opening. Owners were not allowed to reach through the opening while trying to encourage the cat. When the cat arrived to the owner's side of the cardboard, the owner gave it the reward. After this the cat was returned to the starting side and the next trial began. Cats were given a maximum 30s to solve the problem in each trial.

QUANTIFICATION AND STATISTICAL ANALYSIS

Cats' behavior was extracted from the videos with Solomon Coder (copyright: Péter András). We used the following ethogram (we measured frequency of occurrence in the case of each behavior).

- Stops before panel: The cat stops and stays in standing position right in front (within 10 cm) of the panel for more than 1s.
- **Sits before panel**: The cat sits down right in front (within 10 cm) of the panel.
- **Slows down before panel**: The cat does not stop in its forward locomotion while approaching the panel, but noticeably slows down. Momentary (less than 1s) stops were also included to the 'slowing down'.
- **Slows down during passing through**: The cat does not stop while penetrating the opening, but noticeably slows down. Momentary (less than 1s) stops were also included to the 'slowing down'.
- **Stops during passing through**: The cat enters the opening but pauses (for more than 1s) in it in standing position.
- **Sits during passing through**: The cat enters the opening but pauses (for more than 1s) in it, in sitting position.
- **Turns back during passing through**: The cat enters the opening but stops and turns back with its body, or at least with its head.
- **Sniffing panel**: While standing in front of the panel, the cat sniffs (examines from less than 1 cm) the panel, but does not move more than 2 steps in the meantime.
- **Looking for alternative solution**: The cat moves along the panel (within 10 cm from it), examines it by sniffing/looking.
- **Attempt to jump over**: The cat turns its head toward the upper edge of the panel.
- **Jumps over panel**: The cat successfully jumps over the panel to the other side.

As the originally coded behavior units occurred with a very low frequency in the case of the individual cats (usually once per trial) with many 'zero' occurrences, we combined them into three complex behavioral categories: (1) 'Hesitate approach'; (2) 'Hesitate opening'; (3) 'Alternative solution' (Table 4). 'Hesitate approach' was comprised of behaviors where the cats stopped, slowed down, or sat while they approached the obstacle (but before they arrived to it). 'Hesitate opening' was comprised of behaviors where the cats slowed down, stopped, sat, or turned back after they had started to walk through the opening of the obstacle. 'Alternative solution' contained those behaviors, where the cats tried other ways (instead of going through the opening) to get to the other side of the obstacle. The complex categories were binary variables: if in a given trial the cat did not show any of the behaviors that belonged to a particular category, the value was 0; however, if the cat performed any of the behaviors that belonged to a particular category, then it received value 1 in that trial. We identically evaluated the trials in both conditions (same height, or same width openings). Raw data used for statistical analysis can be accessed in the Table S1.

We used the SPSS 29 software for data analysis. We performed GEE (Generalized Estimating Equations with binary logistics) for both conditions, where the three complex behavioral categories were the dependent variables, trial (1–5) was the (repeated) variable, .chest width and height at the withers were independent factors, and cat ID served as random factor. Besides the main effects, we included the two-way interactions of the independent variables to the initial models. With backward model selection, then we removed the non-significant interactions, and in each case, we report the results of the simplest, final model. To compensate for the effect of multiple comparisons, we applied Bonferroni correction separately in both conditions, thus the modified α was 0.017 instead of 0.05.