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## PAPER

# Exploring the advantages of using artificial agents to investigate animacy perception in cats and dogs

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Supplementary material for this article is available [online](#)

## Abstract

Self-propelled motion cues elicit the perception of inanimate objects as animate. Studies usually rely on the looking behaviour of subjects towards stimuli displayed on a screen, but utilizing artificial unidentified moving objects (UMOs) provides a more natural, interactive context. Here, we investigated whether cats and dogs discriminate between UMOs showing animate vs inanimate motion, and how they react to the UMOs' interactive behaviour. Subjects first observed, in turn, the motion of an animate and an inanimate UMO, and then they could move freely for 2 min while both UMOs were present (two-way choice phase). In the following specific motion phase, the animate UMO showed one of three interactive behaviours: pushing a ball, a luring motion, or moving towards the subject (between-subject design). Then, subjects could move freely for 2 min again while the UMO was motionless. At the end, subjects were free to move in the room while the UMO was moving semi-randomly in the room. We found that dogs approached and touched the UMO(s) sooner and more frequently than cats, regardless of the context. In the two-way choice phase, dogs looked at the animate UMO more often, and both species touched the animate UMO more frequently. However, whether the UMO showed playing, luring or assertive behaviour did not influence subjects' behaviour. In summary, both species displayed distinctive behaviour towards the animate UMO, but in dogs, in addition to the physical contact this was also reflected by the looking behaviour. Overall, dogs were more keen to explore and interact with the UMO than cats, which might be due to the general increased stress of cats in novel environments. The findings indicate the importance of measuring multiple behaviours when assessing responses to animacy. The live demonstration using artificial agents provides a unique opportunity to study social perception in nonhuman species.

## 1. Introduction

Rapid recognition of animate entities is important for animals. Researchers identified several motion cues that, even if displayed by an inanimate object, can elicit the perception of the object as animate. Such motion cues elicit an orienting response in observers typically considered as an indication of perceiving the object as animate, or observers describe the object showing such motion as 'animate' (note that static cues, such as face-like stimuli, can also trigger animacy perception, but here we are only concerned with dynamic ones). These cues include motion characteristics such as sudden changes in speed and

direction (e.g. [1–3]), moving against gravity [4], maintaining consistent antero-posterior orientation during motion [5–8] and, when multiple objects are presented, temporal and spatial contingency in their motion (e.g. [9]). Animacy perception has been found in several species and self-propelledness seems to be an important indicator of animacy (e.g. [10–13]). However, methods regularly used to study the phenomenon may be challenging to apply to many non-human species or provide limited information.

Most studies rely on displaying specific stimuli on a screen (e.g. [1, 3, 14–16]). Applying videos instead of a live demonstration has the advantage of being highly controlled, invariable (e.g. [17]) and in the case

of animacy perception, it allows researchers to test how the specific cue in itself, without any disturbing factors, influences perception. However, it may not be the best approach in nonhuman species in general because projected images and videos are far from their natural set of visual inputs (for reviews about the use of video playbacks in studying animal behaviour, see [18, 19]).

The aspect that is measured most often in such studies is the visual preference of subjects between two stimuli (e.g. [10, 16, 20]). This provides important information about the spontaneous discrimination between animate and inanimate (motion) cues, and in some cases, only this behaviour can be assessed (e.g. in new-born human infants; [2, 10]). However, this approach has limitations. For example, recently, a series of studies has been carried out to investigate the perception of chasing motion in dogs (*Canis familiaris*), adult humans (*Homo sapiens*) and cats (*Felis silvestris catus*), relying on their visual preference, using video displays. In these displays geometric shapes were chasing each other on one side of the screen, while two others moved independently from each other on the other side [16, 21–23]. Results showed that both dogs and humans eventually turned their gaze towards the independent motion, likely due to the rapid perception of the chasing pattern [16, 22]. However, cats behaved differently, they first focussed their visual attention on the independent motion, and later increased their look towards the chasing pattern [23]. Authors also found that the frequency of gaze alternation between the patterns are similar in cats and dogs [23], but humans shift their gaze more often than dogs [22] (see also [24]). Differences between the three species are likely due to the differences in their ecological background and/or can be explained by specific perceptual mechanisms, but relying solely on their looking preferences does not provide sufficient information.

Further, the comparative studies showed that dogs looked at the screen less than humans [16], and both dogs and cats looked at the screen less over time [22, 23]. In recent studies, also a large percentage of dogs had to be excluded because they looked at the screen for less than 1 or 2 s in at least one of the trials ([23] and [21], respectively), and in the case of cats, it was difficult to keep them in one place [23]. General lack of visual interest towards the screen thus makes it difficult to measure spontaneous visual behaviour in nonhuman species in this setup. Also, it is difficult to investigate the underlying mental processes by relying solely on visual preferences (see also [25]), and it may lead to false conclusions. In the case of stimuli displayed on a screen, the use of an eye-tracker and measuring pupil dilation provide important insight about the phenomenon [26–28]. However, this method cannot be used with all species, and obtaining accurate data in nonhuman species often requires pretraining [29]. It is also unclear

how the perception of animacy influences subjects' behaviour in real situations.

Studying the implicit interactive behaviour of subjects can be important in revealing how perception influences subsequent actions. In adult humans (and maybe in nonhuman primates), it is possible to use interactive projected stimuli, thus the displays have the same advantage as a video demonstration, but different behaviours can be measured (see e.g. the *Don't-Get-Caught!* task in [30, 31]). In the case of nonhuman species, functionally similar methods should be explored, that is, paradigms relying on the active, ecologically relevant behaviour of the studied species, while keeping the stimuli as controlled as possible. There are some examples of similar studies from recent years. For example, in newly hatched chicks, researchers used the video display of stimuli, but instead of relying on looking behaviour alone, they tested whether subjects preferentially imprint on self-propelled objects [11] or they investigated the subjects' approach towards a stimulus containing motion characteristics described as animate vs inanimate motion [3]. In wild jackdaws (*Corvus monedula*), Greggor *et al* [32] studied the categorization of objects/entities as animate by testing their startle response, subsequent behaviour and whether they produce alarm calls upon the demonstration of a (stationary) model. However, these approaches either cannot be used with all species or do not allow the presentation of different motion cues (respectively).

Using robots in animal behaviour studies has become an interesting new direction (e.g. [33–36]) that can be also advantageous in the investigation of animacy perception. Applying moving artificial agents with unfamiliar embodiment, an unidentified moving object (UMO) [37, 38] allows researchers to present the specific motion as a live demonstration without the influence of the familiar physical appearance. It also provides high flexibility regarding the demonstration of the motion (e.g. context), while having high control and repeatability (see also [39]). Thus, several aspects of the procedure can be tailored to the studied species to maintain ecological relevance, while keeping functional similarity as close as possible between investigations. Further, this method facilitates the assessment of a wider range of behaviours which might be crucial in nonhuman species.

In the case of dogs, chasing perception was already studied using UMOs as moving objects [37]. The chasing and independent motion patterns were presented to subjects in turn, and dogs looked at the stimuli on average 75% of the time. Later, when one UMO from the chasing demonstration and one from the independent motion were presented, each with a ball in front of them, dogs approached the UMO from the chasing motion sooner than the other UMO, and also touched and grabbed the ball carried by this

UMO earlier. Thus, UMOs might provide a unique novel approach to studying animacy perception and its effect on subjects' behaviour in real situations, while having high control and invariability in the displayed stimuli in a more natural context.

In the present study, we wanted to explore the applicability of this approach in a different experimental setup using other motion cues, and to test the method with another nonhuman species. In the above-mentioned study, a chasing pattern was applied, which is a complex motion and thus may attract visual attention even without the perception of the specific pattern. Further, it is difficult to assess which motion cues in themselves (without the availability of the others) can elicit the perception in the case of chasing, and inherently there is contingency in the motion of the two objects that is missing when a single object/entity is presented (see also [3]). Thus, here we relied on simple motion cues that were (1) used in previous studies to test animacy perception (e.g. [3, 40]), and (2) simple depictions of the initiation of a specific interaction.

Both companion cats and dogs have daily interaction with a heterospecific agent but dogs are descendants of a group-living species (e.g. [41]) whereas the ancestors of cats are solitary-living (e.g. [42, 43]). Further, during development the two species have different experiences. For example, dogs are used to going to novel places and encounter many strangers [44], whereas cats have less experience of interacting with unfamiliar social partners and being exposed to novel environments (especially when kept indoors [45]). Thus, whether their behaviour suggests the perception of an artificial agent as animate and how they react to simple initiations of specific interactions, can provide information about how their ecological background and developmental experiences may influence perception and subsequent action. However, here we do not aim to disentangle the influence of the different underlying factors.

Previous findings support the idea that dogs engage in various social interactions with artificial agents (e.g. [46–48]), and are thus likely to recognize the UMO as a (potential) social partner (see also [37]). We have no information about cats in similar situations, but they are extremely efficient predators, and their play behaviour, including interactive object play with the owner, is likely linked to hunting behaviour skills [49, 50]. For example, a study showed that adult cats play longer and more intensely if the toy resemble a prey [49, 51]. Thus, it is possible that upon perceiving the UMO as animate, cats would display hunting behaviour (potential prey).

Here we investigated (1) whether companion cats and dogs discriminate between two UMOs, which display animate vs inanimate motion patterns; and (2) whether they show different behaviour towards a UMO depending on the specific action it carries out. Our aim was twofold: we aimed to compare

the behaviour of cats and dogs towards UMOs, and to establish a novel methodological framework to study animacy perception. We hypothesised that both cats and dogs prefer the animate UMO because they recognize it as a potential social partner or as a potential prey. We also expected that both species would avoid a UMO that shows assertive motion, whereas luring motion and initiation of play by the UMO would elicit interest towards the agent in both cats and dogs. We also hypothesised that dogs would engage more readily and more often with the UMO than cats, because they are interested in interacting with a novel social partner, whereas in the case of a luring motion cats would approach the UMO faster due to its perception of it as prey.

## 2. Methods

### 2.1. Subjects

#### 2.1.1. Cats

All tested cats were habituated to the test room on an earlier, separate occasion; the criteria for being ready for testing was that the cat should accept food from an unfamiliar female experimenter or play with her (see Uccheddu *et al* under review). We tested 27 cats, out of which four had to be excluded: one cat was distressed in the room and the test was terminated early, one cat was excluded because the robot lost the connection to the smartphone during the demonstration phase (movement was not fully demonstrated), one cat was excluded because the owner did not follow the instructions, and one cat because accidentally several animate cues were visible in the case of the inanimate UMO. Thus 23 cats were included in the statistical analyses (nine females; mean  $\pm$  SD age:  $4.2 \pm 3.4$  years) (see supplementary material 2).

#### 2.1.2. Dogs

We tested 29 relatively small dogs, the adult height of which was less than 40 cm high at the withers, to be comparable to cats. We excluded three dogs due to technical issues, three dogs because they looked at (at least) one of the demonstrations for less than 20% of the time, and one dog due to a procedural problem. Thus 22 dogs were included in the statistical analyses (16 females; mean  $\pm$  SD age:  $4.1 \pm 2.6$  years) (see supplementary material 2).

### 2.2. Artificial agent and experimental equipment

We used two Sphero Ollie robots (Sphero, Inc.;  $W \times L$ : 11.5 cm  $\times$  9 cm) as UMOs that were connected to the Sphero Edu app on two Android 8.0.0. smartphones via bluetooth. In the demonstration and specific motion phases (see below) the motion of the robots were preprogrammed using the 'Text Canvas' option in the app, using JavaScript. In the freestyle phase (see below) the UMO was controlled by Experimenter 1 (E1). There were slight differences in the motion

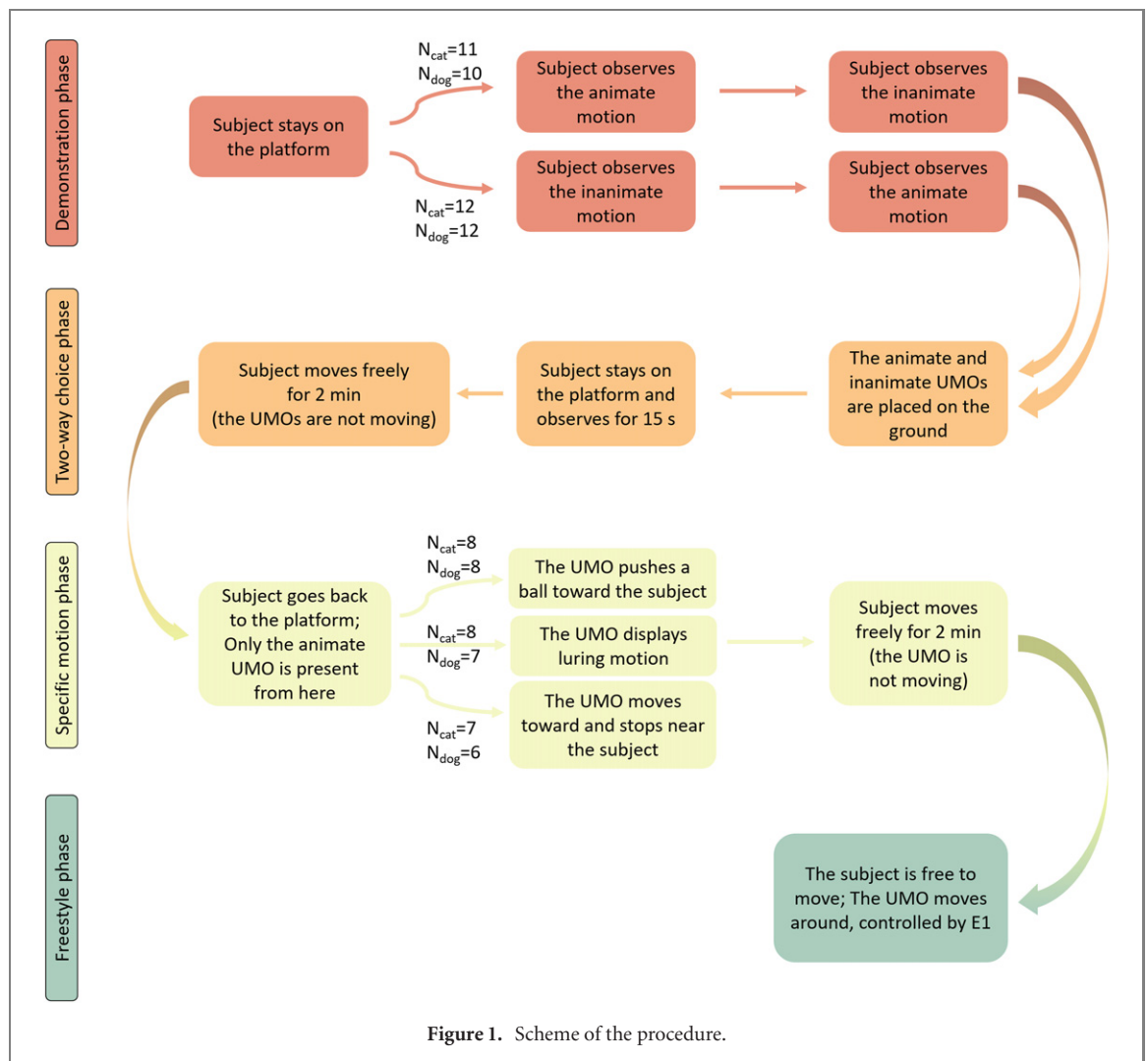


Figure 1. Scheme of the procedure.

of the two Ollie robots (e.g. with the same distance set for both UMOs, one of them moved a shorter distance than the other), thus we used one Ollie as animate, and the other Ollie as inanimate for all subjects. In all tests, one of the Ollies had the original white cover while the other the Ollie had the white parts covered with black self-adhesive wallpaper. We counterbalanced between subjects whether the black or white Ollie was the animate UMO.

Subjects were tested at the Department of Ethology, Eötvös Loránd University, Budapest, Hungary, in a 6.27 m  $\times$  5.4 m testing room, and tests were recorded with multiple cameras (see figure 2 and supplementary material 1). For the experimental equipment, see figure 2 and supplementary material 1.

### 2.3. Procedure

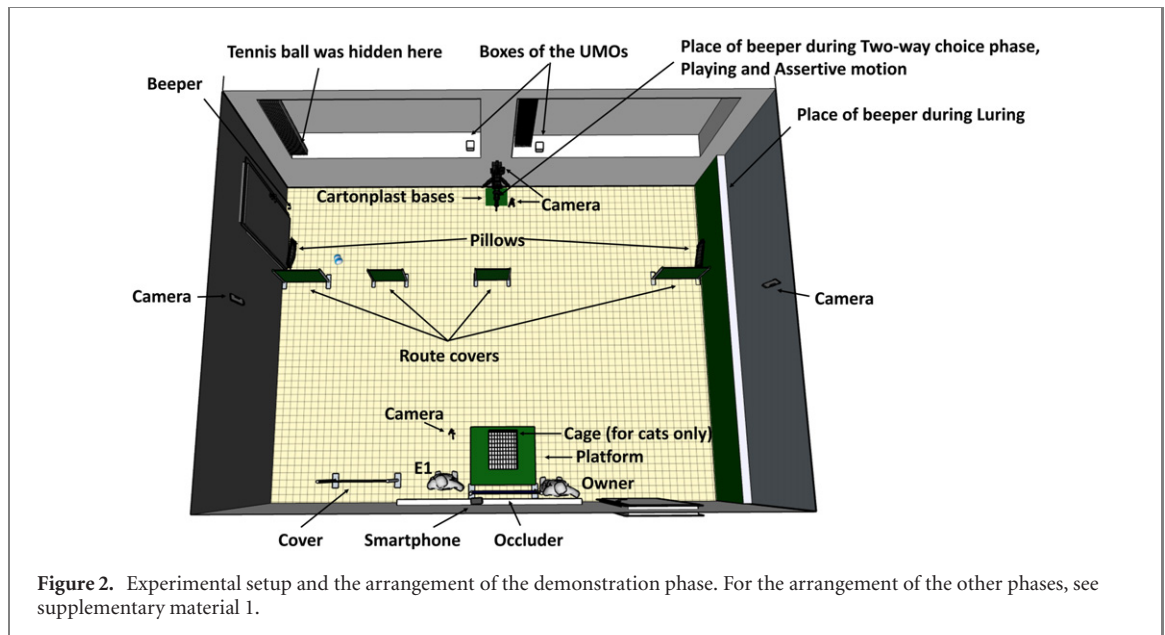
The experiment consisted of four phases following each other without breaks, in a fixed order (see figure 1): (1) *demonstration phase*: demonstrating the animate and inanimate motion to subjects; (2) *two-way choice phase*: both UMOs were placed on the ground, subjects could move freely in the room. After this, only the previously animate UMO was in

the room. (3) *Specific motion phase*: in a between-subject design, the UMO showed one of three actions; it pushed a ball to the subject or displayed luring motion or moved directly towards and stopped near the subject, after which subjects could move freely in the room. And (4) *freestyle phase*: both the subject and the UMO moved around the room (the UMO was controlled by the experimenter and moved semi-randomly).

#### 2.3.1. Demonstration phase

For the arrangement of the room, see figure 2 and supplementary material 1. The subject entered the room with the owner and E(s). Dogs were led on a leash, and cats were carried in their carrier box (the closed carrier was placed on the right side of the platform next to the wall). After entering, owners released the subject and it was able to explore the room for at least 3 min or until they sat or laid down after moving around the room. Following the exploration, cats were put inside a wire-meshed box placed on the platform (not their own carrier), and dogs were held by their owner in the front-middle of the platform (either in the owner's lap or the owner sat next to the dog). We allowed for this difference





**Figure 2.** Experimental setup and the arrangement of the demonstration phase. For the arrangement of the other phases, see supplementary material 1.

in watching the room because in our previous study [23], most owners had difficulties holding their cats in one place for 1–2 min, but most owners reported that their cat is used to (and prefers) being inside a box.

E1 put the UMO to its starting position and its smartphone on a narrow shelf behind the occluder, while the subjects' view of the room was blocked by a cover (figure 2). E1 stood on the right side of the platform. We used a beeping sound to call subjects' attention, and then E1 started the UMO's program. The animate/inanimate UMO started to move immediately.

Both UMOs displayed the same motion, but the inanimate UMO started and stopped closer to the walls. The UMOs started to move from rest, increased their speed (animate: after 140 cm, inanimate: after 170 cm), then decreased it again (after 240 cm) and stopped on the other side (animate: after 105 cm, inanimate: after 170 cm). Three seconds after the UMO stopped, it turned back and carried out the same motion, stopping at the original position. The exact measurements might slightly vary between subjects. In the case of the inanimate UMO, we placed the route covers in a way to cover the starting, stopping, and the moments of accelerations and decelerations. Thus, subjects could see the UMO moving with lower and higher speed, but without the motion cues that were reported to elicit animacy perception. In the case of the animate UMO, the route covers also covered parts of the motion path, but all self-propelled motion cues were visible (see supplementary material 1).

After the UMO stopped at its original position, E1 placed the cover in front of the subject, and changed the UMOs and smartphones. E1 also changed the positions of the route covers. E1 took the cover away and we repeated the same procedure as described

above. We counterbalanced between subjects whether the animate or inanimate motion was demonstrated first.

### 2.3.2. Two-way choice phase

After the second demonstration, E1 placed the cover in front of the subject. She placed the route covers next to the walls, and the beeper on the tripod in the middle (equal distances from the UMOs). E1 also placed the cartonplast bases 220 cm away from the dog and 140 cm away from each other, and put the UMOs to the middle of the bases (one UMO to each base) (see supplementary material 1); we counterbalanced the sides of the UMOs between subjects. E1 removed the cover, and E1/E2 called the subjects' attention using the beeping sound. For 15 s, the subjects stayed at their original places (to be able to measure looking behaviour towards the UMOs). After 15 s, the owner released the dog/E1 opened the cats' cage. Subjects could move freely in the room for 2 min. After the 2 min elapsed, the owner called the subjects back or went to the subject and took it back to the platform.

### 2.3.3. Specific motion phase

Dogs were held on the platform as during the demonstration phase. In the case of cats, we asked the owner whether it is better to put the cat back inside the cage or if they hold the cat for 2–3 min. E1 placed the cover in front of the subject again. In this phase, the UMO either pushed a ball towards the subject (playing,  $N = 8$  cats,  $N = 8$  dogs), displayed a luring motion (luring,  $N = 8$  cats,  $N = 7$  dogs) or moved directly towards the subject and stopped near it (assertive,  $N = 7$  cats,  $N = 6$  dogs).

E1 put the cartonplast bases back under the large tripod, and the inanimate UMO into its box (thus only the animate UMO was present from here). E1 put the animate UMO to its starting position: (a) 350 cm

away from the subject in case of the playing and assertive actions (the beeper stayed on the tripod), or (b) 440 cm away from the subject next to the wall on the right hand side, in case of the luring action (the beeper was placed on a narrow shelf next to the UMO's starting position) (see supplementary material 1). In the case of playing, E1 also put a ball in front of the UMO. E set the 0° direction of the UMO in the app. E1 placed the smartphone in the usual place behind the occluder, and took away the cover. E1/E2 called the subjects' attention with the beeping noise and E1 initiated the preprogrammed motion of the UMO. In the case of playing action, the UMO moved forward about 125 cm while pushing the ball. In the case of the luring action, the UMO moved on a semi-circular route, going near the subject and then moving away again, while continuously increasing its speed until stopping. In the case of the assertive action, the UMO moved 110 cm forward, stopped for a moment, and then moved another 160 cm forward. For a demonstration of the motions, see supplementary material 1. Owners were instructed to release the subject (a) when the UMO pushed the ball (playing), (b) when the UMO moved pass the middle line (the closest point to the dog; luring), or (c) when the UMO started to move again after the brief stop (assertive). Subjects could move freely in the room for 2 min, while the UMO was motionless.

#### 2.3.4. Freestyle phase

After the 2 min elapsed, the UMO started to move, controlled by E1. The UMO started to move slowly to not startle the subject. The UMO's motion was semi-random, that is, it did not move in a predetermined route with predetermined speed, but its motion included speed changes, turns, stops and starts of motion, and approached the subject within 0.5 m at least once (except for three cats and one dog that avoided the UMO during the entire test, thus E1 kept a distance with the UMO from them). The UMO's motion depended on the subjects' reaction. In the case where the subject avoided the UMO (keeping constant distance and moving away when the UMO went closer), the UMO kept a distance from the subject and moved more slowly. In the case that the subject engaged in playful behaviour with the UMO, the UMO moved faster and went closer to the subject. The length of the phase varied between subjects based on subjects' reactions to the UMO (mean (s)  $\pm$  SD; cats, 178.15  $\pm$  61.66; dogs, 136.25  $\pm$  40.66).

## 2.4. Data analyses

All tests were recorded and subjects' behaviour was analysed with Solomon Coder 19.08.02 (developed by András Péter: <http://solomoncoder.com>). Data were analysed by R software version 4.1.2 [52] in RStudio version 1.4.1717 [53]. Inter-coder reliabilities were

carried out on a random subsample (20% of dogs and 20% of cats). Inter-coder reliabilities were acceptable for all variables; see supplementary material 1.

In all analyses described below (except for linear models (LM)), we carried out backward model selections using the drop1 function; selection was based on the likelihood ratio test (LRT). In the case of LM, we carried out backward model selection by comparing the models using the lrtest function ('lrtest' package [54]). The LRT of nonsignificant variables are reported before their exclusion from the models. For significant explanatory variables in the final models, we carried out pairwise comparisons ('emmeans' package [55]) and we report contrast estimates ( $\beta \pm$  SD). In the case of mixed models, we included the ID of subjects as random variables to control for within subject measurement.

#### 2.4.1. Demonstration phase

The duration that a subject looked at the UMO was measured from the moment the animate/inanimate UMO started to move, until it stopped at the original location. Considering that the demonstration time slightly varied, we analysed the proportion of looking duration (looking duration divided by the length of the given demonstration). Looking proportion was analysed using the linear mixed model (LMM; 'lme4' package [56]). Residuals of the model were normally distributed (Kolmogorov–Smirnov test:  $D = 0.071$ ,  $p = 0.732$ ). We estimated the fixed effects of species (dog vs cat), trial (trial 1 vs 2), demonstration (animate vs inanimate), whether there was an error in the demonstration (e.g. single visible speed change in the inanimate motion), and whether animate or inanimate motion was presented first.

#### 2.4.2. Two-way choice phase

Before the subject was released, we measured the subjects' looking duration towards the animate and inanimate UMOs starting from the beeping sound for 15 s. Looking duration was analysed using LMM. Residuals of the model were normally distributed after Tukey's ladder of powers transformation ('rcompanion' package [57]; lambda 0.4) (Kolmogorov–Smirnov test:  $D = 0.104$ ,  $p = 0.287$ ). We tested whether dogs or cats were looking longer at the animate or inanimate UMO (species  $\times$  animacy), the UMO on the left or right side (species  $\times$  side) or the black or white UMO (species  $\times$  colour). We also tested whether the looking duration towards the animate or inanimate UMO was influenced by which demonstration subjects' observed first (UMO  $\times$  FirstDemo) or whether there was an error in the demonstration (UMO  $\times$  DemoError).

After the subject was released, we measured the latency of first choice (when subjects moved inside the area of the cartonplast base) and first touch of the UMO (first choice and first touch were analysed in separate models). We indicated if the event

happened with a 1. In the case the event did not happen, it was indicated with a 0 and we used the maximum time as latency. Considering that the animacy, side and colour of the first chosen/touched UMO could be defined only in the case of subjects that chose/touched one of the UMOs, we had two models for each behaviour. First, we carried out Cox regression ('survival' package [58, 59]) on the data of all subjects, testing whether there was a difference between species in the latency to choose/touch any of the UMOs (species). Following this, we carried out Cox regression on the data of subjects that chose/touched at least one of the UMOs. We tested whether cats ( $N = 10$ ) or dogs ( $N = 20$ ) chose sooner the animate or inanimate UMO (species  $\times$  animacy), the left or right UMO (species  $\times$  side), or the black or white UMO (species  $\times$  colour). We also tested whether the motion pattern was demonstrated first, or whether there was an error in the demonstration that influenced the latency of the first choice of the animate or inanimate UMO (animacy  $\times$  FirstDemo and animacy  $\times$  DemoError, respectively). Regarding the latency of first touch, only five cats touched any of the UMOs, thus only the data of dogs ( $N = 18$ ) were analysed here (for the result, see supplementary material 1). We tested whether the motion pattern demonstrated first, or whether there was an error in the demonstration influenced the latency of first touch of the animate or inanimate UMO (animacy  $\times$  FirstDemo and animacy  $\times$  DemoError, respectively). We also estimated the effect of side (left vs right) and colour (black vs white) on the latency of first touch.

During the 2 min free moving, we measured the frequency of looking at, approaching (within 0.5 m) and touching the UMOs. The frequency of looking at the UMOs was analysed using LMM. Residuals of the model were normally distributed (Kolmogorov–Smirnov test:  $D = 0.074$ ,  $p = 0.726$ ). Regarding the frequency of approaching and touching the UMOs, based on the AIC values (model comparison with ANOVA) Poisson distribution fit both data best ( $AIC_{\text{approach}} = 237.88$ ;  $AIC_{\text{touch}} = 191.50$ ; models with the lowest AIC value were kept and a model was considered better whenever  $\Delta AIC$  was  $\geq 2$ ). We carried out the generalized linear mixed model (GLMM; 'lme4' package) to analyse the frequency of approach and touch. In all three models, we tested whether cats and dogs looked at/approached/touched more often the animate or inanimate UMO (species  $\times$  animacy), the UMO on the left or right side (species  $\times$  side), or the black or white UMO (species  $\times$  colour). We also tested whether the animate motion was demonstrated first or the presence of errors in the demonstration had an effect on the frequency of looking at, approaching and touching the animate or inanimate UMO (animacy  $\times$  FirstDemo and animacy  $\times$  DemoError, respectively).

#### 2.4.3. Specific motion phase

We measured the latency to look, approach (within 0.5 m) and touch the UMO. The presence of the action was denoted with a 1, and its absence with a 0. We analysed the data using Cox regression. We estimated the effect of species and type of action (species  $\times$  type). In the case of playing action, we also measured the latency to touch the ball; here we estimated the effect of species using Cox regression.

We also measured the frequency of looking at, approaching and touching the UMO during the 2 min free movement. Frequency of looking at the UMO was analysed using the linear model (LM). Residuals of the model were normally distributed (Kolmogorov–Smirnov test:  $D = 0.062$ ,  $p = 0.998$ ). Based on the AIC values (model comparison with ANOVA) Poisson distribution fit the frequency of approach data best ( $AIC_{\text{approach}} = 105.24$ ), and negative binomial distribution fit the frequency of touch data best ( $AIC_{\text{touch}} = 85.50$ ) (models with the lowest AIC value were kept and a model was considered better whenever  $\Delta AIC$  was  $\geq 2$ ). We carried out a generalized linear model (GLM) to analyse the frequency of approach and touch. In all three models, we estimated the effect of species and type of action (species  $\times$  type).

#### 2.4.4. Freestyle phase

We measured the duration of looking at the UMO from the moment the UMO started to move until the end of the phase. Considering that the length of this phase varied between subjects, we analysed the proportion of looking at the UMO (looking duration divided by the length of the phase). Proportion of looking at the UMO was analysed using LM. Residuals of the model were normally distributed (Kolmogorov–Smirnov test:  $D = 0.077$ ,  $p = 0.958$ ). We estimated the effect of species and the type of action the UMO carried out in the previous phase (species  $\times$  type).

We also measured the frequency of approaching the UMO by the subject, that is, when the subject and UMO got within 0.5 m of each other. We discriminated whether the subject moved towards the UMO or the UMO towards the subject when they got near each other (if they moved towards each other, we counted it as 'approach by subject'). We also measured the frequency of touching the UMO. Due to the differences in the length of this phase between subjects, we analysed a relative frequency, that is, we divided occurrence by the length of the phase. The relative frequency of approaching and touching the UMO were analysed using LM. Residuals of the models were normally distributed after Tukey's ladder of powers transformation (lambda: approach, 0.425; touch, 0.3) (Kolmogorov–Smirnov test: approach,  $D = 0.133$ ,  $p = 0.430$ ; touch,  $D = 0.140$ ,  $p = 0.371$ ).

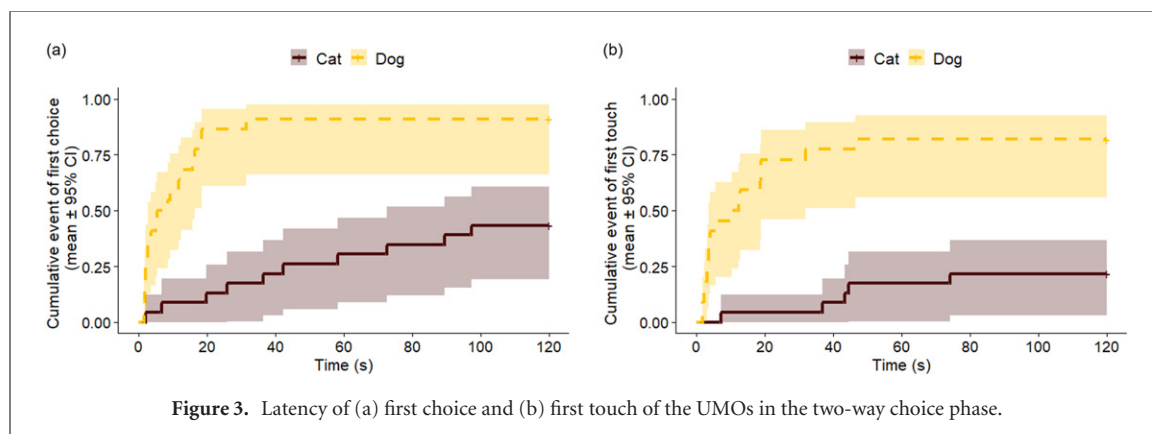


Figure 3. Latency of (a) first choice and (b) first touch of the UMOs in the two-way choice phase.

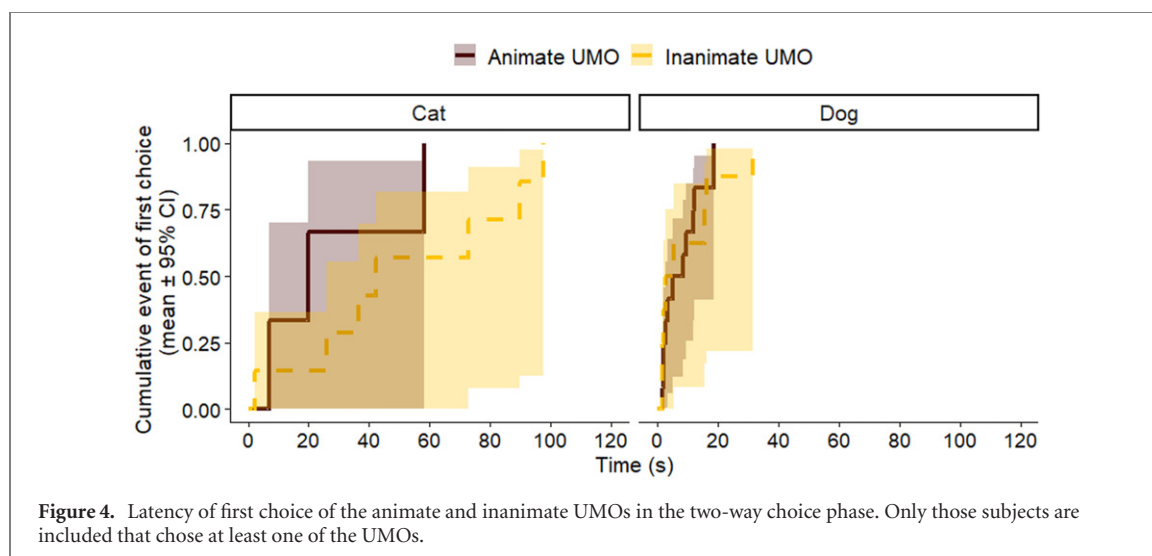


Figure 4. Latency of first choice of the animate and inanimate UMOs in the two-way choice phase. Only those subjects are included that chose at least one of the UMOs.

We estimated the effect of species and the type of action the UMO carried out in the previous phase (species  $\times$  type).

### 3. Results

Due to the volume of the data analyses, we only report the main results here to improve clarity. For all other results, see the supplementary material 1.

#### 3.1. Demonstration phase

We did not find a difference between cats and dogs regarding the proportion of time spent looking at the demonstrations, and subjects did not look for longer at either of the demonstrated motions (LMM, LRT: species,  $\chi_1^2 = 0.076$ ,  $p = 0.783$ ; demonstration,  $\chi_1^2 = 0.107$ ,  $p = 0.744$ ) (see also supplementary material 1). However, subjects looked for longer at the demonstration that was presented first (trial,  $\chi_1^2 = 4.995$ ,  $p = 0.025$ ; trial 1 vs trial 2,  $\beta \pm SE = 0.046 \pm 0.020$ ,  $p = 0.023$ ). Whether the animate or inanimate UMO was presented first, or whether there was an error in the demonstrated motion, did not influence the proportion of time spent looking at the UMOs (FirstDemo,  $\chi_1^2 = 1.909$ ,  $p = 0.167$ ; DemoError,  $\chi_1^2 = 1.744$ ,  $p = 0.187$ ).

#### 3.2. Two-way choice phase

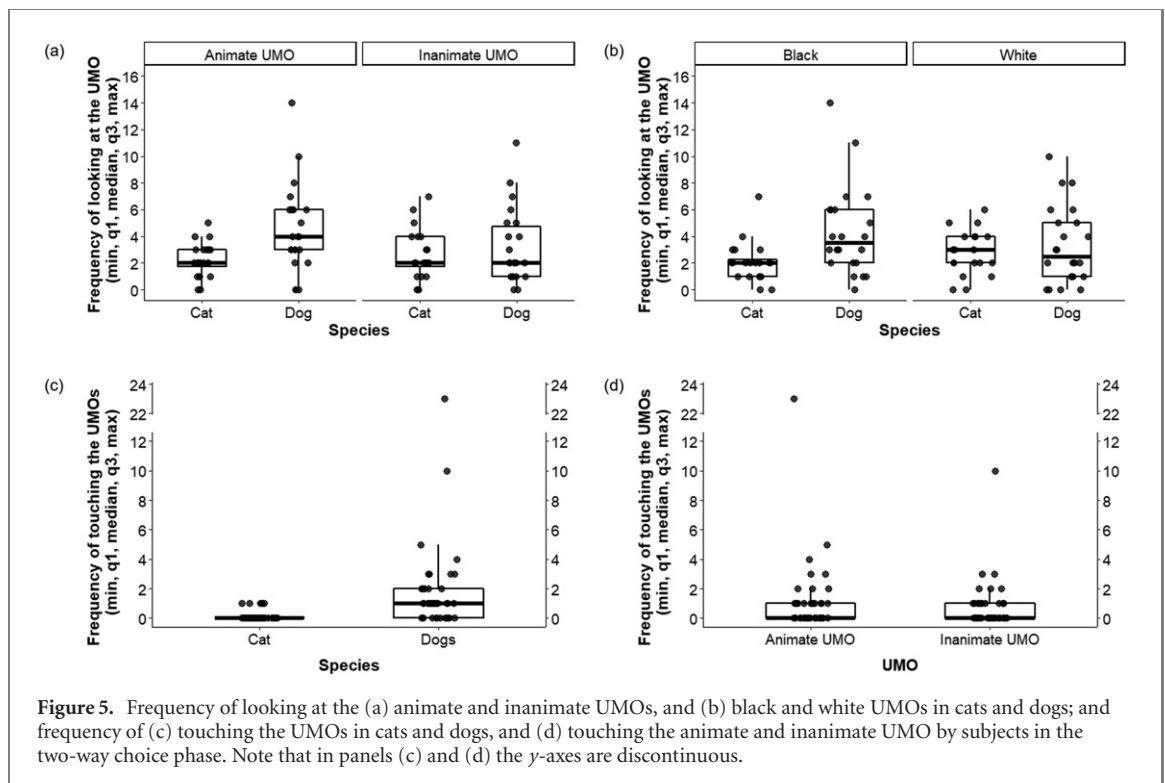
##### 3.2.1. Proportion of time spent looking at the UMOs before release

Neither cats nor dogs looked for longer at one of the UMOs during the 15 s long observation (LMM, LRT: species  $\times$  animacy,  $\chi_1^2 = 0.012$ ,  $p = 0.912$ ; species  $\times$  side,  $\chi_1^2 = 0.242$ ,  $p = 0.623$ ; species  $\times$  colour,  $\chi_1^2 = 1.218$ ,  $p = 0.270$ ). Whether previously the UMO carried out animate or inanimate motion also did not influence subjects' looking duration toward the UMOs (animacy,  $\chi_1^2 = 0.022$ ,  $p = 0.882$ ). However, we found that, overall, dogs looked for longer than cats at the UMOs (species,  $\chi_1^2 = 9.853$ ,  $p = 0.002$ ; cat vs dog,  $\beta \pm SE = -0.595 \pm 0.184$ ,  $p = 0.002$ ), and subjects looked for longer at the UMO on the right hand side, which is the side that was revealed first when the cover was removed (side,  $\chi_1^2 = 6.215$ ,  $p = 0.013$ ; left vs right,  $\beta \pm SE = -0.374 \pm 0.146$ ,  $p = 0.014$ ). The colour of the UMOs did not influence subjects' looking duration (colour,  $\chi_1^2 = 0.017$ ,  $p = 0.898$ ).

##### 3.2.2. Latency of first choice and touch after release

Overall, dogs chose (Cox regression, LRT, choice: species,  $\chi_1^2 = 20.986$ ,  $p < 0.001$ ; cat vs dog,  $\beta \pm SE = -1.820 \pm 0.412$ ,  $p < 0.001$ ) and touched (Cox





regression, LRT, touch: species,  $\chi_1^2 = 20.854$ ,  $p < 0.001$ ; cat vs dog,  $\beta \pm SE = -2.090 \pm 0.516$ ,  $p < 0.001$ ) the first UMO sooner than cats (figure 3).

Regarding only subjects that chose at least one of the UMOs, neither cats nor dogs chose the animate or inanimate UMO sooner than the other UMO (Cox regression, LRT, choice: species  $\times$  animacy,  $\chi_1^2 = 2.359$ ,  $p = 0.125$ ; animacy,  $\chi_1^2 = 1.907$ ,  $p = 0.167$ ) (figure 4). However, the latency of first choice of the UMOs was shorter in the case of dogs than in the case of cats (species,  $\chi_1^2 = 15.945$ ,  $p < 0.001$ ; cat vs dog,  $\beta \pm SE = -2.190 \pm 0.608$ ,  $p < 0.001$ ).

### 3.2.3. Frequency of looking at, approaching and touching the UMOs after release

Regarding the frequency of looking at the UMOs, we found significant two-way interaction between the species and previous animacy of the UMOs (LMM, LRT: species  $\times$  animacy,  $\chi_1^2 = 10.889$ ,  $p < 0.001$ ). Dogs looked at the animate UMO more frequently than at the inanimate UMO, but no difference was found in the case of cats (animate vs inanimate: dogs,  $\beta \pm SE = 1.360 \pm 0.363$ ,  $p < 0.001$ ; cats,  $\beta \pm SE = -0.400 \pm 0.381$ ,  $p = 0.300$ ) (figure 5(a)). We also found that dogs looked at the animate UMO more frequently than cats, but there was no difference between species in the case of the inanimate UMO (cat vs dog: animate UMO,  $\beta \pm SE = -2.250 \pm 0.764$ ,  $p = 0.005$ ; inanimate UMO,  $\beta \pm SE = -0.486 \pm 0.764$ ,  $p = 0.527$ ).

We also found significant two-way interaction between the species and the colour of the UMOs (LMM, LRT: species  $\times$  colour,  $\chi_1^2 = 10.204$ ,  $p = 0.001$ ) for the frequency of looking at the UMOs.

Pairwise comparison revealed that dogs looked at the black UMO more often than the white one, but there was no difference in the case of cats (black vs white: cats,  $\beta \pm SE = -0.700 \pm 0.381$ ,  $p = 0.074$ ; dogs,  $\beta \pm SE = 1.000 \pm 0.363$ ,  $p = 0.009$ ) (figure 5(b)). We also found that dogs looked at the black UMO for longer than cats, but no difference between the species was found in the case of the white UMO (cat vs dog: black,  $\beta \pm SE = -2.218 \pm 0.764$ ,  $p = 0.006$ ; white,  $\beta \pm SE = -0.518 \pm 0.764$ ,  $p = 0.501$ ).

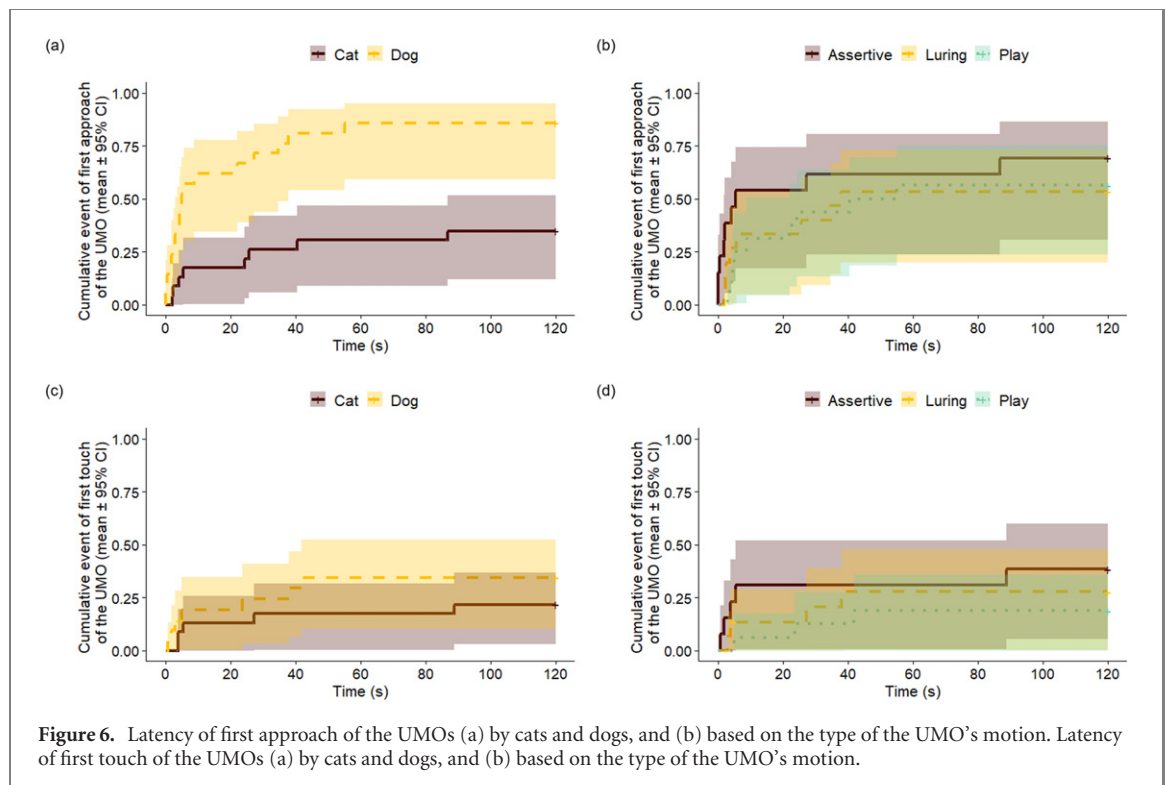
Neither cats nor dogs approached either the animate or inanimate UMO more often (GLMM with Poisson distribution, LRT: species  $\times$  animacy,  $\chi_1^2 = 2.005$ ,  $p = 0.157$ ; animacy,  $\chi_1^2 = 0.654$ ,  $p = 0.419$ ). But overall, dogs approached the UMOs more frequently than cats (species,  $\chi_1^2 = 21.744$ ,  $p < 0.001$ ; cat vs dog,  $\beta \pm SE = -1.410 \pm 0.289$ ,  $p < 0.001$ ).

We found that subjects touched the animate UMO more often than the inanimate UMO (GLMM with Poisson distribution, LRT: animacy,  $\chi_1^2 = 5.002$ ,  $p = 0.025$ ; animate vs inanimate UMO,  $\beta \pm SE = 0.481 \pm 0.218$ ,  $p = 0.028$ ) (figure 5(d)), and that overall dogs touched the UMOs more frequently than cats (species,  $\chi_1^2 = 24.841$ ,  $p < 0.001$ ; cat vs dog,  $\beta \pm SE = -2.690 \pm 0.571$ ,  $p < 0.001$ ) (figure 5(c)).

## 3.3. Specific motion phase

### 3.3.1. Latency of first approach and first touch of the UMO

We found that dogs approached the UMO sooner than cats (Cox regression, LRT: species,  $\chi_1^2 = 13.367$ ,  $p < 0.001$ ; cat vs dog,  $\beta \pm SE = -1.510 \pm 0.434$ ,  $p < 0.001$ ) (figure 6(a)), but the latency of approach was not influenced by whether the UMO pushed a



ball toward the subject, displayed a luring motion or moved directly toward the subject (species  $\times$  type,  $\chi^2_2 = 0.517$ ,  $p = 0.772$ ; type,  $\chi^2_2 = 2.404$ ,  $p = 0.301$ ) (figure 6(b)).

Regarding the latency of first touch of the UMO, we did not find a difference between species or depending on the type of action the UMO displayed (Cox regression, LRT: species  $\times$  type,  $\chi^2_2 = 3.602$ ,  $p = 0.165$ ; species,  $\chi^2_1 = 0.960$ ,  $p = 0.327$ ; type,  $\chi^2_2 = 1.713$ ,  $p = 0.425$ ) (figures 6(c) and (d)).

### 3.3.2. Frequency of looking at, approaching and touching the UMO

Regarding the frequency of looking at the UMO, we did not find a difference between species or the type of action the UMO displayed (LM, LRT: species  $\times$  type,  $\chi^2_2 = 2.556$ ,  $p = 0.279$ ; species,  $\chi^2_1 = 2.075$ ,  $p = 0.150$ ; type,  $\chi^2_2 = 0.084$ ,  $p = 0.959$ ).

We found that dogs approached the UMO more frequently than cats (GLMM with Poisson distribution, LRT: species,  $\chi^2_1 = 15.646$ ,  $p < 0.001$ ; cat vs dog,  $\beta \pm SE = -1.410 \pm 0.398$ ,  $p < 0.001$ ). The type of action the UMO displayed before did not influence the frequency of approaching the UMO (species  $\times$  type,  $\chi^2_2 = 1.367$ ,  $p = 0.505$ ; type,  $\chi^2_2 = 0.563$ ,  $p = 0.755$ ).

Analyses also showed that dogs touched the UMO more frequently than cats (GLMM with negative binomial distribution, LRT: species,  $\chi^2_1 = 4.684$ ,  $p = 0.030$ ; cat vs dog,  $\beta \pm SE = -1.370 \pm 0.657$ ,  $p = 0.037$ ). The type of action the UMO displayed before did not influence the frequency of touching the UMO (species  $\times$  type,  $\chi^2_2 = 3.010$ ,  $p = 0.222$ ; type,  $\chi^2_2 = 4.767$ ,  $p = 0.092$ ).

### 3.4. Freestyle phase

Regarding the proportion of time spent looking at the UMO, we did not find a difference between species, nor was it based on the type of action the UMO had carried out before (LM, LRT: species  $\times$  type,  $\chi^2_2 = 1.707$ ,  $p = 0.426$ ; species,  $\chi^2_1 = 0.213$ ,  $p = 0.645$ ; type,  $\chi^2_2 = 2.515$ ,  $p = 0.284$ ). However, we found that dogs approached and touched the UMO more often than cats (LM, LRT, approach: species,  $\chi^2_1 = 16.144$ ,  $p < 0.001$ ; cat vs dog,  $\beta \pm SE = -0.127 \pm 0.031$ ,  $p < 0.001$ ; LM, LRT, touch: species,  $\chi^2_1 = 11.406$ ,  $p < 0.001$ ; cat vs dog,  $\beta \pm SE = -0.159 \pm 0.045$ ,  $p = 0.001$ ). The frequency of approach, nor touch, was influenced by whether the UMO pushed a ball toward the subject, displayed a luring motion or moved directly toward the subject (approach: species  $\times$  type,  $\chi^2_2 = 0.987$ ,  $p = 0.611$ ; type,  $\chi^2_2 = 5.938$ ,  $p = 0.051$ ; touch: species  $\times$  type,  $\chi^2_2 = 3.271$ ,  $p = 0.195$ ; type,  $\chi^2_2 = 1.433$ ,  $p = 0.489$ ).

## 4. Discussion

In general, dogs approached and touched the UMO(s) more readily and more frequently than cats, indicating that dogs are more keen to explore and interact with the artificial agent, independent of the context. When relying solely on the looking behaviour of subjects (before they could approach them), we did not find a visual preference towards the animate (or inanimate) UMO in cats or in dogs. However, when they were free to move around the room for a longer time, dogs looked at the passive animate UMO more frequently than at the passive inanimate

UMO, and importantly, both species touched the animate UMO more often than the inanimate one. Thus, although looking behaviour before the subject was allowed to move in the room would indicate no discrimination between the UMOs based on their animacy, differentiation between the animate and inanimate UMOs could be detected in the frequency of looking at the UMOs when dogs were free to move, and in the frequency of physical contact in the case of both species. Thus, we suggest that experimental approaches assessing a wider range of behaviours may be important in the study of the phenomenon in nonhuman species.

Our results also showed that dogs looked at the black UMO more frequently than at the white UMO. Based on the present study, especially because the preference was not detected in any other behaviours measured, it is not clear what caused their relative preference to this UMO. Future studies should explore the role of colour of the moving agents in similar studies.

In the case of the specific actions carried out by the previously animate UMO, we expected subjects to show interest in the playing and luring UMO, and to avoid the assertive one. However, we did not find a difference in the behaviour of either species towards the UMOs. This may suggest that subjects did not recognize the specific action of the UMO, but several alternative explanations may account for our result. First, here we had a between-subject design and thus the subject number was low in the different groups. Second, the specific action presented by the UMO could be too short or the motion did not accurately represent the planned behaviour (e.g. the assertive motion was not assertive). Third, although the UMO displayed an interactive behaviour, when the subject was released, the UMO was stationary which could reduce the interest in interacting with it. Fourth, although we measured several different behaviours, it is possible that including the assessment of other behaviours could provide further information (e.g. body posture while approaching the UMO).

We found a difference between cats and dogs across contexts, regarding their readiness to interact with the UMO(s). Considering that several cat subjects did not even approach or touch the UMO(s), it is possible that they were afraid of the novel moving agent. Cats tend to display stress-related behaviours in novel environments including, for example, a lack of exploration, freezing or crawling (see e.g. [60–62]). Thus, prior to the experiment, on a separate occasion, we habituated them to the test room. All cats tested in the present study had engaged in interaction with a stranger in the test room, accepting food from her or playing with her (Uccheddu *et al* under review). These behaviours have been reported to occur in nonhuman species only when the level of fear is low [63]. However, we cannot exclude that the novelty

of the environment (although habituated) and the novel agent together elicited stress in cats. Regarding habituation, it should be noted that almost 60% of cats could not be habituated to the novel environment on the first occasion, and even overall during the maximum of three occasions, only 60% of cats accepted food from and played with both the owner and the experimenter (Uccheddu *et al* under review). In the same study, all invited dogs were habituated to the test room during their first time in the test room. Thus, to provide a more natural context to cats, we suggest to test their behaviour towards artificial agents in their home environment.

We suggest that in the study of motion perception, testing both subjects' looking behaviour when the stimulus is displayed on a screen and using artificial agents in live demonstrations can provide important insights about the phenomenon. The use of video projection can facilitate the identification of important elements in a well-controlled context, especially when combined with eye-tracking and pupillometry [26–28]. The application of artificial agents as moving objects further allows us to test the effect of these in real situations and to test the influence of the perception on the behaviour that provides more information about its real-life function (see also [37]).

In previous studies applying video projection, chasing motion was used to test the animacy/chasing perception of dogs and cats. However, considering that they showed relatively short visual interest even towards the more complex, ecologically relevant motion pattern (chasing) when displayed on a screen [16, 21–23], studying the influence of more simple cues would be difficult. It is important to note that, although in the present study both species looked less at the UMO during the second demonstration, still they followed the motion about 80% of the time. Further, our results show that preference towards the UMO based on its animacy could not be detected in all behaviours, including when the subjects could only passively look at the UMOs. Thus, we argue that live presentations are more likely to evoke interest and differential behaviour towards the agent.

## 5. Conclusions

We propose that the methodological approach applied here offers several advantages in the research of perception in nonhuman species, including the high control over the displayed stimuli, the ability to measure multiple interactive behaviours, and the possibility of designing functionally similar procedures to test different species (see also [37]). The use of this experimental framework facilitates the development of further experiments that can test the implicit interactive behaviour of nonhuman species. The wider application of this novel approach in perception research may shed light on the underlying

mental process and facilitate a greater understanding of whether and how the social and ecological background of the different species influence social perception.

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## Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

## Ethical statement

Ethical approval was obtained from the National Animal Experimentation Ethics Committee for both cats and dogs (PE/EA/1550-5/2019). All methods were carried out in accordance with relevant guidelines and regulations, the experiment was performed in accordance with the EU Directive 2010/63/EU. Owners provided a written informed consent to voluntarily permit their cats and dogs to participate in the study.

## Conflict of interest

The authors have no relevant financial or non-financial interests to disclose.

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## References

- [1] Tremoulet P D and Feldman J 2000 Perception of animacy from the motion of a single object *Perception* **29** 943–51
- [2] Di Giorgio E, Lunghi M, Vallortigara G and Simion F 2021 Newborns' sensitivity to speed changes as a building block for animacy perception *Sci. Rep.* **11** 542
- [3] Rosa-Salva O, Grassi M, Lorenzi E, Regolin L and Vallortigara G 2016 Spontaneous preference for visual cues of animacy in naïve domestic chicks: the case of speed changes *Cognition* **157** 49–60
- [4] Szego P A and Rutherford M D 2008 Dissociating the perception of speed and the perception of animacy: a functional approach *Evol. Hum. Behav.* **29** 335–42
- [5] Rosa-Salva O, Hernik M, Broseghini A and Vallortigara G 2018 Visually-naïve chicks prefer agents that move as if constrained by a bilateral body-plan *Cognition* **173** 106–14
- [6] Hernik M, Fearon P and Csibra G 2014 Action anticipation in human infants reveals assumptions about anteroposterior body-structure and action *Proc. R. Soc. B* **281** 20133205
- [7] Ewert J P and Burghagen H 1979 Configurational prey selection by Bufo, Alytes, Bombina and Hyla *Brain Behav. Evol.* **16** 157–75
- [8] Kutschera U, Burghagen H and Ewert J P 2008 Prey-catching behaviour in mudskippers and toads: a comparative analysis *Online J. Biol. Sci.* **8** 41–3
- [9] Bassili J N 1976 Temporal and spatial contingencies in the perception of social events *J. Pers. Soc. Psychol.* **33** 680–5
- [10] Di Giorgio E, Lunghi M, Simion F and Vallortigara G 2017 Visual cues of motion that trigger animacy perception at birth: the case of self-propulsion *Dev. Sci.* **20** 1–12
- [11] Mascalonzi E, Regolin L and Vallortigara G 2010 Innate sensitivity for self-propelled causal agency in newly hatched chicks *Proc. Natl Acad. Sci. USA* **107** 4483–85
- [12] Tsutsumi S, Ushitani T, Tomonaga M and Fujita K 2012 Infant monkeys' concept of animacy: the role of eyes and fluffiness *Primates* **53** 113–9
- [13] Hauser M D 1998 A nonhuman primate's expectations about object motion and destination: the importance of self-propelled movement and animacy *Dev. Sci.* **1** 31–7
- [14] Morikawa K 1999 Symmetry and elongation of objects influence perceived direction of translational motion *Percept. Psychophys.* **61** 134–43
- [15] McAleer P and Love S A 2013 Perceiving intention in animacy displays created from human motion *Social Perception: Detection and Interpretation of Animacy, Agency, and Intention* ed M D Rutherford and V A Kuhlmeier (Cambridge, MA: MIT Press) pp 139–70
- [16] Abdai J, Ferdinandy B, Terencio C, Pogány Á and Miklósi Á 2017 Perception of animacy in dogs and humans *Biol. Lett.* **13** 20170156
- [17] Pongrácz P, Péter A and Miklósi Á 2018 Familiarity with images affects how dogs (*Canis familiaris*) process life-size video projections of humans *Q. J. Exp. Psychol.* **71** 1457–68
- [18] D'Eath R B 1998 Can video images imitate real stimuli in animal behaviour experiments? *Biol. Rev.* **73** 267–92
- [19] Fleishman L J and Endler J A 2000 Some comments on visual perception and the use of video playback in animal behavior studies *Acta Ethol.* **3** 15–27
- [20] Rochat P, Morgan R and Carpenter M 1997 Young infants' sensitivity to movement information specifying social causality *Cognit. Dev.* **12** 537–61
- [21] Abdai J and Miklósi Á 2022 Selection for specific behavioural traits does not influence preference of chasing motion and visual strategy in dogs *Sci. Rep.* **12** 2370
- [22] Abdai J, Ferdinandy B, Lengyel A and Miklósi Á 2021 Animacy perception in dogs (*Canis familiaris*) and humans (*Homo sapiens*): comparison may be perturbed by inherent differences in looking patterns *J. Comp. Psychol.* **135** 82–8
- [23] Abdai J, Uccheddu S, Gácsi M and Miklósi Á 2021 Chasing perception in domestic cats and dogs *Anim. Cogn.* (<https://doi.org/10.1007/s10071-022-01643-3>)
- [24] Park S Y, Bacelar C E and Holmqvist K 2020 Dog eye movements are slower than human eye movements *J. Eye Mov. Res.* **12** 4
- [25] Scholl B J and Gao T 2013 Perceiving animacy and intentionality *Social Perception: Detection and Interpretation of Animacy, Agency, and Intention* ed M D



- Rutherford and V A Kuhlmeier (Cambridge, MA: MIT Press) pp 197–230
- [26] Völter C J, Karl S and Huber L 2020 Dogs accurately track a moving object on a screen and anticipate its destination *Sci. Rep.* **10** 19832
- [27] Völter C J and Huber L 2021 Dogs' looking times and pupil dilation response reveal expectations about contact causality *Biol. Lett.* **17** 20210465
- [28] Völter C J and Huber L 2022 Pupil size changes reveal dogs' sensitivity to motion cues *iScience* **25** 104801
- [29] Karl S, Boch M, Virányi Z, Lamm C and Huber L 2020 Training pet dogs for eye-tracking and awake fMRI *Behav. Res.* **52** 838–56
- [30] Gao T, Newman G E and Scholl B J 2009 The psychophysics of chasing: a case study in the perception of animacy *Cogn. Psychol.* **59** 154–79
- [31] Gao T and Scholl B J 2011 Chasing vs stalking: interrupting the perception of animacy *J. Exp. Psychol. Hum. Percept. Perform.* **37** 669–84
- [32] Greggor A L, McIvor G E, Clayton N S and Thornton A 2018 Wild jackdaws are wary of objects that violate expectations of animacy *R. Soc. Open Sci.* **5** 181070
- [33] Romano D, Benelli G, Kavallieratos N G, Athanassiou C G, Canale A and Stefanini C 2020 Beetle-robot hybrid interaction: sex, lateralization and mating experience modulate behavioural responses to robotic cues in the larger grain borer *Prostephanus truncatus* (Horn) *Biol. Cybern.* **114** 473–83
- [34] Quinn L K et al 2018 When rats rescue robots *Animal Behav. Cogn.* **5** 368–79
- [35] Marras S and Porfiri M 2012 Fish and robots swimming together: attraction towards the robot demands biomimetic locomotion *J. R. Soc. Interface.* **9** 1856–68
- [36] Romano D, Donati E, Benelli G and Stefanini C 2019 A review on animal-robot interaction: from bio-hybrid organisms to mixed societies *Biol. Cybern.* **113** 201–25
- [37] Abdai J, Baño Terencio C and Miklósi Á 2017 Novel approach to study the perception of animacy in dogs *PLoS One* **12** e0177010
- [38] Abdai J, Korcsok B, Korondi P and Miklósi Á 2018 Methodological challenges of the use of robots in ethological research *Animal Behav. Cogn.* **5** 326–40
- [39] Ladu F, Bartolini T, Panitz S G, Chiarotti F, Butail S, Macri S and Porfiri M 2015 Live predators, robots, and computer-animated images elicit differential avoidance responses in zebrafish *Zebrafish* **12** 205–14
- [40] Nunes A R, Carreira L, Anbalagan S, Blechman J, Levkowitz G and Oliveira R F 2020 Perceptual mechanisms of social affiliation in zebrafish *Sci. Rep.* **10** 3642
- [41] Topál J, Miklósi Á, Gácsi M, Dóka A, Pongrácz P, Kubinyi E, Virányi Z and Csányi V 2009 The dog as a model for understanding human social behavior *Advances in the study of behaviour* vol 39 ed H J Brockman, T J Roper, M Naguib, K E Wynne-Edwards, J C Mitani and L W Simmons (Burlington: Academic) pp 71–116
- [42] Bradshaw J W S 2016 Sociality in cats: a comparative review *J. Vet. Behav.* **11** 113–24
- [43] Driscoll C A, Macdonald D W and O'Brien S J 2009 From wild animals to domestic pets, an evolutionary view of domestication *Proc. Natl Acad. Sci. USA* **106** 9971–78
- [44] Fugazza C and Miklósi Á 2014 Measuring the behaviour of dogs: an ethological approach *Domestic Dog Cognition and Behavior* ed A Horowitz (Berlin: Springer) pp 177–200
- [45] Rochlitz I 2005 A review of the housing requirements of domestic cats (*Felis silvestris catus*) kept in the home *Appl. Anim. Behav. Sci.* **93** 97–109
- [46] Abdai J, Gergely A, Petró E, Topál J and Miklósi Á 2015 An investigation on social representations: inanimate agent can mislead dogs (*Canis familiaris*) in a food choice task *PLoS One* **10** e0134575
- [47] Qin M, Huang Y, Stumph E, Santos L and Scassellati B 2020 Dog sit! Domestic dogs (*Canis familiaris*) follow a robot's sit commands *ACM/IEEE Int. Conf. Human-Robot Interaction* pp 16–24
- [48] Shaw N and Riley L M 2020 Domestic dogs respond correctly to verbal cues issued by an artificial agent *Appl. Anim. Behav. Sci.* **224** 104940
- [49] Bradshaw J W S, Casey R A and Brown S L 2012 *The Behaviour of the Domestic Cat* (Wallingford: CABI)
- [50] Cecchetti M, Crowley S L and McDonald R A 2021 Drivers and facilitators of hunting behaviour in domestic cats and options for management *Mamm. Rev.* **51** 307–22
- [51] Hall S L 1998 Object play by adult animals *Animal Play: Evolutionary, Comparative and Ecological Perspectives* ed M Bekoff and J A Byers (Cambridge: Cambridge University Press) pp 45–60
- [52] R Core Team (2021) R: A Language and Environment for Statistical Computing <https://www.R-project.org/>
- [53] RStudio Team (2020) RStudio: Integrated Development for R <http://www.rstudio.com/>
- [54] Zeileis A and Hothorn T 2002 Diagnostic checking in regression relationships *R News* **2** 7–10
- [55] Lenth R V (2022) emmeans: Estimated Marginal Means, aka Least-Squares Means <https://CRAN.R-project.org/package=emmeans>
- [56] Bates D, Maechler M, Bolker B and Walker S 2015 Fitting linear mixed-effects models using lme4 *J. Stat. Softw.* **67** 1–48
- [57] Mangiafico S (2022) rcompanion: Functions to Support Extension Education Program Evaluation <https://CRAN.R-project.org/package=rcompanion>
- [58] Therneau T M and Grambsch P M 2000 *Modeling Survival Data: Extending the Cox Model* (New York: Springer)
- [59] Therneau T M (2021) A Package for Survival analysis in R <https://CRAN.R-project.org/package=survival>
- [60] Vinke C M, Godijn L M and van der Leij W J R 2014 Will a hiding box provide stress reduction for shelter cats? *Appl. Anim. Behav. Sci.* **160** 86–93
- [61] Rochlitz I, Podberscek A L and Broom D M 1998 Welfare of cats in a quarantine cattery *Vet. Rec.* **143** 35–9
- [62] Gourkow N, LaVoy A, Dean G A and Phillips C J C 2014 Associations of behaviour with secretory immunoglobulin A and cortisol in domestic cats during their first week in an animal shelter *Appl. Anim. Behav. Sci.* **150** 55–64
- [63] Forkman B, Boissy A, Meunier-Salaün M C, Canali E and Jones R B 2007 A critical review of fear tests used on cattle, pigs, sheep, poultry and horses *Physiol. Behav.* **92** 340–74