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The contribution of the shading pictorial cue on the  
tridimensionality perception in dogs

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*A Bilbo,  
per avermi aiutata a vedere la mia strada.  
Per sempre parte di questa tesi,  
per sempre parte di me.*



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## **ABSTRACT**

The perception of bidimensional images in dogs has been largely investigated; however, to this date, there is very limited empirical evidence regarding their ability to infer tridimensionality from bidimensional representations, through the elaboration of pictorial cues. Existing literature suggests that these cues, such as shading, might play an important role in their ability to infer depth. The present study aims to assess the contribution of shading pictorial cue on dogs' perception of tridimensionality. Twenty-four dogs were tested in two conditions: a control, in which a tridimensional stimulus (i.e., a ball) was shown rolling on a planar surface on an apparatus until it fell into a real hole, and a test condition, in which the same tridimensional stimulus rolled on the planar surface until passing over a depicted hole (i.e., a bidimensional pictorial representation of the shade of the real hole). Using a violation-of-expectation paradigm, the study found no significant difference between the two conditions in observation times toward the area where the hole was present/depicted, suggesting that the shaded depiction alone did not elicit tridimensional perception. This may imply that the shading gradation wasn't salient enough to produce a shadow effect rather than dogs being unable to perceive or use this cue. Additionally, attention varied across trials, with a greater looking rate towards the hole area during the first trial. This isolated trial order effect was likely due to the limited sample size, suggesting a larger sample could help balance out any anomalies in isolated observation.





# 1. INTRODUCTION

## 1.1. Depth Perception overview: cues and mechanisms of depth perception in animals

Visual perception involves more than the simple reception of light through the eyes; it is an active interpretation of sensory data, shaped by external stimuli and internal cognitive mechanisms. The brain transforms the visual input into a meaningful understanding of the surrounding environment to act accordingly (Goldstein & Brockmole, 2017). Our knowledge of animals' functional properties involving eyes structures such as visual acuity, colour perception and light sensitivity is quite rich, however, our understanding of the higher-level processes, such as object shape and size discrimination or depth and tridimensionality perception, is not as deep. This gap is critical considering that several studies on non-human animals are based on performing visual tasks (Bensky et al., 2013).

Depth perception is the brain's capability to interpret spatial relationships and perceive the world in three dimensions (Goldstein & Brockmole, 2017). It is an essential skill that enables animals to estimate distances and move through space effectively.

In humans, the perception of tridimensionality occurs due to different mechanisms which lead to the processing of the bi-dimensional image gained by the retina (Marr & Nishihara, 1978). This process is based on visual cues divided into binocular and monocular depth cues (Rokers et al., 2015).

Binocular cues, such as binocular disparity and convergence, require the contribution of both eyes in the perception process. Convergence consists in inward movement of the eyes as they focus on closer objects. The ocular rotation will provide information to the brain about the distance of objects as the angle of convergence increases when the objects comes closer, giving the viewer the sense of depth (Goldstein, 2017). Binocular disparity is based on the differences in the images

received by the two eyes due to their slightly different position. The brain will then integrate these discrepancies between the two retinal images to perceive tridimensionality (Julesz B., 1964). This ability to perceive depth through the merging and interpretation of binocular cues is known as stereopsis, which for many years was thought to be limited to humans, non-human primates and a few other mammal species, in particular front-facing eye predators (Nityananda & Read, 2017). Over the past few decades however, many independent studies have proved stereopsis in various animal species (sheep: Clarke et al., 1976), including some non-mammals, belonging to different taxa (toads: Collett, 1977; falcon: Fox et al., 1977; praying mantis: Nityananda et al., 2016).

Unlike previous ones, monocular cues provide information about depth and distance even when using just one eye. It is possible to identify four main categories of monocular depth cues, i.e., accommodation, angular declination, motion parallax and pictorial cues.

The accommodation process consists of the change in the eye lens shape thanks to ciliary muscles, to focus on an object at different distances (Nityananda & Read, 2017).

Angular declination is the angle between an observer's eye level and an object positioned below the horizon which is used by the visual system to calculate the distance of objects on the ground through a trigonometric relationship. Specifically, the farther an object is, the smaller the angular declination, and vice versa (Ooi et al., 2001).

Motion parallax is one of the most important monocular cues. As different objects move at a constant speed those closer to the observer will shift more rapidly across the visual field compared to objects further away. In the same way, as the viewer moves with the respect to still objects, closer objects appear to move quickly in the opposite direction of the viewer's movement, while distant objects appear to move more slowly. The relative motion allows the visual system to infer the tridimensionality of the scene, even in the absence of other depth cues as motion parallax can provide depth perception independently (Rogers & Graham 1979).

Finally, pictorial cues also play an important role in the perception of tridimensionality as they are the only ones that can be used to perceive depth in bidimensional static stimuli. These monocular

cues include: familiar size, where previous knowledge of an object's actual size allows us to estimate its distance based on its perceived size in our visual field; relative size, which allows us to judge distance by comparing the perceived sizes of familiar objects, where the smaller one is seen as farther away, relying this judgement on past experience with similarly-sized objects; interposition, arising when one object overlaps another, making the overlapped object appear farther away; linear perspective, in which objects of known size appear smaller as they are positioned farther away, creating the perception of increased distance, similarly, parallel lines, such as roads or railway tracks, seem to converge as they recede into the distance ; height in the visual field, where objects positioned higher within the visual field are interpreted as being farther away compared to lower objects; aerial perspective, where distant objects appear as less distinct due to atmospheric scattering, which disperses light and desaturates colours; texture gradient, where the texture of a surface appears progressively less distinct as it recedes into the distance; shading, when variations in reflected light across a surface reveal its orientation with respect to the light source (Palmer, 1999; Kalloniatis & Luu, 2005).

In humans, the perception of tridimensionality relies on a variety of depth cues, with binocular and monocular cues contributing differently depending on the visual context. Different studies performed in natural or “real-world” settings with real objects have shown that binocular depth estimation tends to be more accurate than monocular estimation (Frisby et al., 1996; Loomis et al., 2002; Allison et al., 2009). Even without monocular cues, depth can still be perceived through binocular disparity, i.e., based on differences in images seen by each eye (Julesz, 1964). At the same time, when observing a natural scene with one eye, the depth perception is not significantly diminished, indicating that binocular disparity might be less critical in some naturalistic settings than previously assumed (Gibson, 1950).

It's suggested that, in cases where bidimensional stimuli are designed with conflicting monocular and binocular depth cues, monocular cues dominate the interpretation of depth. For example, when

presented with a flat image mimicking tridimensionality, the visual system often prioritises pictorial cues over binocular disparity (Stevens & Brookes, 1988).

Thus, the interplay of binocular and monocular cues in depth perception depends significantly on whether the scene involves true tridimensional stimuli or merely a representation of them, and on the availability and reliability of each type of cue in the specific visual environment.

In non-human animal species, providing bidimensional stimuli is a largely diffused experimental procedure. However, only a limited number of empirical studies support the assumptions that the mental processes used to understand tridimensional stimuli are similar to those used for bidimensional ones and that animals can perceive depth using monocular cues. Parron and colleagues study (Parron et al. 2008) represents the first study in which the perception of bidimensional images as tridimensional stimuli was demonstrated. The study investigated the interaction with photographic representations of non-human primates, specifically baboons, gorillas, and chimpanzees, to see if they would treat photographs as real objects. As a result of the exposure baboons frequently mistook images of bananas for actual bananas, attempting to grab, smell, and even eat them, suggesting difficulty in distinguishing the photo from reality. Gorillas showed similar behaviours, while chimpanzees were generally more cautious. These findings highlighted the variability in response across species showing both the potential usefulness and limitations in representational understanding but didn't provide any information on the image characteristics used by the animals to perceive the tridimensionality.

The ability to deduce the tridimensionality in bidimensional stimuli implies the viewer's capability to perceive and elaborate pictorial cues. By manipulating these pictorial cues different studies tried to investigate if and how several species perceive them and their contribution to tridimensionality perception. Walk and Gibson (1961) were the first to introduce the use of pictorial cues, in particular texture gradient, to study the depth perception abilities of numerous species, including rats, chickens, goats, lambs, pigs, dogs, turtles, cats, and monkeys. Additional studies investigated the texture gradient cue alone (cuttlefish: Josef et al., 2014) or together with other pictorial cues

such as linear perspective and relative size (macaque: Gunderson et al., 1993) exploring once again the use of such pictorial cues and their role in depth perception. The study of depth interpretation was then widened to the other pictorial cues, for instance occlusion, relative size, and height in the visual field, which were investigated in pigeons by Reid and Spetch (1998).

Researchers started investigating animals' susceptibility to visual illusions to understand if animals use cognitive processes for depth and spatial interpretation similar to those of humans. If animals are affected by the same illusions as humans, we can infer that they might also rely on the involved pictorial cues, thus providing insight into their perceptual abilities and visual cognition. Different studies investigated visual illusions in humans and other animal species, finding similar, absent or opposite processing of the spatial depth cues compared to humans.

The Corridor illusion, relying on linear perspective and texture gradient cues, induces the objects placed in the foreground of a corridor-like background to appear larger than identical objects placed in the background. It was studied by Barbet and Fagot (2002, 2007) on baboons demonstrating that these animals, like humans, can be influenced by these depth cues, suggesting they might process spatial depth cues similarly to humans. In the Ponzo illusion, two identical lines or objects appear different in size when placed within converging lines, creating the perception that the line nearer the converging point is larger by relying on linear perspective and relative size cues. Gregory's (1963) Inappropriate Constancy-Scaling Theory explains this phenomenon as the brain's misinterpretation of depth cues, scaling objects based on perceived distance rather than actual size. Studies by Bayne and Davis (1983) on rhesus monkeys and Fujita and colleagues (1991) on pigeons showed that both species are sensitive to the Ponzo illusion, suggesting they interpret linear perspective cues as depth indicators, although susceptibility may vary across species. The Müller-Lyer illusion consists of lines of equal length appearing different due to the addition of converging or diverging arrowheads at their ends. It relies on pictorial cues such as linear perspective (Weidner & Fink, 2007), and several studies assessed susceptibility in different species suggesting cross-species perceptual similarities (capuchin monkeys: Suganuma et al., 2007; budgerigars: Watanabe, 2022). The

Delboeuf illusion involves a central circle whose perceived size changes based on the size of a surrounding ring and it relies on relative size and contextual contrast cues. When surrounded by a smaller ring, the central circle looks larger while it appears smaller when surrounded by a larger one. In Parrish's 2020 review are reported studies showing varying susceptibility to this illusion across animals, including primates and fish. While primates, like humans, often experience the illusion strongly, responses in other animals like fish vary, suggesting species-specific differences in processing relative size and spatial context.

Similarly to the Delboeuf illusion, the Eddinghaus illusion also relies on relative size and contextual contrast cues. However, the latter is based on a central circle surrounded by multiple circles, creating a size contrast based on multiple contextual elements. This illusion was also examined across different taxa showing varying degrees of susceptibility across species. Some animals, like pigeons and certain fish and sharks, experience the illusion similarly to humans, while others, such as chicks and dolphins, may interpret it differently, suggesting differences in depth perception and size contrast interpretation (Fuss & Schlüssel, 2017; Parrish, 2019).

## **1.2. Depth perception in dogs**

Dogs' depth perception and tridimensional vision are essential to their natural behaviours, such as tracking moving objects and browsing different environments, despite the relatively narrow range of their binocular overlap, estimated between 30° and 60°, which is substantially smaller than the 140° typical in humans (Miller & Murphy, 1995). This limited binocular field is complemented by a broader monocular field, supporting a wide visual range but limiting precise depth estimation at closer distances (Miller & Murphy, 1995). As a result, dogs often rely on monocular cues which become crucial in their peripheral vision to estimate distance and depth, e.g. motion parallax becomes essential when detecting or tracking prey in motion (Walk & Gibson, 1961; Miller & Murphy, 1995).

Some important anatomical studies provide additional context for depth perception in dogs, finding that they possess fewer alpha ganglion cells in the peripheral regions of the retina, specifically within the outer 15° areas of binocular overlap (Peichl, 1992; McGreevy et al., 2004). This suggests that dogs have limited high-quality depth perception in the binocular field, as these cells are essential for processing high-resolution, depth-related information. Instead, their visual system appears adapted for a broader peripheral vision, a trait which seems beneficial in open habitats where spotting movement is more important than detailed depth perception (Peichl, 1992; McGreevy et al., 2004).

As done in other animal species some studies, though not primarily focused on pictorial cues, have begun to examine dogs' susceptibility to visual illusions. Through this research, scientists have indirectly started exploring how dogs respond to pictorial cues.

Dogs showed, for example, limited susceptibility to the Ponzo illusion, suggesting that their depth perception may not heavily rely on perspective cues, unlike humans (Byosiere et al., 2016). Similarly to the Ponzo illusion, dogs demonstrated a lack of susceptibility to the Müller-Lyer illusion (Byosiere et al., 2020). Studies performed on Ebbinghaus-Titchener and Delboeuf illusions showed that dogs had mild susceptibility to both, especially the Delboeuf illusion, indicating that dogs may process some relative size cues similarly to humans, though with less consistency (Byosiere et al., 2016).

These studies suggest dog-specific differences in visual processing, supporting the different roles that various cues play in canine perception, which might be based more on contextual size and motion cues rather than on prospective ones (Byosiere et al., 2020).

Another important study investigating depth perception in dogs was performed by Walk and Gibson (1961). These authors used the “visual cliff” apparatus, a glass-covered drop-off, to investigate depth perception across species, including puppies, rats, kittens, turtles, chicks, and human infants. Most animals avoided the “deep” side of the apparatus, suggesting that depth perception is either innate or develops early. In the study the authors suggests that different species probably relied on

varying depth cues: primates and other animals with forward-facing eyes tended to use binocular cues, while puppies, with a more limited binocular field, likely relied on monocular cues such as texture gradients and motion parallax.

More recently, a study by Broseghini and colleagues (2024) specifically investigated the role of two pictorial depth cues, linear perspective and shading, in dogs' perception of tridimensionality. The study, suggesting that dogs can perceive both cues and use them to elaborate information on depth, represents the first experiment specifically investigating pictorial cues in these animals.

Despite this, scientific studies on depth perception in dogs remain limited. There isn't specific knowledge regarding either motion parallax or the majority of the pictorial cues.

### **1.3. The role of shading on depth perception**

Unlike other pictorial cues, the shading monocular cue was less often properly investigated. Nevertheless, some Authors did study the role of shadow on tridimensionality perception, highlighting the important role that this particular cue seems to play in depth perception across different species.

In humans, shading plays a key role in tridimensional perception by providing depth cues that our brain processes automatically (Castiello, 2001). When light interacts with an object, the resulting shadows create visual information about the shape, position, and distance of the object relative to the light source. Humans interpret this shading subconsciously, using it to construct a spatial model of the object's position and form. This process allows for rapid and intuitive depth perception, fundamental for interpreting tridimensional space in real-world environments (Ramachandran, 1988; Castiello, 2001).

In non-human species, different independent studies proved that in various species across different taxa, depth perception is also based on the unconscious interpretation of shadow orientation. Hess (1950) and Hershberger (1970) demonstrated that chicks can apply their ability to distinguish



between concave and convex surfaces of photographs of these shapes, suggesting that they may have some capacity for depth processing based on shading cues present in photographic stimuli. Pigeons can also discriminate between concave and convex surfaces based on shading cues, indicating they also can perceive tridimensional shapes from bidimensional images (Cook et al., 2012). These researches, suggests that birds, like humans, can use shading as a valuable visual cue to navigate their environment and recognise objects' depth. Imura and Tomonaga (2003) investigated depth perception from shading in infant chimpanzees, demonstrating their ability to differentiate between concave and convex shapes presented in images. Their findings suggest that shading plays an important role in how chimpanzees process tridimensional shapes, similar to depth perception mechanisms in humans. If this similarity between human and non-human primates was expected, what we can appreciate is the variety of taxa in which this very similar mechanism was found. The perception of depth from shading cues was more recently demonstrated also in cuttlefish. In their study, Zylinski and colleagues (2016) demonstrated that cuttlefish can adjust their body patterns in response to this pictorial cue and light direction. When presented with images that used shading to indicate depth, cuttlefish modified their colouration to match the perceived tridimensional textures, such as lighter colours on raised areas and darker ones in concave regions. This response suggests that cuttlefish interpret shading as an indicator of depth, showing an advanced perceptual ability to interact with their environment through adaptive camouflage. This study is also an important example of the ecological role that shading plays for many species.

The animals' kingdom is rich in examples of how shading and the perception of depth relying on this particular monocular cue, can represent a key aspect of the animals' adaptation. One of the most important and spread is countershading, a common camouflage strategy, involving a gradient in body colour with a darker dorsal surface and a lighter ventral side. This pattern favours top-down lighting, reducing visible shadows and helping animals blend into their surroundings, being particularly effective in both aquatic and terrestrial environments, and representing an important

anti-predation strategy that was proven effective in many different animal species (Poulton, 1890; Cott, 1940).

In dogs, a study by Broseghini and colleagues (2024) found that they can perceive tridimensionality from bidimensional images presenting both shading and linear perspective cues. However, no study at present has investigated shading as a single monocular cue used by dogs to perceive tridimensionality.

## **2. AIM OF THE STUDY**

Research on canine vision generally supports the idea that dogs can use shading as a cue to understand the tridimensional world. (Walk & Gibson, 1961; Broseghini et al. 2024).

As part of a series of experiments, this study aims to investigate the role of the shading pictorial cue on dogs' perception of depth and tridimensionality.

To this aim, dogs were exposed to two scenarios: a ball rolling into a real hole (control) and a ball rolling over a pictorially represented hole (depicted), created with shading. To identify possible susceptibility of dogs to the shading cues used to depict the hole we used a “violation of expectation” approach, where dogs’ longer gaze signals surprise at the unexpected situation (Mongillo et al., 2021).



### **3. METHODS**

#### **3.1. Subjects**

In the present study, the experimental sample consisted of 24 pet dogs. The owners, participating voluntarily, were recruited either from the Laboratory of Applied Ethology database or were either students or employees of the University of Padua.

To be enrolled in the study, each dog had to meet four requirements: being in good health conditions, in particular absence of vision problems, being older than eight months old, being at ease in new environments and having a height at eye level equal to or lower than 100 cm in a sitting position.

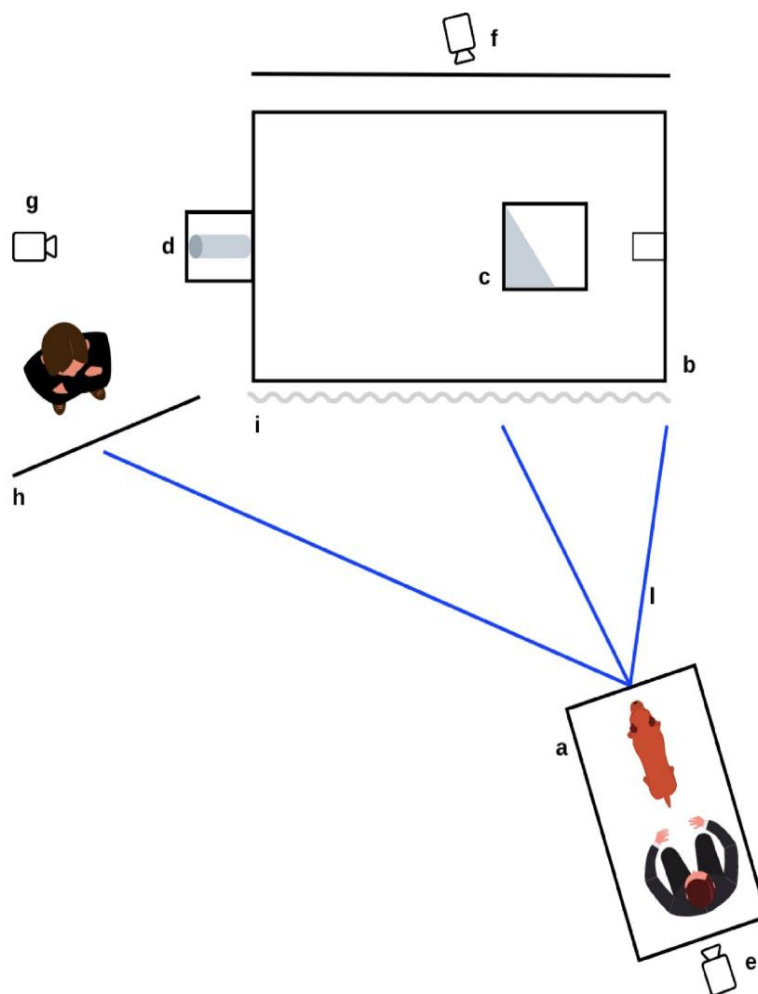
The sample involved a heterogenic group of pet dogs made of 13 males and 11 females, aged between 11 years and 8 months old (average age  $\pm$  SD = 5.0  $\pm$  3.0 year), 9 were mixed breed and 15 were pure breed (1 Australian Shepherd, 3 Border Collie, 1 Cocker Spaniel, 1 Dachshund, 1 French Bulldog, 1 German Shepherd, 2 Jack Russel, 3 Lagorai Shepherd, 1 Maltese, 1 Pitbull).

#### **3.2. Experimental Setting**

The experimental space measured 6 x 3.6 m. Noise from outside the experimental room was minimised as much as possible.

The experimental setting (*Figure 1*) comprehended the experimental apparatus, a platform to seat the dog with the owner, one white panel to hide one experimenter and a second one as background, to hide the frontal camera, a white curtain to hide the apparatus from the dog's view before the trial starts, and three cameras to record the whole process.

**Figure 1:** Illustration of the experimental setting showing the position of the dog and the owner on the platform (**a**), the experimental apparatus (**b**), the illusionary/real hole (**c**), the paper tube structure used to drop the ball (**d**), the camera focusing on the dogs' head from up top (**e**), the camera focusing on the dogs' eye from behind the panel (**f**), the camera focusing on the apparatus (**g**), the panel hiding the experimenter (**h**), the white curtain hiding the apparatus before the beginning of the trial (**i**), the blue stripes on the floor used as guidance for the head's movement coding (**l**). The elements of the representation are not scaled.



The platform (125 x 60 cm) was used as a sitting place for the dog and the owner and was oriented towards the experimental apparatus with an angle of 15° degrees, with respect to the hole. It was composed of polyurethane foam rectangles, 10 or 5 cm high. The total height was then adjusted, by building the platform with a certain number of foam panels, based on the distance between the dog's eyes and the floor when sitting, so that the overall height between eyes and floor would be 100 cm. The experimental apparatus (*Figure 2*) was placed at a distance of 240 cm from the platform. It was formed by a plastic, completely white, board (152 x 102 x 1 cm), supported by a 25 cm high structure. The board presented a hole (30 x 30 cm), at 85 cm from the left end, in the middle of its

width, with white plastic panels forming the walls under the apparatus (12 cm). A net, hidden from the dog thanks to the supporting structure, was under the hole, to catch the falling ball and prevent it from bouncing or rolling off.

During the “Real hole” condition the hole was left open so the ball would fall into the net when it reached it. During the “Depicted hole” condition it was covered by a panel consisting of a printed image of the real hole, taken from the dog's perspective, to accurately reproduce the shadow formed on the hole walls in the “Real hole” condition.

A structure, formed by a paper tube (diameter 5 cm) attached to the board with a 30° inclination was present on the left side of the apparatus. This structure was the starting point for the ball (diameter 4 cm) which was dropped through it acquiring the necessary acceleration to cross the entire board. At the opposite end, on the right side of the apparatus, a small box was placed (15 x 9 x 8 cm). During the “Depicted hole” condition the box functioned as arriving point of the ball. To ensure the ball would keep the correct trajectory from the beginning to the end of the apparatus, two transparent fishing lines ran from each side of the initial tube structure to the final box one. The physical lane was ensured as the lines were kept slightly raised from the board.

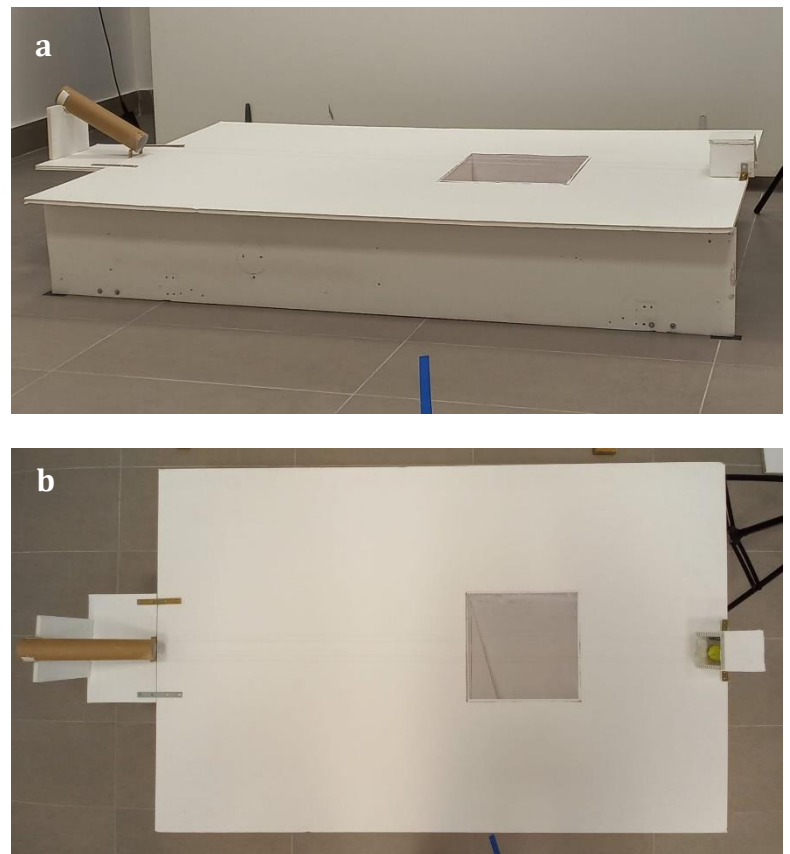
To the left of the apparatus, a white panel was positioned to prevent the dog from seeing the experimenter positioned behind it during the experiment. The panel presented a small gap, at the height of 90 cm, covered by a white, dense net allowing the experimenter to see the dog but preventing the dog from seeing the experimenter back.

Behind the apparatus, with respect to the platform, another white panel was positioned to create a homogenous background. In the middle of this a round hole was present and behind it, a camera was hidden, placed on a tripod at a height of 95 cm from the ground. This camera (Canon XA20, Tokyo, Japan), oriented toward the dog's face, was used to record the dog's eye orientation, which would later be analysed and compared with the head orientation to confirm the dog's attention direction.

Two other cameras (AVer TR311HWV2, Taipei, Taiwan) were involved in the recording process. One, mounted on the left wall toward the apparatus, was used to record the movement and position of the ball during the experiment. The other one, mounted to the ceiling right above the dog's head, was used to record the dog's head movements.

Three blue stripes were placed on the floor between the platform and the apparatus to facilitate the data collection of the head movements. The stripes, visible from the camera used to monitor the head movements, were used to delimit the different areas toward which the dog could be oriented: “Begin of apparatus”, “End of apparatus”, and “Elsewhere”.

**Figure 2:** Pictures of the apparatus in the “Depicted hole” experimental condition, viewed from the dog’s point of view (a), and from above (b). In this condition a plastic panel (30x30x1 cm), representing the shadow of the “Real hole” condition, was placed on top of the real hole to reproduce it through an illusion, which was best perceived from the dog’s point of view.



### 3.3. Procedure

Before the beginning of the experiment, the owners were generally introduced to the study, and they were given instructions about the procedure. The platform was then adjusted based on the measured



distance between the dog's eye and the floor. Afterwards, the owner and dog were led inside the testing room where they were asked to sit on the platform. The owner sat back to the wall, with spread legs to position the dog between them, facing the apparatus, and was required to hold gently the dog by the shoulders or the harness throughout the whole experiment, to prevent the dog from jumping off the platform, and to stay still. He/she was also told to avoid any interactions with the dog and to look straight down to prevent any possible influence on the dog's behaviour.

When the owner and dog were correctly positioned the test started.

One experimenter (experimenter A), after leading the owner and the dog inside the testing room and assisting them in positioning correctly on the platform, removed the white curtain in front of the apparatus, moving it to the left side of the room and remaining hidden behind it. At this point, a second experimenter (experimenter B), who was hidden for the whole time behind the panel on the left of the apparatus, pulled out the left hand while holding a ball, and simultaneously called for the dog's name to attract its attention. If the dog was still not attracted and focused on the ball after 10 seconds, it was excluded from the testing. If the dog was attentive, the ball was released by the experimenter into the paper tube. When the ball stopped, either fallen inside the hole or in the box at the end of the apparatus, the experimenter B would start timing thirty seconds, after which, he/she said the word "OK" to signal the trial end. At this point experimenter A covered the apparatus again with the curtain and then lead the owner and the dog outside the room.

In order to test both conditions the same procedure was repeated twice, one in the "Real hole" condition and one in the "Depicted hole", for each dog, with a time interval of five minutes between the two trials, during which the dog and the owner waited in a separate room.

The order of the two conditions was counterbalanced across the sample.

### **3.4. Data collection and analysis**

The data gathering of the dog's head orientation and eye movement was conducted with Observer XT software (version 12.5, Noldus, Groningen, The Netherlands), with a continuous sampling technique, from the dog's first attentive reaction at the ball to the word "OK".

The coding of the head movement was based on the blue tape lines on the floor which delimited the three different orientation areas: "Beginning of apparatus", from the panel on the left of the apparatus to the beginning of the hole; "End of apparatus", from the beginning of the hole to the end of the apparatus; "Elsewhere", anywhere else in the room.

The two recordings of the head and eye were synchronised and analysed together to code correctly the gaze direction. If the head was directed toward the apparatus but the gaze was not i.e., looking higher than the apparatus itself, the looking behaviour was coded, according to the eyes orientation, as "Elsewhere". The coders initially coded the videos while unaware of the experimental condition.

During this first coding, the coders had only access to the frontal video of the eyes, and the up top video of the head. After the coding of the whole trial was finalised, the coders had access to the third video, recording the apparatus. At this point three events were identified: "Stimulus appears", the first frame in which the ball was visible after exiting the tube; "Stimulus disappears", the first frame in which the ball either fell in the hole or disappeared completely in the box; "Test ends" 30 s after "stimulus disappears".

To assess interobserver reliability, 37% of the videos were coded by a second person. Interobserver reliability was considered good for the data about the orientation of the dog, collected from the moment "stimulus appears" to the moment "Test ends" (ICC "Beginning of apparatus" = 0.86; ICC "End of apparatus" = 0.78; ICC "looking Elsewhere" = 0.82)

In the "Real hole" condition, the mean time during which the ball was visible to the dogs was calculated, defined as the time from when the stimulus first appeared out of the paper tube, until it fell into the hole. This value, which was considered sufficiently constant across trials was used as the fixed interval in which the ball travelled from the beginning of the apparatus until it reached the hole. This allowed to determine the dogs' attention toward the beginning of the apparatus in the

time interval when the ball was traveling in that area, across the two conditions. Therefore, a paired t-test was applied to compare in the two conditions, the dog's looking time at the begin of apparatus. The percentage of time the dogs spent looking at the begin of the apparatus while the ball was travelling through that area was also calculated.

A Generalized Estimating Equation (GEE) model was used to analyse the dog's attention toward the begin of apparatus in order to see if a difference was present between the first and second trials. Moreover, only in the "Depicted hole" condition, percentage of time the dogs spent looking at the end of the apparatus while the ball was travelling through that area (i.e., from the time the ball was on the depicted hole to "stimulus disappears") was calculated and compared, through a paired t-test, with the percentage of time the dogs spent looking at the begin of the apparatus while the ball was travelling through that area.

The 30 seconds after the disappearance of the stimulus were analysed to assess any difference in attention between the two conditions. This analysis aimed at understanding if the dogs were sensitive to pictorial representation of the hole and consequentially, surprised by the fact that the ball didn't fall in the hole but kept rolling instead. According to the violation of expectation paradigm in fact, surprise is revealed by an increase in attention, or looking time, towards the area where the unexpected phenomenon occurred, which in our case corresponds to the area "End of apparatus" (Winters et al. 2015).

Three Generalized Estimating Equation (GEE) models were used to analyse the dog's orientation toward the end and beginning of apparatus and elsewhere. The observation time "End of apparatus", "Beginning of apparatus" and "Elsewhere", were considered dependent variables in the model. The experimental condition, trial order, and interaction between these two were considered independent variables. The dog's identity was included as a random effect to account for the repeated measurements on the same subject.

All statistical analyses were performed with SPSS (v. 28, IBM, Armonk, NY). The level of statistical significance was set at 0.05.

All the results are presented as mean values  $\pm$  SD for the t-tests analyses, while for the GEE models are presented as estimated mean  $\pm$  SE, unless otherwise stated.

#### 4. RESULTS AND DISCUSSION

In the “Depicted hole” condition, the duration of the trial from “stimulus appears” to 30 s after “stimulus disappears”, was  $31.73 \pm 0.27$  s. In the “Real hole” condition, the duration of the trial was  $30.99 \pm 0.09$  s.

For the “Real hole” condition the time interval in which the ball was visible to the dogs, i.e. the mean time for the ball to go from “stimulus appears” to “stimulus disappears” was  $0.99 \pm 0.09$  s.

No significant difference emerged from the comparison between the two conditions in looking “Beginning of apparatus” during this time interval (“Depicted hole” condition =  $0.82 \pm 0.16$  s; “Real hole” condition =  $0.81 \pm 0.15$  s;  $t = 0.306$ ,  $df = 23$ ,  $p = 0.763$ ). In the “Depicted hole” condition dogs looked at this area for  $83.15 \pm 16.51\%$  of the time interval, and in the “Real hole” condition for  $81.90 \pm 15.34\%$ .

A GEE model was performed to analyse the difference in attention toward “Beginning of apparatus” between the first and second trials. No significant difference emerged in the attention toward the stimulus (Wald Chi-square = 0.656,  $p = 0.418$ ; First Trial =  $0.80 \pm 0.33$  s; Second Trial =  $8.32 \pm 0.03$  s)

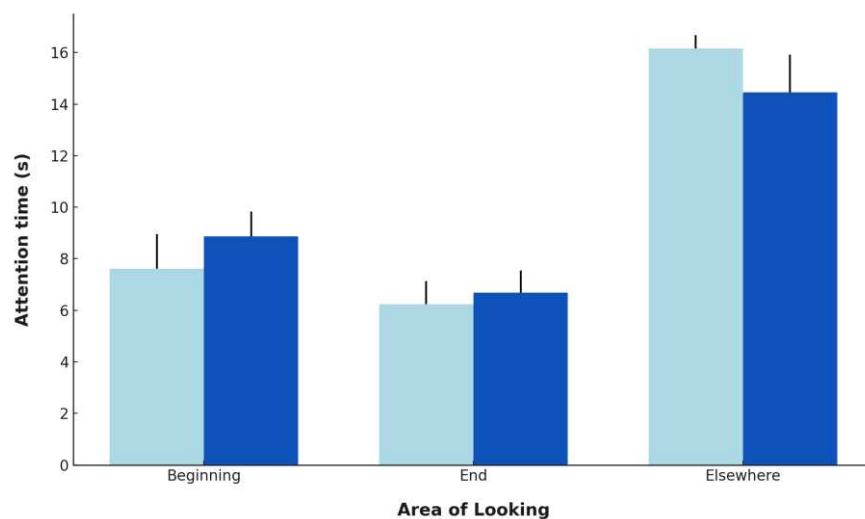
In the “Depicted hole” condition, the percentage of time the dog looked at end of apparatus from the moment the ball reached the depicted hole to the “stimulus disappears” at the end of the apparatus was  $90.52 \pm 21.17\%$ . No significant difference emerged in the attention of the dogs toward the ball between the beginning of the apparatus, in the first 0.99 s, and the end of the apparatus, from 0.99 s to “stimulus disappears” ( $t = -1.125$ ,  $df = 23$ ;  $p = 0.272$ ), suggesting constant and equal attention to the ball throughout the whole trial.

Based on these data there is no significant difference in the attention paid by the dogs to the stimulus between the two conditions nor between the two trials. Moreover, the stimulus, thanks to its familiar and engaging nature, was capable of drawing almost completely the attention of the

dogs, proving to be an effective stimulus, in line with prior finding (Broseghini et al., 2024). The effectiveness of the ball as a stimulus to consistently attract sustained attention probably stems from its association with positive activities, such as play and social interactions (Abdai, 2017), and its role as a positive reinforcement in training (Rooney & Cowan, 2011; Gerencsér et al., 2018). Additionally, its motion likely enhanced attention, aligning with evidence that dogs are highly attuned to moving objects (Miller & Murphy, 1995).

Data regarding the dogs' attention toward the two different parts of the apparatus (“beginning of apparatus” and “end of apparatus”) and “elsewhere” during the 30 s time interval after the “stimulus disappears”, under both experimental conditions are reported in *Figure 3*.

**Figure 3:** Mean attention  $\pm$  SE paid by dogs to the two different areas of the apparatus (Beginning and End) and to Elsewhere, in the condition Depicted (light blue) and Real hole (dark blue), during the 30 s after the ball disappeared.



The GEE model applied to the dogs' looking time “Elsewhere” in the 30 s after the stimulus disappeared, revealed no significant difference between the two conditions (Wald Chi-square = 1.787,  $p = 0.181$ ), the order of conditions (Wald Chi-square = 1.082,  $p = 0.298$ ) and the interaction between these variables (Wald Chi-square = 0.246,  $p = 0.620$ ) indicating the looking time was similar for both conditions (“Depicted hole” condition =  $16.15 \pm 0.52$  s; “Real hole” =  $14.45 \pm 1.46$  s) and trials order (First Trial =  $14.64 \pm 1.38$  s; Second Trial =  $15.96 \pm 1.59$  s).

This result highlights that while when the stimulus is present the dog's attention is consistently focused on the apparatus where the stimulus is located, once it disappears the attention to the apparatus drops significantly. Dogs indeed address their attention differently splitting it almost equally between the apparatus and the surroundings. This response is coherent in both trials with no influence given by the condition and order. The decrease in attention toward the apparatus was unexpected, as a prior experiment with the same apparatus and similar stimulus did not show such a steep decline in attention (Broseghini et al., 2024). This suggests that the drop in focus may not be due to the apparatus itself but rather to other factors, such as the specific illusory condition being tested in the current experiment.

The GEE model applied to the time looking "Beginning of apparatus" during the 30 s after the disappearance of the ball, revealed that there is no significant effect of the condition on the dogs' attention toward this part of the apparatus (Wald Chi-square = 1.018,  $p = 0.313$ ), meaning the time the dogs spent looking in the two conditions was similar ("Depicted hole" condition =  $7.61 \pm 1.33$  s; "Real hole" =  $8.86 \pm 0.96$  s). No difference in attention was given also by the order in which the conditions were presented (Wald Chi-square = 0.61,  $p = 0.805$ ) as the looking time was also similar (First Trial =  $8.08 \pm 1.03$  s; Second Trial =  $8.39 \pm 1.28$  s). Moreover, there was no significant difference in attention given by the interaction between these two independent variables (Wald Chi-square = 0.404,  $p = 0.525$ ).

This outcome implies that no significant effect of the condition was observed, which aligns with expectations, as the element of surprise was not expected in this area. Since the unexpected event occurs in the terminal position, a surprise reaction should be expected there.

Finally, the model applied to the time the dogs spent looking "End of apparatus" during the 30 s after the disappearance of the ball, revealed no significant differences in attention given by the interaction between Condition and Trial Order (Wald Chi-square = 2.612,  $p = 0.106$ ) or by the two conditions (Wald Chi-square = 0.422,  $p = 0.516$ ), which had almost the same looking time ("Depicted hole" condition =  $6.23 \pm 0.89$  s; "Real hole" =  $6.68 \pm 0.85$  s). However, a significant

difference in attention was observed between the first and the second trial (Wald Chi-square = 5.516,  $p = 0.019$ ) indicating a longer looking time at the “End of apparatus” during the first trial compared to the second one (First Trial =  $7.27 \pm 0.83$  s; Second Trial =  $5.65 \pm 0.91$  s) (*Table 1*).

These findings indicate no significant effect of the condition on dogs’ looking time, which implies dogs not being surprised by either the ball falling in the real hole or not falling in the depicted hole. This result is likely due to a low stimulus salience. In particular, the greyscale gradient used may lack sufficient contrast for dogs to perceive it as expected. A different explanation might be the lack of capability of dogs to use the gradient itself to infer depth. However, as the gradient has been effectively used across various taxa, including species with a lower development of cognitive abilities compared to dogs, this second hypothesis seems unlikely. Our outcome suggests that the pictured stimulus may have simply lacked a contrast gradient clear enough to create the intended perceptual effect, which would have probably held the dogs’ attention by presenting a “surprising” event that violated their expectation (chicks: Hess (1950), Hershberger (1970); infant chimpanzees: Imura and Tomonaga, 2003; pigeons: Cook et al., 2012; cuttlefish: Zylinski, Osorio, and Johnsen, 2016). Additionally, a trial order effect was observed, only for the “End of apparatus” region (*Table 1*). Despite being plausible to observe an order effect (Fecteau & Munoz, 2003; Eatherington et al., 2018), this would be expected across multiple variables, not on a single one as in this case. Moreover, it is even more unexpected given that the stimulus captured almost full attention consistently in both trials, and no order effect has been detected in the previous same experiment (Broseghini et al., 2024). Therefore, the most likely explanation of this result may be attributed to the small sample size, which could lead to random issues clustering within this specific observation. With a larger sample size, possibly no order effect would be observed as a broader dataset would balance out any abnormalities of isolated observations.



**Table 1:** Mean attention in seconds paid by dogs in the first (1) and second (2) trial, toward “Elsewhere” (a), “Beginning of apparatus” (b), and “End of apparatus” (c)

Trial number	Mean	Std. Error
1	14,641666666666667	1,384373019603972
2	15,963333333333335	1,586682131110447

**a.**

Trial number	Mean	Std. Error
1	8,085000000000000	1,031520699600208
2	8,390000000000000	1,284953883017395

**b.**

Trial number	Mean	Std. Error
1	7,273333333333333	,829654937196672
2	5,646666666666667	,914140964897483

**c.**



## 5. CONCLUSIONS

This study demonstrates that shading alone might not elicit depth perception in dogs. However, existing literature suggests that shading may play a role in their ability to infer tridimensionality and depth. Therefore, it is possible that dogs can perceive shading cue, but that in this experiment the light-shadow contrast stem from the used grey gradient was too subtle to create the desired visual effect and so to fully engage the dogs' attention. Additionally, an order effect was observed, showing significantly shorter attention toward the hole area in the second trial, compared to the first one. Given the high attention received by the stimulus overall and the absence of an order effect in previous similar studies, this trial effect was likely due to the small sample size. Future experiments could explore shading perception in dogs using stronger light-shadow contrasts to facilitate the perception of the cue for the animals, and a larger sample size which may provide clearer insights, reducing localized effects as a broader dataset would balance out anomalies in isolated observations.



## APPENDIX

**Appendix 1:** Individual data of the sample, reporting name, gender, breed and age (expressed in years) for each of the 24 dogs of the final sample.

<b>Name</b>	<b>Gender</b>	<b>Breed</b>	<b>Age (years)</b>
Aaron	M	German Shepherd	2.2
Ares	M	Australian Shepherd	4.0
Baby	F	French bulldog	3.5
Balù	M	Border collie	1.6
Beauty	F	Mixed Breed	6.2
Bilbo	M	Mixed Breed	11.1
Bolla	F	Border collie	4.6
Doc	M	Cocker spaniel	8.9
Dream	F	Border collie	7.7
Glera	F	Mixed Breed	3.0
Google	M	Jack Russell terrier	4.7
Kinder	M	Mixed Breed	8.5
Lana	F	Lagorai Shepherd	0.9
Lucy	F	Jack Russell terrier	10.9
Milù	F	Mixed Breed	5.0
Pedro	M	Pitbull	7.8
Pelù	M	Maltese	6.3
Pepe	M	Lagorai Shepherd	3.3
Pippo	M	Mixed Breed	1.0
Roe	F	Mixed Breed	4.4
Rollo	M	Mixed Breed	2.3
Scott	M	Mixed Breed	4.1
Tequila	F	Dachshund	0.8
Zelda	F	Lagorai Shepherd	6.3



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