universität wien

MASTERARBEIT | MASTER'S THESIS

Titel | Title

Body size perception and solidity principle in pet dogs

verfasst von | submitted by

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angestrebter akademischer Grad | in partial fulfilment of the requirements for the degree of

Master of Science (MSc)

Wien | Vienna, 2025

Studienkennzahl lt. Studienblatt | Degree programme code as it appears on the student record sheet:	UA 066 878
Studienrichtung lt. Studienblatt | Degree programme as it appears on the student record sheet:	Masterstudium Verhaltens-, Neuro- und Kognitionsbiologie
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Abstract *(English)*

Body awareness is crucial for navigating the environment, allowing animals to interact effectively with their surroundings. This study provides new insights into canine self-awareness by investigating both body size perception and the solidity principle in domestic dogs (*Canis familiaris*). Unlike previous research, which primarily focused on body size awareness in isolation, this study also examines body shape perception and dogs' understanding of material properties, covering several "building blocks" of self-awareness and establishing a more coherent animal model. Moreover, we compared a group of agility-trained dogs to untrained dogs to further contribute to the discussion on how learned motor skills influence self-awareness. Two experiments were conducted using a two-choice paradigm.

In **Experiment 1**, dogs were presented with barriers of varying shapes and sizes, and their ability to select an appropriate opening based on their body size and shape was assessed. Results revealed that while dogs avoided openings too small to navigate, they showed no consistent preference for vertical or horizontal openings, nor for circular ones or medium vs. large openings, questioning their body shape awareness. Agility-trained dogs demonstrated faster task completion but did not outperform untrained dogs in accuracy.

Experiment 2 investigated dogs' understanding of object solidity by offering barriers made of materials with different solidity levels (wood, paper, and plant). Dogs generally preferred less solid materials, though agility-trained dogs exhibited greater hesitation, possibly due to reliance on owner cues. Untrained dogs performed better overall, suggesting that contextual factors influence problem-solving.

While dogs demonstrated some awareness of body size and material properties, their recognition of body shape and reliance on environmental cues is yet to be determined. These findings highlight the complexity of self-awareness and provide a foundation for future research into self-awareness and ecological decision-making in animals.

Abstract *(German)*

Körperwahrnehmung ist entscheidend für die Navigation in der Umwelt und ermöglicht es Tieren, effektiv mit ihrer Umgebung zu interagieren. Diese Studie liefert neue Erkenntnisse über die Selbstwahrnehmung von Hunden, indem sie sowohl die Wahrnehmung der Körpergröße als auch das Prinzip der Solidität bei Haushunden (*Canis familiaris*) untersucht. Im Gegensatz zu früheren Untersuchungen, die sich in erster Linie auf die Wahrnehmung der Körpergröße konzentrierten, werden in dieser Studie auch die Wahrnehmung der Körperform und das Verständnis der Hunde für materielle Eigenschaften untersucht, wodurch mehrere „Bausteine" der Selbstwahrnehmung abgedeckt und ein kohärenteres Tiermodell erstellt werden. Darüber hinaus haben wir eine Gruppe von Hunden, die für Agility trainiert wurden, mit untrainierten Hunden verglichen, um einen weiteren Beitrag zur Diskussion darüber zu leisten, wie erlernte motorische Fähigkeiten die Selbstwahrnehmung beeinflussen. Es wurden zwei Experimente mit einem Zwei-Optionen-Paradigma durchgeführt.

In **Experiment 1** wurden Hunde vor Barrieren mit unterschiedlichen Formen und Größen gestellt, um ihre Fähigkeit zu bewerten, Öffnungen basierend auf ihrer Körpergröße und -form auszuwählen. Während die Hunde konsequent zu kleine Öffnungen vermieden, zeigten sie keine klare Präferenz für vertikale, horizontale oder kreisförmige Öffnungen oder für mittelgroße gegenüber großen Öffnungen, was auf eine eingeschränkte Wahrnehmung der Körperform hinweist. Agility-trainierte Hunde bewältigten die Aufgaben schneller, übertrafen jedoch untrainierte Hunde in der Genauigkeit nicht.

In **Experiment 2** wurde das Verständnis der Hunde für die Eigenschaften von Materialien untersucht, indem Barrieren aus unterschiedlichem Festigkeitsgrad (Holz, Papier und Pflanzen) angeboten wurden. Die Hunde bevorzugten im Allgemeinen weniger feste Materialien, obwohl sich Agility-trainierte Hunde zögerlicher zeigten, was möglicherweise auf ihre Abhängigkeit von Signalen des Besitzers zurückzuführen ist. Untrainierte Hunde schnitten insgesamt besser ab, was darauf hindeutet, dass kontextbezogene Faktoren das Problemlösungsverhalten beeinflussen.

Während die Hunde ein gewisses Bewusstsein für Körpergröße und Materialeigenschaften zeigten, bleibt ihre Wahrnehmung der Körperform und ihre Abhängigkeit von

Umweltsignalen unklar. Diese Ergebnisse verdeutlichen die Komplexität der Selbstwahrnehmung und bieten eine Grundlage für künftige Forschungen zur Selbstwahrnehmung und ökologischen Entscheidungsfindung bei Tieren.

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1. Introduction

The level or kind of self-knowledge in non-human animals has been of great interest in several disciplines for years. Despite extensive research efforts, only a limited number of definitive conclusions on whether animals have a sense of self or what they know about themselves have been reached. While some may say that being successful in the mirror test by Gallup Jr. et al. (2002) is a proof for self-knowledge, it has become clear over the past years that first, being able to recognize oneself is a rare capacity among animals, and second, the experimental set-up of the mirror test cannot suit the various sensory or display modalities of different species (Bekoff, 2003; Bekoff & Sherman, 2004; Cazzolla Gatti, 2016; Horowitz, 2017).

Moreover, according to Bekoff & Sherman (2004), self-knowledge is a continuum with three levels: self-referencing, self-consciousness and self-awareness. Self-referencing is characterized by matching characteristics of others against characteristics of yourself and can be non-cognitive (e.g. in immune responses). Self-awareness would already require a brain and allows an individual to discriminate its own possessions from others or differentiate between its own body and those of others. This process can be conscious or unconscious. Lasty, self-consciousness is characterized by sensing that the body you are in is you and by reflecting your own and others' behavior. It also requires a brain but can only be conscious (Bekoff & Sherman, 2004).

Most animals are believed to have a sense of self-awareness, which is a multimodal concept with underlying complex cognitive processes that serve as "building blocks" (Bekoff, 2003; Bekoff & Sherman, 2004; Kaiser, 2016). One of the building blocks is body-awareness, which is "the ability to hold information about one's own body in mind as an explicit object of attention in relation to other objects in the world" (Brownell et al., 2007, p. 1427; Lenkei et al., 2020). In simpler terms, this means being aware of the posture, size, shape and weight of your body (parts) in space and in relation to other animals and objects.

Body-awareness is composed of two parts. First, animals need to perceive themselves as an objective entity with physical characteristics ("*objective self*"). The objective self includes understanding that the self is an object like others but still unique in its shape or form (Moore et al., 2007; Wicklund, 1975). Second, animals need to sense themselves as different from and situated in the environment ("*ecological self*"), meaning they need to understand that they act upon their immediate physical environment and that their actions have consequences (Neisser, 1995, 2010). In order to move through the environment, it is crucial to put the properties of one's own body in relation to the properties of other objects in the environment. Thus, understanding the physical properties (e.g. solidity, continuity and gravity) of objects in the environment, also referred to as physical reasoning, is essential for species with active locomotion. For example, to navigate the environment, it is critical for many non-human animals to understand that objects can be solid and function as a barrier, that movement is continuous even when out of view and that objects fall down when being dropped (Espinosa et al., 2022; Kundey et al., 2010) and thus is thought to be a part of "core knowledge" domains that are innate and deeply rooted in evolutionary history (Espinosa et al., 2022).

Self-awareness and physical reasoning have been tested extensively in humans and human infants (see Brownell et al., 2007; Moore et al., 2007; Rochat, 1995, 1998; Van Den Bos & Jeannerod, 2002) but more recently also with non-human animals. A study on brown rats showed that rats were successful crossing a bridge, that was either loose like a seesaw or fixated, from one shelf to another, by relating their body weight to the strength of support of the bridge (Khvatov et al., 2021). In Asian elephants, body-awareness has been tested by using the "own body as an obstacle" paradigm where subjects were tasked to hand a stick attached to a mat to the experimenter while standing on the mat. Results showed that they were able to understand that their body acted as an obstacle and got off the matt to fulfill the task (Dale & Plotnik, 2017). The same experimental approach has been used in dogs but with added controls for alternative explanations. The dogs reliably left the mat to hand over the stick and did not seem to rely on the tension of the rope tied to the stick or the movement of the mat (Lenkei et al., 2021). Other studies on dogs presented subjects with a single opening differing in size (too small, mid-size and large). Results showed that dogs approached the too small opening significantly later than the large one and the latency to approach the mid-size opening fell in between. It is assumed that the dogs used the mental representations of their body size acquired through experience to decide about the suitability of the opening size (Horowitz et al., 2021; Lenkei et al., 2020). However, it is unclear how much experience with openings/small spaces is required to allow animals to achieve a high-level of body-awareness or whether it makes a difference at all. Infants, for example, become more accurate and show less variability in their movement with the experience they gained (Ishak et al., 2014). Moreover, while many studies have investigated whether animals can estimate their size in relation to their environment, whether they recognize their shape is yet unknown.

To accurately determine what animals truly understand about themselves, it is crucial to identify a coherent animal model that encompasses every “building block” of self-awareness in a manner that aligns with ecological and evolutionary principles. The domestic dog is considered a suitable model species for testing self-awareness as it occupies a special niche – the complex human-environment with many obstacles – and partakes in an array of human-dog interactions (Lenkei et al., 2020) with some of them providing extensive opportunities to learn about their body size and shape (e.g. agility, search & rescue dogs, dogdance). Proprioception and exceptional body-awareness is especially important in agility dogs as they have to decide within milliseconds how to move their body to not throw off a bar at a jump, to balance on the dogwalk when running at high speeds, to navigate through the weaves without hitting the poles and to run through tunnels, that eventually can be smaller than the dog itself depending on the breed (Inkilä et al., 2022b, 2022a). To prevent injuries and perform at a competition level, agility dogs receive a lot of proprioceptive training, strengthening and balance training, which might lead to a better sense of body-awareness (Cullen et al., 2013; Edge-Hughes & Nicholson, 2007; Marcellin-Little et al., 2005).

This work aimed to provide further insight into domestic dogs’ perception of their own body size and body shape by testing them in a two-choice paradigm. In the test set-up, they were presented with a barrier that has two openings that differ in size and shape providing access to a food reward positioned on the other side of the barrier. To reach the reward, the dogs had to pass through one of the openings.
We hypothesized that dogs are aware of their body-size and would therefore choose an opening adequate to their body size and shape. If this were true, we would predict that they would choose a bigger opening more often than a medium sized and too small opening and vertical barriers over horizontal ones since their body is taller than wider when walking and circular barriers over all others. Furthermore, they would show longer latencies to reach the reward once a side is chosen when presented with medium sized or too small barriers or horizontal barriers when compared to the other barriers. If dogs were not aware of their own body size, they would choose randomly between the different barriers.

Due to the likelihood that experience influences body-awareness, we hypothesized that dogs' experience across trials and especially receiving regular agility training would improve performance. Thus, we predicted that if they learned across trials e.g. that we see a training effect in the task both in their attempts to pass through an opening and the latency to walk through it. Moreover, agility trained dogs should outperform untrained dogs in the body-size awareness and solidity task. If training provided no insight, we would detect no differences in performance between the groups.

Furthermore, to test the ecological self, we tested if the animals take the solidity of objects into account by presenting them with two openings covered with either of three different materials (wood, paper or leaves). The dogs chose one of the openings and went through the material to reach a food reward on the other side. We hypothesized that dogs have an understanding of the "solidity of self". They should be aware of the physical properties of different materials that they have encountered prior to the test. The leaves are easy to walk through and allow the dogs to see through them whereas the paper obstructs their view entirely and needs to be destroyed to get to the other side of the fence. The wooden barrier blocks their view as well but cannot be destroyed. Therefore, they would choose the one with the least solidity (plant) over medium solidity (paper) over highest solidity (wood). The latencies would be shortest when the barrier is made of leaves and longest when made of wood. If dogs had no understanding of the "solidity self", we expected to detect no preferences between the materials.

2. General Methods

2.1. Ethical statement

Participation was voluntary and the procedure itself was non-invasive and short. The study was discussed and approved by the institutional ethics and animal welfare committee of the University of Veterinary Medicine Vienna in accordance with internal Good Scientific Practice guidelines and national legislation (approval number ETK-140/09/2023). Written consent by the dog owners was obtained prior to the data collection.

2.2. Subjects

For the study we tested pet dogs of different breeds. To determine the effect of training we had one group of agility-trained dogs and one of untrained dogs per experiment. A dog was considered agility-trained if they regularly participated in agility training and performed at A1 level (lowest category to start in agility competitions in Austria). All owners were recruited using the Clever Dog Lab database or via social media and participated voluntarily. Prior to data collection, the owners had to give their written consent. We planned to test each dog in two experiments. However, if owners were not able to attend on two dates, their dogs participated in only one of the experiments.

2.3. General Experimental Set-up

The experiments were conducted in a test room (6m x 7m) of the Clever Dog Lab in Vienna. The room was divided into two parts by a fence containing two openings (see figure 1). Owners held their dog in a spot equally distant from both openings. The subjects were able to choose between the openings when released by their owners. Owners were asked to cover their eyes during the trials using a sleeping mask. Each trial started with the owner releasing their dog and giving them a search cue upon a signal of the experimenter (knocking on the wall). The trial ended when the dog reached the reward on the other side of the fence or after 60 seconds. The experimenter then signaled the end of the trial by knocking on the wall again. The owner then took off their sleeping mask, called their dog, leashed it and left the room.

The trials were recorded by three different cameras. Two cameras of the same model (Panasonic HC-V777) were mounted on the wall, one above the owner filming the fence and one between the windows filming the owner. Additionally, we used one fish-eye camera (Model: AXIS M3058 PLVE) attached to the ceiling to capture the entire room.

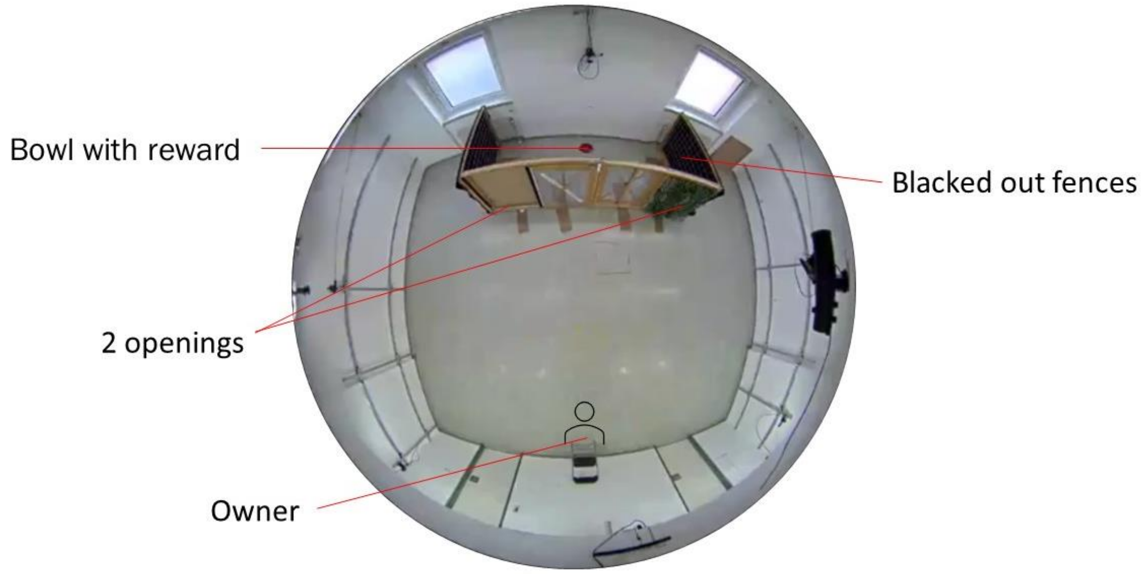

Figure 1: Experimental set-up from above.

2.4. Video Coding

To measure the latencies and note down the side chosen, we coded the recordings in Loopy (http://loopb.io, loopbio GmbH, Vienna, Austria). For both experiments we measured the side approached, side attempted, side chosen, and the latency to walk through the barrier until reaching the reward.

The side approached (left or right) was defined as the side first encountered by the dog within the radius of one body length. The side attempted was considered as the side (left or right) either first touched by the dog (paw, snout, back) or when visibly trying to go through but refraining from it. One side (either left or right) counted as chosen when the dog went through the opening with at least half of its body length. The latency to reach the reward was then defined as the time spent from the first approached side until reaching the reward or until the trial ended.

3. Experiment 1: Shape & Size

In Experiment 1, we aimed to determine if dogs showed a consistent preference for specific shapes or sizes.

3.1. Subjects

In total we tested 49 dogs (29 females, 20 males) in the shape & size experiment. The dog's age ranged from 14 to 140 months with a mean age of 72 months. The group of agility-trained dogs contained 25 individuals, and the group of untrained dogs contained 24 individuals. Each dog had been measured before the start of the experiment. The following measurements were taken: height at withers (HW), body height (BH) and chest width (CW) (see figure 2).

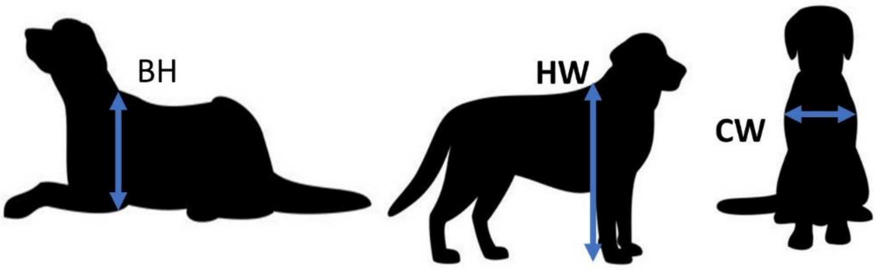

Figure 2: Measurements taken of dogs to adjust size of openings individually. BH = Height at withers when lying down, HW = Height at withers, CW = Chest width

3.2. Methods

3.2.1. Training phase

The experiment started with a training phase where subjects were trained to go through the two openings while one of them was closed. After being released by their owner, the dog was free to go through the opening and get the reward on the other side. We moved on to the test phase as soon as the subject walked through one of the openings 6 consecutive times.

3.2.2. Test phase

The procedure was similar to the training phase. At each opening there was a differently shaped barrier (rectangular or circular, see figure 3) uniquely sized to the measurements of each subject according to calculations from table 1. Subjects faced three different sizes of horizontal and vertical barriers (large enough, medium and too small) and two sizes of circular barriers (large enough and medium). Location and combination of the barriers were randomized and counterbalanced across trials (see table 2). A trial was considered finished after 60 seconds or as soon as the subjects reached the reward on the other side of the fence. The subjects were tested in a single session containing 18 trials.

Table 1: Calculations used to adjust size of the openings to each dog.

	Horizontal	Vertical	Circular (Ø)*
Large enough	HW * the door width	(1.5 * CW) * the door height	BH
Medium size	(2*HW/3) * the door width + 5	CW * the door height	2BH/3

Too small	(1*HW/3) * the door width	(0.5*CW) * the door height	/

*rounded to the closest multiple of 5

Table 2: List of combinations for each trial in Experiment 1.

Combination Number	Left opening	Right opening	Combination Type
1	Horizontal large enough	Vertical large enough	Comparison 1: Effect of shape 1*
2	Horizontal medium size	Vertical medium size	
3	Horizontal large enough	Circular large enough	Comparison 2: Effect of shape 2*
4	Vertical large enough	Circular large enough	
5	Horizontal large enough	Horizontal medium size	Comparison 3: Effect of size horizontal*
6	Horizontal large enough	Horizontal too small	
7	Horizontal medium size	Horizontal too small	
8	Vertical large enough	Vertical medium size	Comparison 4: Effect of size vertical*
9	Vertical large enough	Vertical too small	
10	Vertical medium size	Vertical too small	
11	Horizontal large enough	Circular medium size	Mixed effect*
12	Vertical large enough	Circular medium size	Mixed effect*
13	Horizontal large enough	Vertical medium size	Mixed effect*
14	Horizontal large enough	Vertical too small	Mixed effect*
15	Vertical large enough	Horizontal medium size	Mixed effect*
16	Vertical large enough	Horizontal too small	Mixed effect*
17	Horizontal medium	Vertical too small	Mixed effect*
18	Vertical medium	Horizontal too small	Mixed effect*

** Combination Type for statistical analysis*

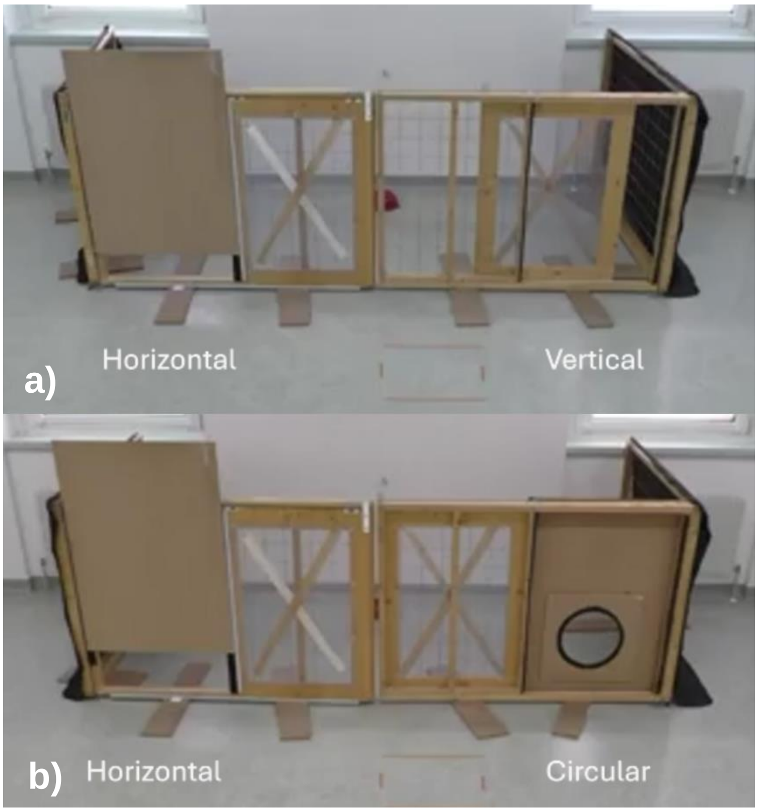

Figure 3: Apparatus with barriers of different shapes attached. a) Horizontal (left) vs. vertical (right); b) Horizontal (left) vs. circular (right)

3.3. Statistical Analysis

For the data analysis and visualization, we used R (version 4.4.1; R Core Team, 2024). The models were fit using the packages *lme4* (version 1.1-35.4; Bates et al., 2015), *survival* (version 3.6-4; Therneau & Grambsch, 2000) and *coxme* (version 2.2-20; Therneau, 2024). For plotting the packages *survminer* (version 0.4.9; Kassambara et al., 2021), *ggplot2* (version 3.5.1; Wickham, 2016) and *ggbeeswarm* (version 0.7.2; Clarke et al., 2023) were used.

To begin with, we assessed the combinations 1-10 which only contained the effect of shape or size but never both. We predefined a "correct" choice for each attribute: circular openings were always designated as correct, and vertical openings were correct over horizontal ones. For size, large openings were considered correct, whereas small openings were not. We categorized these combinations into four groups: Effect of shape 1, Effect of shape 2, Effect of size horizontal and Effect of size vertical. The remaining combinations were classified as “mixed effect” (see table 2).

To analyze choice behavior, we used three Generalized Linear Mixed Models (GLMMs) with a binomial distribution for each group, examining three response variables: the side each dog first approached, the side it first attempted to pass through, and the opening it ultimately chose. In each model, we set the outcome of the trial (coded as 1 for a correct choice and 0 for an incorrect choice) as the response variable, incorporated training, combination number and the interaction of the two as fixed effects, and included subject ID as a random effect to account for variability among subjects. If appropriate, random slopes were added. We also conducted a survival analysis using Mixed-Effects Cox Models (COXME) to assess latencies in reaching the reward, measuring the time from when each subject was within one body length of an opening until it reached the reward bowl. Following our initial analysis of combinations that isolated either shape or size effects, we assessed overall preference. For each remaining combination (combinations 11-18), we applied two-tailed binomial tests ($p=0.5$) to evaluate whether the shape or size of the openings was more salient to the animals. We also applied the p-value correction for multiple comparison using the Bonferroni method. This approach allowed us to systematically examine the relative influence of these attributes on dog choice behavior.
Our main analysis started with a full-null comparison to test for an overall effect. The null model was limited to the intercept (and slope when relevant), excluding other predictors. Upon finding a significant effect, we evaluated the role of the interaction term using the *drop1* function to determine its impact. If the interaction was non-significant, we refined the model by excluding the interaction term and re-fitting it. We then used the *emmeans* package to compute estimated marginal means, which allowed us to determine the probability of the dog choosing the correct option. To assess whether performance differed from chance, we created separate models for agility-trained and untrained subjects, with these models including only the combination number as a fixed effect and a random intercept for each subject. This approach enabled a clear comparison of performance between trained and untrained subjects.

3.4. Results

The presented results only correspond to the reduced models, excluding the fixed effect of interaction between training and combination number. This is due to not detecting any significant effect of the interaction in any of our models ($p>0.05$).

3.4.1. Effect of Shape 1 (Horizontal against Vertical)

The effect of shape 1 compares horizontal to vertical openings of the same size category. We did not find any effect of training or combination number on our key variables. The full-null model comparisons for the side approached (X^2=0.504, p=0.777), side attempted (X^2=3.612, p=0.164) and side chosen (X^2=3.078, p=0.215) were non-significant. The probability to choose the “correct” shape (vertical) was not significantly different between trained and untrained dogs (33.4% for trained dogs and 51% for untrained dogs). Trained dogs did not significantly choose different from chance but there seems to be a trend that they choose to go through the horizontal shape more often than the vertical one (p=0.053). In contrast, the untrained dogs also did not choose different from chance and there seems to be no trend (p=0.884) (see table 3).

Table 3: Effect of Shape 1 (Horizontal vs. Vertical openings) including training

Variable	**Training**	**p-value**	**probability**	**LCL**	**UCL**
Side approached	Trained	0.0508’	36%	0.24	0.501
	Untrained	0.2504	41.7%	0.287	0.559
Side attempted	Trained	0.0264*	31.5%	0.188	0.477
	Untrained	0.3877	43.8%	0.305	0.579
Side chosen	Trained	0.053‘	32%	0.18	0.502
	Untrained	0.884	51.1%	0.371	0.649

To investigate not only the ultimate side chosen but also how the latency to reach the reward differed between groups and combinations, we did a survival analysis (see figure 4). Overall, trained dogs were not significantly faster than untrained dogs but there was a positive trend (hazard ratio=0.437, p=0.08). Moreover, dogs were significantly slower in combination 2 compared to combination 1 (hazard ratio=0.365, p<0.001).

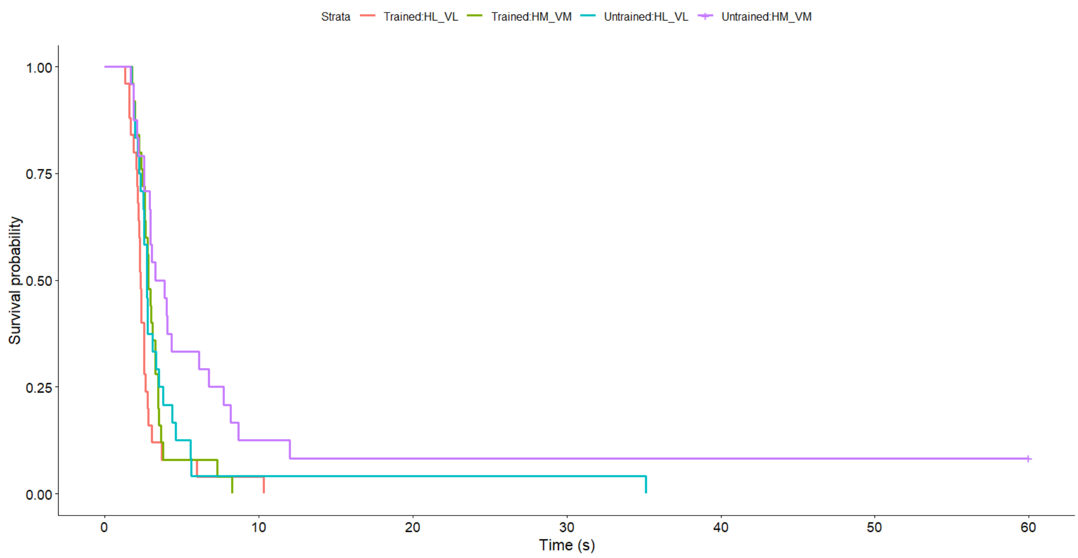

Figure 4: Survival plot for latency to reach reward in Comparison 1

3.4.2. Effect of Shape 2 (Circular vs. Horizontal/Vertical)

The effect of shape 2 compares circular to horizontal or vertical openings of the same size category. We did not find any effect of training or combination number on our key variables. The full-null model comparisons for the side approached (X^2=1.381, p=0.501), side attempted (X^2=3.715, p=0.294) and side chosen (X^2=1.6373, p=0.441) were non-significant. Both groups, agility-trained and untrained dogs performed below chance when it came to choosing to go through the “correct” shape, indicating that they avoided the circular openings.

The probability to choose to go through the “correct” shape was almost the same between the two groups (7% for trained dogs and 7.7% for untrained dogs). Both the trained and the untrained dogs chose significantly from chance and avoided the circular one (trained: p<0.01; untrained: p=0.0029; see table 4).

Table 4: Effect of Shape 2 (Circular vs. Horizontal/Vertical openings) including training

Variable	Training	p-value	probability	LCL	UCL
Side approached	Trained	0.004*	24%	0.142	0.377
	Untrained	0.0032*	27.7%	0.168	0.42
Side attempted	Trained	<0.01*	18%	0.096	0.311
	Untrained	0.0066*	0.1%	<0.001	0.128
Side chosen	Trained	<0.01*	12%	0.055	0.242
	Untrained	0.0029	<0.1%	<0.001	0.066

The survival analysis (see figure 5) showed that trained dogs were significantly faster than untrained dogs in Comparison 2 (hazard ratio=0.432, p=0.01). Our subjects were significantly faster in combination 3 compared to combination 4 (hazard ratio=1.59, p=0.05)

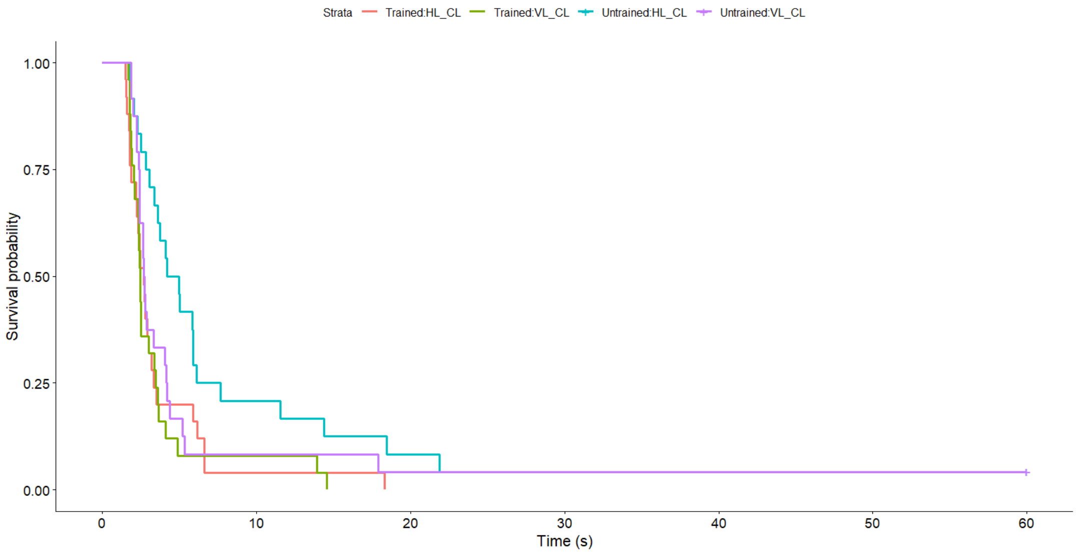

Figure 5: Survival plot for latency to reach reward in Comparison 2

3.4.3. Effect of Size (Horizontal)

The effect of size horizontal compares preferences of different sizes (small, medium, large) within the same shape (horizontal). We did not find any effect of training or combination number on the side approached in our full-null model comparison (X^2=3.948, p=0.267). Both trained and untrained dogs approached the bigger option more often than the smaller one. Moreover, there was no effect of training on the side attempted (p=0.839). Both groups performed at chance level. However, the combination number did make a significant difference. The subjects' attempt to go through the correct side in combination 5 was at chance level (probability=56.3%), whereas they performed significantly above chance in combination 6 (probability=83.7%) and combination 7 (probability=97.9%). Therefore, our subjects reliably attempted the larger option only when the other option was too small. The analysis for the side chosen to go through was only done for combination 5 (Large vs. medium) by using the drop1 function as all other combinations included one too small opening which was impossible to go through. Training had no effect on the side chosen, both groups performed similarly (p=0.951). Also, the probability to choose the "correct" side (in this combination the large opening) was 60% for both agility-trained and untrained dogs, showing again that they had no preference for either side (see table 5).

Table 5: Effect of Size horizontal

Variable	Training	p-value	probability	LCL	UCL
Side approached	Trained	0.0089*	67.2%	0.545	0.778
	Untrained	0.0773'	60.6%	0.488	0.712
Side attempted	Trained	<0.01*	78.7%	0.68	0.865
	Untrained	0.0066*	79.7%	0.686	0.876
Side chosen (combination 5 only)	Trained	0.4244	60%	0.387	0.789
	Untrained	0.4049	60.9%	0.385	0.803

Our survival analysis (see figure 6) showed that overall, trained dogs were significantly faster than untrained dogs (hazard ratio=0.498, p=0.04). Moreover, both groups showed shortest latencies in combination 5 and longest latencies in combination 7 (combination 5 vs. 7: hazard ratio=0.244, p<0.01). Compared to combination 7, dogs were faster in combination 6 but still slower than in combination 5 (combination 5 vs. 6: hazard ratio=0.571, p=0.016).

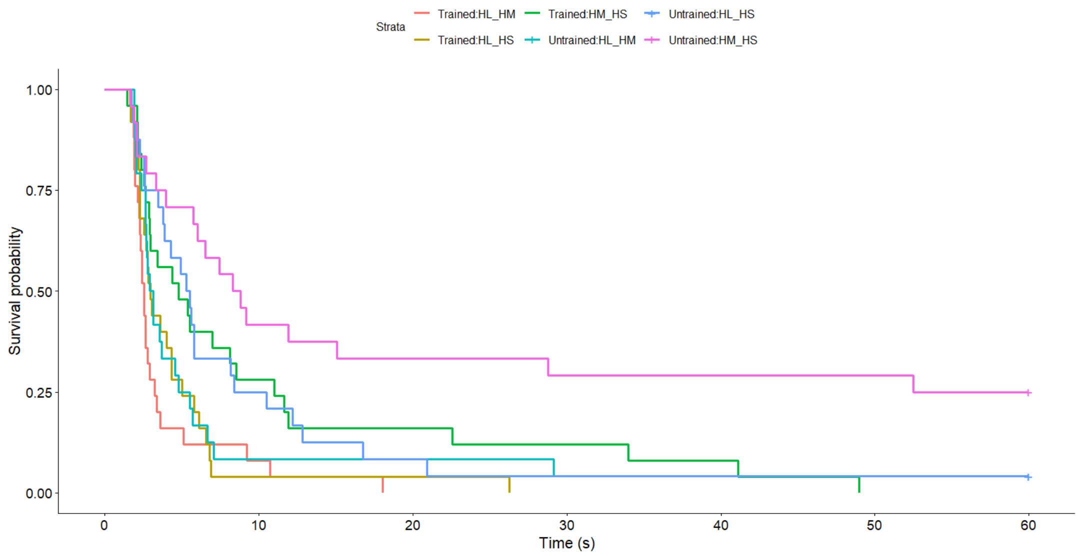

Figure 6: Survival plot for latency to reach reward in Comparison 3

3.4.4. Effect of Size (Vertical)

The effect of size vertical compares preferences of different sizes (small, medium, large) within the same shape (vertical). We did not find any effect of training on the side approached (p=0.726), side attempted (p=0.765) and side chosen (p=0.30, see table 6). Both trained and untrained dogs approached the bigger option more often than the smaller one. Nevertheless, the outcomes for combination number significantly differed from each other. When looking at which side the dogs approached first, they chose the correct side more often in combination 9 (probability=82.3%) than in combination 8 (probability=53.3%) and 10 (probability=47.1%). When it came to the side first attempted the subjects performed significantly above chance for combination 9 (probability=88.2%) and 10 (probability=83%). However, in combination 8 subjects attempted randomly to move through the openings (probability=53.7%). For the side chosen to go through, we again only included combination 8 (large vs. medium) in our analysis as all other combinations included one too small opening which was impossible to go through. Similar to side attempted, dogs chose randomly (see table 6).

Table 6: Effect of size vertical

Variable	**Training**	**p-value**	**probability**	**LCL**	**UCL**
Side approached	Trained	0.03	62.7%	0.514	0.728
	Untrained	0.136	59.3	0.472	0.705
Side attempted	Trained	<0.01*	73.3%	0.622	0.821
	Untrained	0.0048	75.4%	0.584	0.87
Side chosen (combination 8 only)	Trained	1	48%	0.278	0.687
	Untrained	0.3075	62.5%	0.406	0.812

The survival analysis (see figure 7) showed that overall, trained dogs were faster than untrained dogs (hazard ratio=0.638, p=0.010). Moreover, there was a significant difference between combinations. Both groups showed shortest latencies in combination 8 and longest latencies in combination 10 (combination 8 vs. 10: hazard ratio=0.333, p<0.01). Compared to combination 10, dogs were faster in combination 9 but still slower than in combination 8 (combination 8 vs. 9: hazard ratio=0.634, p=0.031).

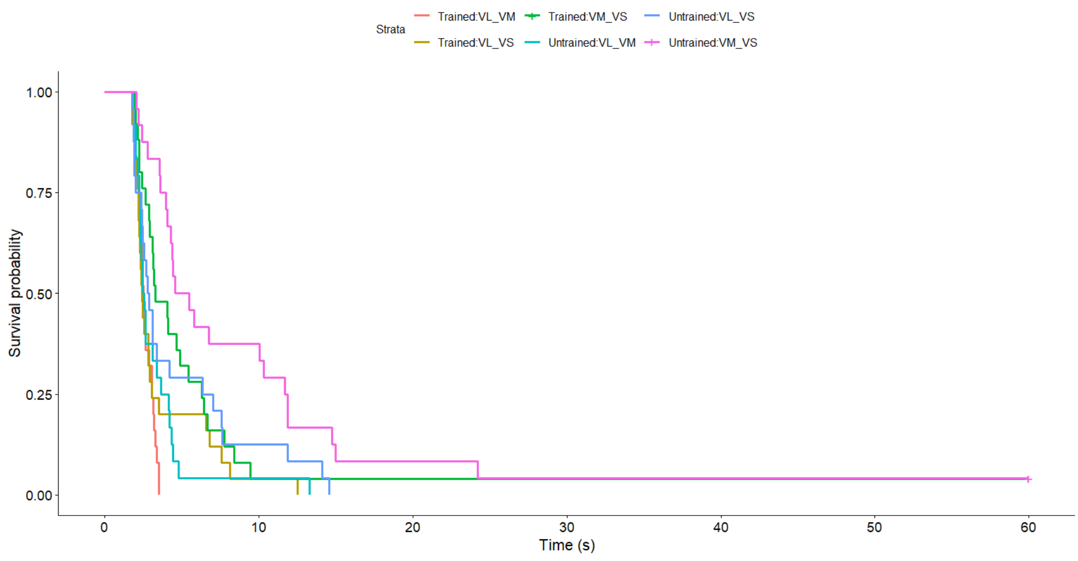

Figure 7: Survival plot for latencies to reach reward in Comparison 4

3.4.5. Mixed combinations of different sizes and shapes

In combinations where shapes and sizes were mixed up (combination 11-18) we only analyzed the side ultimately chosen to go through. Training did not have an effect. To define "correct" choices we used the results from all other comparisons (e.g. no preference between horizontal or vertical; avoiding circular openings; no preference between large and medium openings; choosing large or medium over small openings). For combinations where no preference was expected (e.g. Horizontal large vs. Vertical medium) we defined the "correct" choice to be set by size rather than shape and therefore larger openings would be preferred over medium size.

Both groups chose significantly above chance in all combinations but combination 13 and 15 which we already expected from our results in the other comparisons. That means that the subjects chose the option we defined as being "correct" significantly more than the other option. However, in combination 13 and 15 subjects chose at chance level indicating that our assumption, size would matter more than shape, was not true. In combinations 16, 17 and 18 one of the sides was a small opening meaning that this side was almost impossible to go through and therefore leading to the subjects choosing the other side provided with 100% probability (see table 7).

Table 7: Effect of mixed combinations for side chosen with adjusted p-values for multiple comparison using Bonferroni method

Combination Number	Training	p-value	Adjusted p-value	probability	LCL	UCL

11	Trained	<0.01*	<0.01*	96%	0.796	0.999
	Untrained	<0.01*	<0.01*	100%	0.839	1.000
12	Trained	<0.01*	<0.01*	88%	0.688	0.975
	Untrained	<0.01*	<0.01*	91.7%	0.730	0.990
13	Trained	0.0433*	0.1346	72%	0.506	0.879
	Untrained	0.8318	0.3463	54.5%	0.322	0.756
14	Trained	<0.01*	<0.01*	91.7%	0.730	0.990
	Untrained	<0.01*	<0.01*	100%	0.858	1.000
15	Trained	0.69	1	56%	0.349	0.756
	Untrained	0.0931	1	69.6%	0.471	0.868
16	Trained	<0.01*	<0.01*	100%	0.863	1.000
	Untrained	<0.01*	<0.01*	100%	0.852	1.000
17	Trained	<0.01*	<0.01*	100%	0.846	1.000
	Untrained	<0.01*	<0.01*	95.2%	0.762	0.999
18	Trained	<0.01*	<0.01*	100%	0.858	1.000
	Untrained	<0.01*	<0.01*	100%	0.846	1.000

3.5. Discussion – Experiment 1

To summarize, dogs did not have a significant preference for either vertical or horizontal openings even though we could see a slight trend for agility-trained dogs to prefer horizontal openings. This result did not support our predictions as we assumed dogs would approach, attempt and choose the shape that required less body adaptation, which would have been vertical. Additionally, we saw some dogs hitting the horizontal barrier with their back which reaffirmed our assumption during testing that dogs would choose vertical barriers over horizontal ones. However, looking at the results, this issue seemed to have no effect on the dogs' choice in the following trials.
Both groups avoided the circular opening, no matter of its size. This could be explained by the fact that the dogs had to either lift their legs very high or do a little jump to move through the opening. Although agility dogs are experienced jumping through a tire which is the reason why we expected them to perform better than untrained dogs, they preferred the other opening offered as well. The overall avoidance of the circular shape could be multifactorial and should therefore be further investigated.

All in all, we could not conclude whether dogs are aware of their body shape as they did not show a preference for either presented shape. However, taking into consideration that the presented openings were big enough for the dogs to fit through, maybe shape just did not matter to them.

By offering the dogs two different options, we aimed to minimize the influence of motivation on their decision-making. Contrary to the claim made by Lenkei and colleagues (Lenkei et al., 2020) that a two-choice paradigm could lead dogs to select the "more convenient" option, we observed no such effect. However, even if they had chosen the “more convenient” option, this result would not be detrimental to the assumption that dogs are aware of their body size because they would still have to decide which opening is the “most convenient” according to their body size. When being confronted with a medium-sized barrier that is just the right size and a large-sized barrier that offers more room to move through, our subjects had no preference for either barrier. However, when confronted with a barrier that was too small to pass through, our subjects decided not to approach and attempt this opening but rather opt for the side where they actually could pass through.

According to our hypothesis that dogs are aware of their body size, we expected them to always prefer the large option. While this has not proven to be true as the dogs had no preference for a medium vs. large opening, one could still argue that they were aware of their size because they did approach and attempt the small opening way less often than the other two openings. As expected, and against Lenkei et al.’s (2020) statement that a one-choice paradigm should be used in such an experiment, not only could we test the dogs’ preference when directly being offered two differently sized barriers but we could even minimize the effect of motivation in our two-choice paradigm, which might have caused dogs to squeeze through a small opening because there was no other option available in a one-choice-paradigm.

Furthermore, Lenkei et al. (2020) measured the latency to approach while we measured latency to reach the reward. In our results we can clearly see that measuring the latency to approach did not provide a lot of information as our subjects chose randomly when approaching but then still made a “correct” decision in attempting and choosing one of the openings.

Throughout almost all combinations the latencies of agility-trained dogs to reach the reward were lower compared to untrained dogs. Faster times could be explained by the fact that agility-trained dogs were specifically trained to make quick decisions, be confident while solving problems and to do so at a high pace. However, agility-trained dogs did not significantly outperform untrained dogs in accuracy.

4. Experiment 2: Object solidity

4.1. Subjects

In total we tested 51 dogs (28 females, 23 males) in the solidity condition. The dog's age ranged from 15 to 141 months with a mean age of 70 months. The group of agility-trained dogs contained 26 individuals, and the group of untrained dogs contained 25 individuals.

4.2. Methods

4.2.1. Familiarization phase

During this phase the subjects were tested in the testing room with a small box where one side was made of different material (wood, paper, or green plant) than the rest of the box (see figure 8). Food was placed inside the box to encourage foraging. Each subject took part in 3 familiarization trials per material, so 9 trials in total. A trial ended after 1 minute or as soon as the subject opened the box.

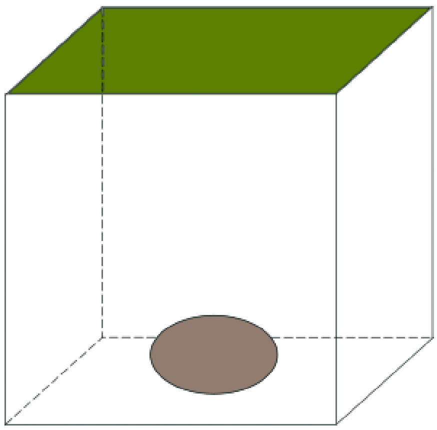

Figure 8: The wooden box used for the familiarization phase. The green cover represents the side that was built out of a different material (either plant, paper or wood). The other sides of the box were built of wood. The brown object in the box represents a piece of food placed there for motivation.

4.2.2. Test phase

Similar to experiment 1, we used a two-choice paradigm where the subject could choose between the two openings in the fence. However, in this experiment, the shape of both openings remained the same, but the openings were covered by a material of different solidity: paper, plant or wood (see figure 9). The position of the materials was randomized and counterbalanced across trials. A trial was considered finished after 1 minute or as soon as the subjects reached the reward on the other side of the barrier. Subjects were tested in a single session containing 18 trials. Therefore, each subject was provided with 6 trials per combination of materials (see table 8).

Table 8: List of combinations in Experiment 2.

Combina-tion No.	Material combinations	
1	Green plant	Paper
2	Green plant	Wood
3	Paper	Wood

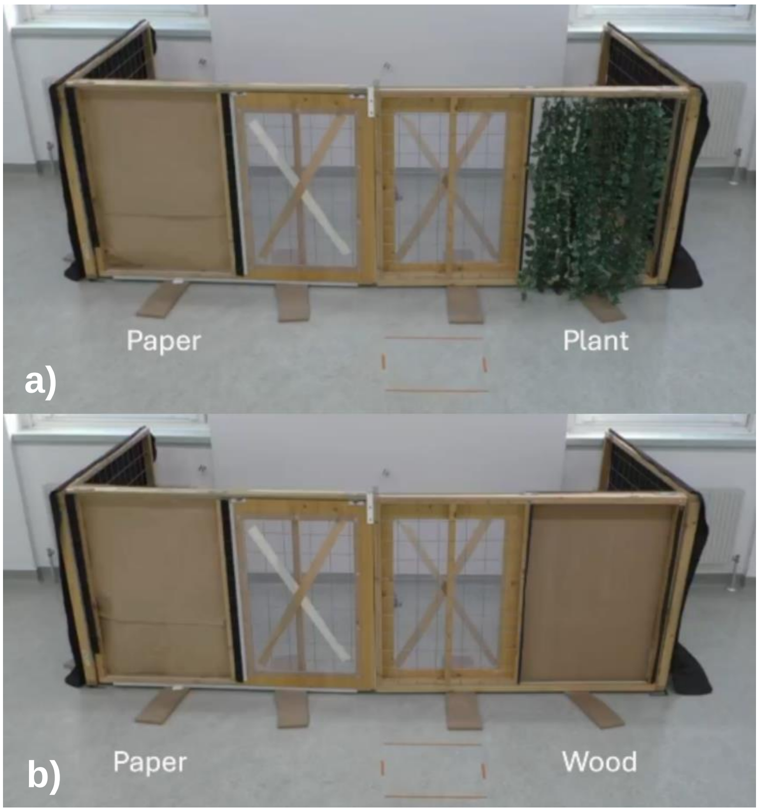

Figure 9: Apparatus with barriers of different solidity attached. a) Paper (left) vs. decorative plastic plant (right); b) Paper (left) vs. wood (right)

4.3. Statistical Analysis

The statistical analysis remained mainly the same as in experiment 1. However, in experiment 2, we focused on material preference, designating plant-based openings as “correct” and wood-based openings as “incorrect” choices, and including the z-transformed trial number as an additional predictor in our models. In the model examining the side ultimately chosen by the dogs, only the first combination (plant vs. paper) was included because the other two combinations (plant or paper vs. wood) did not allow for an incorrect choice

4.4. Results

Both agility training and material combination significantly influenced the probability of a dog approaching and attempting the correct choice, while the trial number did not have a significant effect. Specifically, the z-transformed trial number yielded high p-values for both approach ($p=0.979$) and attempt ($p=0.156$), indicating no meaningful impact. When examining the probability to approach the “correct” barrier (see figure 10), the subjects performed very similarly in combinations 1 (plant vs. paper) and 2 (plant vs. wood). In combination 3 (paper vs. wood), their performance was only slightly worse, and the difference was not statistically significant. The probability of attempting the “correct” barrier (see figure 11) was highest for combination 2, lowest for combination 3, and combination 1 fell in between. Lastly, the probability to actually go through the “correct” barrier was above chance for both groups of dogs. Untrained dogs performed slightly better than untrained dogs, however, this difference was not statistically significant (see figure 12).

Across all combinations, untrained dogs outperformed trained dogs, suggesting that training may have inadvertently affected performance (see table 9).

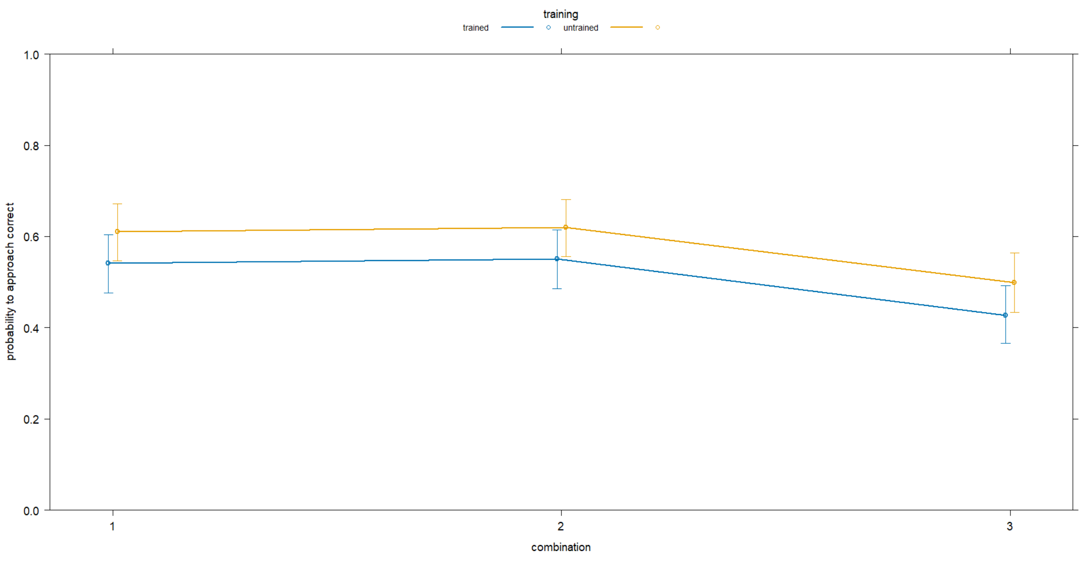

Figure 10: Probability of agility-trained and untrained dogs to approach the "correct" barrier. Combination 1: Plant vs. Paper; Combination 2: Plant vs. Wood; Combination 3: Paper vs. Wood.

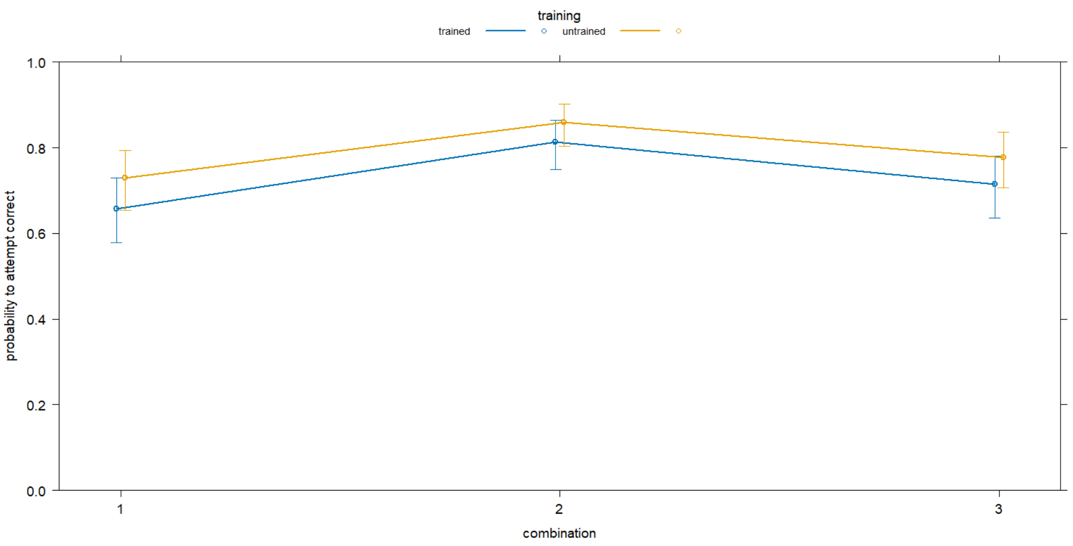

Figure 11: Probability of agility-trained and untrained dogs to attempt the "correct" barrier. Combination 1: Plant vs. Paper; Combination 2: Plant vs. Wood; Combination 3: Paper vs. Wood.

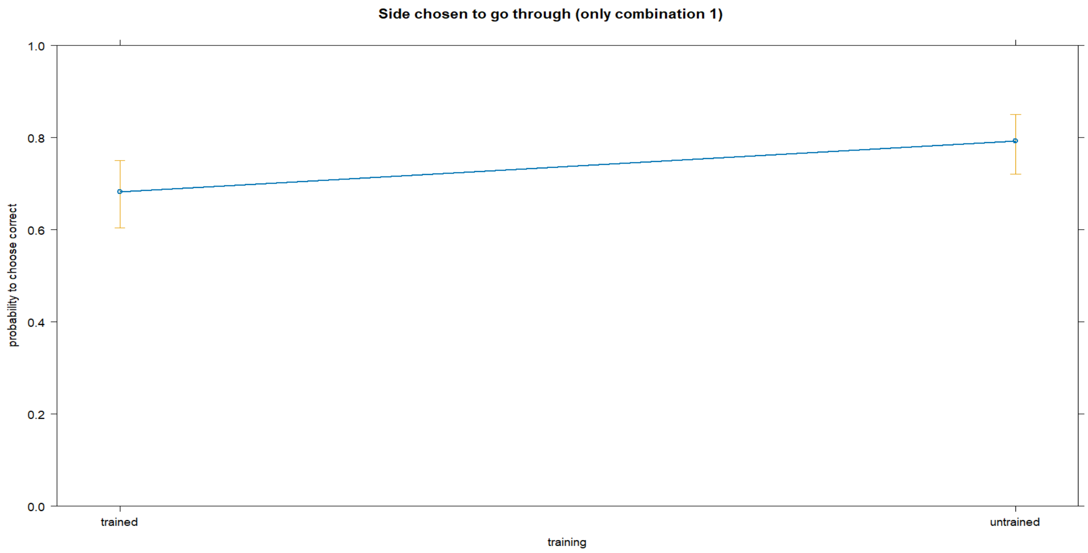

Figure 12: Probability of agility-trained and untrained dogs to go through the "correct" barrier (side chosen), only for Combination 1 (Plant vs. Paper).

Table 9: Effect of training on side first approached, side first attempted and side chosen

Variable	Training	p-value	probability	LCL	UCL
Side approached	Trained	0.0321	50.6%	0.461	0.552
	Untrained		57.7%	0.531	0.623
Side attempted	Trained	0.1058	73.4%	0.675	0.785
	Untrained		79.4%	0.740	0.840
Side chosen (combination 1 only)	Trained	0.0282	68.2%	0.604	0.750
	Untrained		79.3%	0.721	0.851

Additionally, we measured the latencies to reach the reward in all three combinations. The survival analysis (see figure 13) showed that there was no significant effect in training (hazard ratio=0.931, p=0.573) but we did detect a significant difference between combinations.

Both groups showed shortest latencies in combination 2 (combination 1 vs. 2: hazard ratio=0.695, p<0.01) and longest latencies in combination 3 (combination 1 vs. 3: hazard ratio=0.195, p<0.01).The latency for combination 1 was in-between.

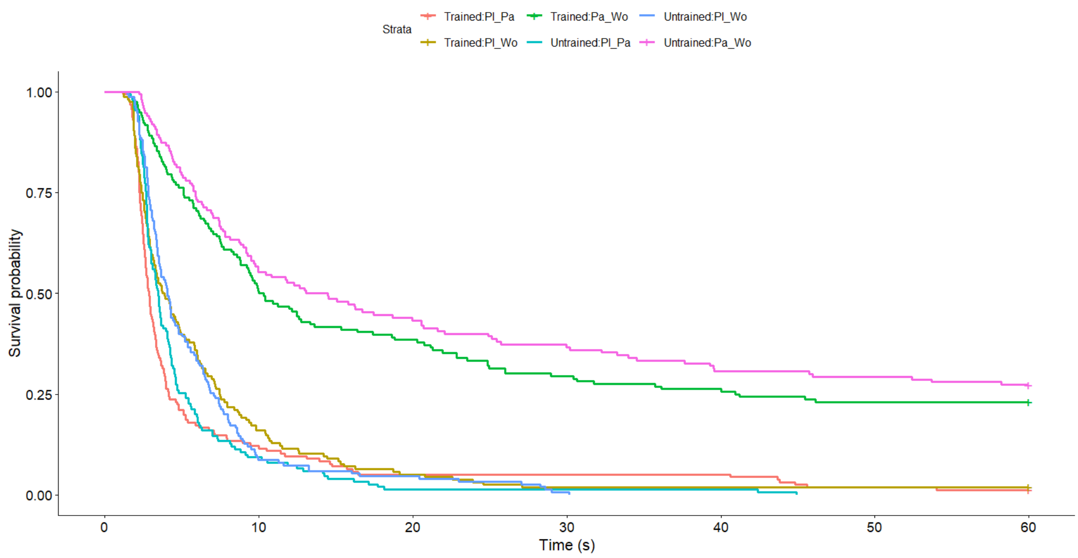

Figure 13: Survival plot for latency to reach reward in Experiment 2 for all material combinations.

4.5. Discussion – Experiment 2

To sum up, our results showed that dogs can acquire certain information about materials (like their physical properties) just after a short encounter and based on that decide whether they can move through it. Our subjects approached randomly at first but then had a clear preference for the softer materials when attempting to move through the opening. This might be because they needed to come closer to the barriers to assess the solidity and decide on one of the materials. Moreover, we found a significant effect of training (agility-trained vs. untrained dogs) on the probability to opt for the "correct" barrier where untrained dogs performed above chance while agility-trained dogs performed at chance level. These findings suggest a complex interaction where training and combination type affected approach and attempt behaviors in varied ways, with untrained dogs unexpectedly performing better.

We expected combination 2 (plant vs. wood) to be the easiest as the two barriers were visually easy to distinguish, and the wooden barrier was impossible to go through anyway, which made the decision-making process faster. In contrast, combination 1 (plant vs. paper) and combination 3 (paper vs. wood) both included paper which could be destroyed but hesitation was expected due to dogs usually not being allowed to destroy things. This expectation could be confirmed by our results. Not only was the probability to attempt "correctly" highest in combination 2 but also the latency to reach the reward was shortest. Furthermore, our expectation that combination 3 (paper vs. wood) would be the hardest was confirmed as well. The dogs approached and attempted this combination “correctly” with a lower probability, almost at chance level, and showed the longest latencies to reach the reward overall. These results can probably be explained by the dogs’ difficulty distinguishing between wood and paper since the dogs had to rely only on visual information. Plant and wood were clearly different in colour and solidity, whereas wood and paper looked similar (see figure 9) and could almost only be differentiated by their solidity. Moreover, walking through paper required destroying the barrier which more obedient dogs might have felt inhibited doing. Despite this difficulty, we could show that dogs indeed noticed the different levels of solidity and, as we hypothesized, found the plant easiest and the wood hardest to walk through.

We expected that if dogs understood the different solidities of different materials, they would choose the one with least solidity (plant) over medium solidity (paper) over highest solidity (wood). Our results point in that direction as the probability of going for the “correct” material was highest in the combination of plant vs. wood and the latency to reach the reward was shortest as well, suggesting that dogs do understand the solidity of barriers even after just a short interaction with them. Although it might have been harder for the dogs to spot the difference between paper and wood as they looked very similar, the fact that they did approach the paper more often than wood further indicates that they understood the properties of the materials. Taking this into consideration we suggest to further investigate this research question by including more materials and making them easier to distinguish by choosing different colours.

What we did not expect was that the untrained dogs outperform the agility-trained dogs in all combinations. Even though agility training per se would not have a huge impact on the dogs’ performance in this task, dogs receiving agility training are generally confronted with many stimuli and thought to be more confident and driven (Carlson, 2024). In our experiment 2 the group of untrained dogs performed better than the group of agility-trained dogs, hence our data does not support this statement. However, the fact that our prediction and results do not match could be due to the fact that dogs that actively train and compete in agility are generally more obedient. Agility-trained dogs are not only more obedient in training itself, but usually also receive stricter training in everyday life and are therefore better able to adhere to the rules imposed. As most owners forbid their dogs to destroy things, it is possible that those dogs that have received more training do not feel confident enough to destroy something without explicit instructions. Therefore, these dogs often sat in front of the fence, looking at their owner and waiting for their feedback. A study by Marshall-Pescini et al. (2009) comparing trained and untrained pet dogs' performance in an "solvable" vs. "unsolvable" task has reported the same: agility dogs alternated their gaze between apparatus and human more frequently and looked longer at the human than untrained dogs. On the other hand, untrained dogs explored their environment on their own maybe because they adhere less to rules and have less inhibitory control.

5. General discussion

In this study, we examined animal choice behavior in response to different combinations of openings, focusing on attributes like shape, size, and material. Dogs have been successfully used as a model species to investigate different aspects of body- and self-awareness in an ecological context (Dobos & Pongrácz, 2025; Lenkei et al., 2020, 2021; Pongrácz et al., 2023). Similarly to Lenkei's and colleague's (2020), we investigated whether dogs have a mental representation of their own body size. In contrast to their method, we used a two-choice paradigm. In addition, we included a new approach to investigate the perception of body shape in dogs and dog's understanding of different materials. To complete the portrait, we evaluated the impact of experience in the context of self-awareness by comparing a group of agility-trained dogs to a group of untrained dogs.

In **Experiment 1**, dogs demonstrated an awareness of their body size by consistently avoiding openings too small to navigate, supporting the idea that they can mentally represent their physical dimensions. These results align with findings from studies on dogs using a "detour an obstacle or shortcut" approach. Dogs successfully relied on their body size to assess the size of an opening for the shortcut and opted for the detour when the opening was too small (Dobos & Pongrácz, 2025; Pongrácz et al., 2023). Moreover, we could successfully show that against Lenkei et al.'s (2020) statement a two-choice paradigm does not lead to dogs choosing the "more convenient"

option. If this was true, they would have had a preference for the large openings compared to the medium-sized openings, but this was not the case.
The dogs' lack of preference for specific shapes (e.g. vertical or horizontal) and avoidance of circular openings could suggest limitations in their body shape awareness. However, it could also be explained by simply not caring for the shape as long as the opening is big enough to comfortably fit through it. Similar results have been found in developmental studies with human infants (Franchak & Adolph, 2012) that highlighted that in door choice tasks making the "wrong" decision does not come with high costs. Remarkably, the children avoided too small openings more reliably when the consequences switched from lower-cost entrapment to higher-cost falling down. There might have been no difference cost-wise for dogs between the different shapes.
In studies with children, it was found that the more experience they gained in a locomotor task, the more precise their performance became (Ishak et al., 2014). Furthermore, Horowitz et al. (2021) delivered possible evidence that dogs do update the perception of their body with experience in a task where differently sized sticks were carried through an opening. However, agility-trained dogs, while presumably more experienced in tasks involving assessment of their body size, did not significantly outperform untrained dogs in accuracy. This indicates that training and experience may influence behavior differently than anticipated. Future research could investigate how specific experiences shape an animal's innate sense of size.

In **Experiment 2**, dogs showed some understanding of the solidity principle. They displayed tendencies to avoid certain materials, such as wood, and consistently attempted the "correct" barrier above chance in all combinations. While we have not found studies using a similar approach for testing the "solidity self", assessing the material's characteristics visually surely played a pivotal role in this task. Humans and capuchin monkeys have been shown to perform similarly well in a task where images representing different kinds of material had to be categorized. Capuchins performed especially well when categorizing images of a well-known material like fur (Hiramatsu & Fujita, 2015). It is therefore likely that dogs also have a good ability to visually distinguish between different materials, especially if they have already been confronted with them in everyday life.
Unexpectedly, untrained dogs performed better than agility-trained dogs, who performed at chance level. However, our results align with the findings of Müller et al.'s

(2014) study testing dogs in a solidity task. Two transparent tubes were baited with a treat and a barrier inserted either in front or behind the treat. The tubes were then tilted and the dogs had to choose the tube where the treat was not blocked from falling out. Not only did none of the dogs succeed in this task, but they also showed no learning effect across trials, implying that experience does not matter in this context.
Moreover, during the experiment, agility-trained dogs were observed sitting in front of the fence when they were not successful after a few attempts and looking at the owner. This anecdotal observation suggests that agility-trained dogs might rely more on human cues in problem-solving, which were absent in the experimental context. Similar effects have been observed in studies comparing the performance of trained vs. untrained pet dogs in an "unsolvable" task (Marshall-Pescini et al., 2009). Agility dogs shifted their gaze between the apparatus and the human more often and gazed at the human for longer periods compared to untrained dogs.

These results highlight the complexity of the different aspects of self-awareness, especially body-awareness. Dogs seem to be aware of their size to a certain degree and have shown understanding of different material's properties. Whether they are aware of their body shape or if other parameters such as opening size play a more vital role in their decision-making remains unclear. Agility training, although advantageous in certain contexts, did not enhance overall problem-solving performance in this study.
This work underscores the need for further research to clarify the nuances of canine self-awareness and problem-solving abilities, particularly in relation to their ecological and experiential backgrounds. By refining methodologies and exploring broader contexts, future studies can build on these findings to better understand how dogs perceive and interact with their physical environment.

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