

1 **Effect of age on discrimination learning,**  
2 **reversal learning, and cognitive bias in family**  
3 **dogs**

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13 **Abstract**

14 Several studies on age-related cognitive decline in dogs involve laboratory dogs  
15 and prolonged training. We developed two spatial tasks that required a single one-  
16 hour session. We tested 107 medium-large sized dogs: “young” (N=41, aged 2.5–  
17 6.5 years) and “old” (N=66, aged 8–14.5 years). Our results indicated that, in a  
18 discrimination learning task and in a reversal learning task, young dogs learned  
19 significantly faster than the old dogs, indicating that these two tasks could  
20 successfully be used to investigate differences in spatial learning between young  
21 and old dogs. We also provide two novel findings. First, in the reversal learning,  
22 the dogs trained based on the location of stimuli learned faster than the dogs  
23 trained based on stimulus characteristics. Most old dogs did not learn the task  
24 within our cut-off of 50 trials. Training based on an object’s location is therefore  
25 more appropriate for reversal learning tasks. Second, the contrast between the  
26 response to the positive and negative stimuli was narrower in old dogs, compared  
27 to young dogs, during the reversal learning task, as well as the cognitive bias test.  
28 This measure favours comparability between tasks and between studies.  
29 Following the cognitive bias test, we could not find any indication of differences  
30 in the positive and negative expectations between young and old dogs. Taken  
31 together, these findings do not support the hypothesis that old dogs have more  
32 negative expectations than young dogs and the use of the cognitive bias test in  
33 older dogs requires further investigation.

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*Keywords: reversal learning; cognitive bias; dog; learning; memory; ageing*  
AD, Alzheimer Disease; CB, Cognitive Bias; CBS, Cognitive Bias Score; CCDS,  
Canine Cognitive Dysfunction Syndrome

## 9 **Introduction**

### 10 **The family dog as a model for human ageing**

11 An increasing amount of evidence describes the domestic dog (*Canis*  
12 *familiaris*) as a good translational model for the study of ageing (e.g. Cotman &  
13 Head, 2008; Cummings et al., 1996; Kaeberlein, Creevy & Promislow, 2016;  
14 Head, 2013; Neus Bosch, Pugliese, Gimeno-Bayón, Jose Rodriguez & Mahy,  
15 2012; Schütt et al., 2016). Both dogs and humans spontaneously develop similar  
16 medical conditions that increase the risk of death, as they age, such as cancer  
17 (Hoffman, Creevy, Franks, O'Neill & Promislow, 2018). Behavioural changes,  
18 such as increased anxiety, confusion, alteration of the sleep-wake cycle, may be  
19 similarly observed (e.g. dog: Landsberg, Nichol & Araujo, 2012; human: Delphin-  
20 Combe et al., 2016). This body of evidence may reflect a naturally occurring and  
21 age-related cognitive decline, which follows similar pathways in dogs as it does in  
22 humans (Head et al., 1995; Head, 2013). For example, beta-amyloid accumulation  
23 has been observed in dogs as early as 9 years of age in the brain region of the  
24 prefrontal cortex and from 14 years on in the entorhinal cortex (Head, McCleary,  
25 Hahn, Milgram & Cotman, 2000). Atrophy of the cerebral cortex and  
26 enlargement of the brain ventricles have also been described in MRI (Magnetic  
27 Resonance Imaging) scans of a group 16 years old dogs (Kimotsuki et al., 2005)  
28 and in morphometry studies of the cerebral ventricles of both young and old dogs  
29 (2-5 years vs 10-12 years, Gonzalez-Soriano et al., 2001). One study looked at  
30 MRI scans of a group of 18 dogs aged between 4 and 15 years (with age treated as  
31 continuous variable), observing a non-linear relationship between age and brain  
32 ventricles enlargement, cortical atrophy. Interestingly, individual differences were

1 also detected, as one 6 year old dog in the sample was as severely affected as the  
2 14 year old dogs in the group; this suggests that some individuals can develop  
3 age-related brain degeneration before others and this can be as early as 6 years of  
4 age (Su et al., 1998). The same dogs had been tested for their cognitive  
5 performance in a different study (Head, Callhan, Muggenburg, Cotman &  
6 Milgram, 1998), but no relationships between cognitive findings and brain  
7 changes was reported (Su et al., 1998). The dogs had been tested for cognitive  
8 performance up to 2 years prior to the MRI scanning (Su et al., 1998; Head et al.,  
9 1998) and the results of the cognitive tests were reported according to 3 distinct  
10 age groups (young: < 5 years, middle aged: 5-10 years, old: 10+ years; Head et  
11 al., 1998), which made any comparison difficult to interpret. Studzinski et al.,  
12 (2006) also investigated cognitive decline in dogs; they observed spatial deficits  
13 starting from the age of 6 and reported that age alone predicted 48.2% of the  
14 variability in learning in a task to assess memory. Overall, a large body of  
15 evidence indicates that functional decline in cognitive domains, such as learning,  
16 memory, executive function, and spatial function, occurs similarly in dogs and  
17 humans as they age (for reviews, Cotman & Head, 2008; Head et al., 2013). It  
18 should however be noted that, in this body of research, it is difficult to evaluate  
19 the effect of age alone as these findings are rarely adjusted to the lifespan  
20 variability that is due to factors such as breed, size, or weight (Szabó et al., 2016).

21 In addition to the physiological reasons described above, the use of family  
22 dogs as models for ageing research is also supported by ecological reasons.  
23 Through their unique domestication history, dogs have adapted to a specific niche,  
24 i.e. the human social environment (Miklósi, Polgárdi, Topál & Csányi, 1998;  
25 Hare, Brown, Williamson & Tomasello, 2002). However, a large proportion of the  
26 research on dog cognitive decline involves purpose-bred and raised laboratory  
27 animals (Head, 2013 for a review). It should be noted that laboratory conditions  
28 are unrelated to animals' natural environment (Wood, Desjardins & Fernald,  
29 2011). There is some evidence that family dogs (i.e. dogs living with humans as  
30 pets) and purpose-bred research dogs (i.e. kennel reared domestic dogs) diverge in  
31 their performance during some cognitive tasks (Lazarowski & Dorman, 2014).  
32 Indeed, it has been argued that dogs residing long-term in kennel environments  
33 may be affected by cognitive deficits, due to the lack of stimulation provided by  
34 their living environment (Miklósi & Topál, 2011; Mongillo et al., 2013). Thus,

1 results from canine cognitive tests, when performed in conditions similar to those  
2 of the human environment, are likely to have strong ecological validity (Waters,  
3 2011). Family dogs, which share the same living environment as humans, are  
4 promising subjects for research that is both clinically relevant and provide the  
5 necessary vertical integration of findings originated from invertebrate and rodent  
6 models (Waters, 2011). Consequently, studies on family dogs' cognitive ageing  
7 have begun to emerge (e.g. Chapagain et al., 2017; González-Martínez et al.,  
8 2013; Heckler, Tranquilim, Svicero, Barbosa & Amorim, 2014; Mongillo et al.,  
9 2013; Piotti et al., 2017; Wallis et al., 2016; Wallis et al., 2017). One remaining  
10 issue is that some of these tests still require prolonged and complex procedures  
11 (discussed below); this limits the replicability of such studies, especially outside  
12 of the laboratory setting (Heckler et al., 2014 for a discussion). The importance of  
13 replicability is being discussed in psychology research, as replications and data  
14 reproducibility are necessary to generalise research findings to the general  
15 population (Westfall, Judd & Kenny, 2015), and further efforts should be made to  
16 increase the replicability of research (Asendorpf et al., 2013).

### 17 **Cognitive testing of ageing dogs**

18 Decline in the spatial function (i.e. the ability to perceive, remember, and  
19 manipulate information within a spatial context, Tapp et al., 2003a), pertaining to  
20 executive function (i.e. the selection and monitoring of behaviours for the  
21 attainment of goals, Malenka, Nestler & Hyman, 2009), and learning is a part of  
22 the normal ageing process (Cotman & Head, 2008). Impairment in the spatial  
23 function is particularly of interest because it may be detected before other  
24 cognitive deficits emerge (e.g. Dog: Head et al., 1995; Studzinski et al., 2006;  
25 Piotti et al 2017; Human: Becker et al., 1988). Reversal learning tasks are often  
26 used to detect changes in these two domains as they rely on the dog's ability to  
27 differentiate and mentally adjust previously learned behaviours (Cotman & Head,  
28 2008; Milgram et al., 1994). Dogs are initially trained to discriminate between  
29 two stimuli (one associated with a reward, usually food, and the other with no  
30 reward). Following a delay period, the dogs are presented with the same stimuli,  
31 though the discrimination is reversed. Thus the subjects must inhibit their  
32 previously learned response to the rewarded object (perseverative behaviour), and  
33 learn a new association between the previously unrewarded object and the food

1 reward (Milgram et al., 1994). Older dogs typically require a longer time to learn  
2 the associations and commit more errors than younger dogs (Chan et al 2002;  
3 Head et al., 1998; Mongillo et al., 2013; Studzinski et al., 2006; Salvin et al.,  
4 2011). However, in the literature, grouping based on dogs' age often varied  
5 between studies. One study compared old and young dogs, classifying young dogs  
6 as 3-5 years and old dogs as 9-12 years (Chan et al., 2002). Another study looked  
7 at age both as a continuous variable and after splitting their population into young  
8 (< 8 years) and old dogs ( $\geq$  8 years; Mongillo et al., 2013). Others chose more  
9 than one cohort; for example, Head et al. (1998) compared young (< 5 years),  
10 middle aged (6-9 years) and old dogs (>10 years), while Studzinski et al. (2006)  
11 split their sample into 6 cohorts (puppies < 1 years, young 1-2.99 years, adults 3-  
12 5.99 years, middle-aged 6-7.99 years, old 8-9.99 years, senior 10-11.99 years).  
13 Authors do not always provide the rationale behind their grouping choices or they  
14 base it on literature about other species (e.g. primates, Head et al., 1998).  
15 However, interestingly, Studzinski et al. (2006) observed deficits in the spatial  
16 function from the age of 6 and decline in the performance of reversal learning  
17 tasks has been related to age-associated atrophy of the frontal lobe and possibly  
18 cortical areas such as the hippocampus and entorhinal cortex (Tapp et al., 2004;  
19 Siwak-Tapp, Head, Muggenburg, Milgram & Cotman, 2008). It should be noted  
20 that, in some studies, on simple visual discrimination tasks and procedural  
21 learning measures, aged dogs performed as well as younger subjects (Milgram et  
22 al., 1994). Authors have suggested that these results may reflect differential  
23 susceptibility of various cognitive functions to ageing (Head, 2013) – reversal  
24 learning being the more sensitive measure (Milgram et al., 1994). Szabó et al.  
25 (2016), however, argued that the disregard of intrinsic and extrinsic factors, such  
26 as gender or social environment, may be an underlying cause of inconsistency in  
27 the ageing research findings, which may be addressed through more standardised  
28 identification of ageing phenotypes (Szabó et al., 2016). While this may be  
29 achieved with testing large and diverse populations, such as those of family dogs,  
30 it is also not always feasible due to the training methods of the existing research  
31 protocols, which require days or hours of practice. For example, Mongillo et al.  
32 (2013) developed a maze-based navigation task designed as learning and reversal  
33 learning tasks to test the effect of age on cognitive performance. Comparing dogs  
34 younger and older than 8 years, the authors were able to detect an effect of age in

1 the reversal task but not in the learning task or in a retention phase – where dogs  
2 were tested 2 weeks after the learning task (Mongillo et al., 2013). However, the  
3 test required several weeks to be performed as well as a large apparatus, which  
4 makes the procedure difficult to reproduce, e.g. with diseased and demented dogs  
5 or in veterinary clinical settings.

## 6 **Measuring emotional changes in aged dogs**

7         There is evidence that, in humans, cognitive state and mood, i.e. long term  
8 emotional states, are closely intertwined. For example, depression and emotional  
9 dysregulation are related with deficits in working memory, alteration of inhibitory  
10 processes, especially in the presence of negative stimuli, and inability to use  
11 rewarding stimuli (for a review: Gotlib & Joormann, 2010). Moreover, humans’  
12 risk of developing depression increases as they age, e.g. due to sleep-disturbance  
13 and disability (Cole & Dendukuri, 2003), which is in turn a risk factor for the  
14 development of Alzheimer Disease, a type of dementia (Ownby, Crocco &  
15 Acevedo, 2006). Therefore, frailty has an overall negative impact on the  
16 emotional state and quality of life of elderly people (Delphin-Combe et al., 2016).  
17 Interestingly, geriatric conditions are considered reasons of welfare concern in  
18 relation to the quality of life and welfare of dogs as well (Yeates & Main, 2009).  
19 According to dog owners, aged pet dogs present behaviour symptoms that are  
20 very similar to those reported in humans, such as increased anxiety, alteration of  
21 the wake-sleep cycle, and disorientation (Landsberg et al., 2012; Madari et al.,  
22 2015; Neilson, Hart, Cliff & Ruehl, 2001). These have a rather high prevalence,  
23 ranging from 28% in 11–12 years old dogs to 68% in 15–16 years old dogs  
24 (Neilson et al., 2001). However, to our knowledge, no attempts have been made to  
25 investigate the relationship between age-related changes in emotional states and  
26 cognitive decline. There are recommendations on monitoring the quality of life of  
27 old dogs, however the existing methods are prone to subjectivity (Yeates & Main,  
28 2009). For this reason, it was recently suggested that monitoring quality of life in  
29 old dogs may benefit from the use of objective methods such as those based on  
30 changes in cognitive performance as measured through behaviour tests (Piotti,  
31 2017).

32         One such test is the “cognitive bias test”, which measures changes in dogs’  
33 tendency to approach ambivalent stimuli (Mendl et al., 2010). A cognitive bias

1 (or, more specifically, a judgement bias) is a known phenomenon, where  
2 individuals experiencing long term negative emotional states (moods) tend to  
3 interpret ambiguous stimuli more negatively than individuals experiencing more  
4 positive moods do (Harding, Paul, & Mendl, 2004; Mendl, Burman, Parker &  
5 Paul, 2009; Roelofs, Boleij, Nordquist & van der Staay, 2016). One advantage of  
6 cognitive biases is that they are responses to threat of punishment or prediction of  
7 reward that generalise beyond the trigger stimuli (Paul & Mendl, 2017).  
8 Therefore, measurements obtained during the test may be used to infer the long  
9 term emotional state of the animal beyond the testing conditions.

10         The judgment bias phenomenon is described in several species, including  
11 dogs, and has led to the development of behaviour tests that can objectively  
12 measure the bias in this species (Harding et al., 2004; Mendl et al., 2009).  
13 Typically, subjects are trained to discriminate between positive stimuli (P, which  
14 predict a reward, e.g. food) and negative stimuli (N, which predict the absence of  
15 reward or a mild punishment). Once the discrimination is established, subjects are  
16 exposed to one or more ambiguous stimuli (A), which have features that are in  
17 between those of the positive and the negative stimulus. The intensity of response  
18 toward each stimulus type is measured. Animals experiencing a negative mood  
19 are thought to have negative expectations, i.e. when they are exposed to  
20 ambiguous information, they expect a negative outcome rather than the positive  
21 one – the opposite is true for animals experiencing a positive mood (Harding et  
22 al., 2004). As a consequence, in the cognitive bias test, responses to the  
23 ambiguous stimulus (A) that are on average more similar to those directed to the  
24 negative stimulus (N) are considered as an indication of a more negative mood;  
25 responses that are more similar to those directed to the positive stimulus (P)  
26 reflect a more positive mood (Harding et al., 2004; Mendl et al., 2009). In dogs,  
27 the test could successfully separate dogs affected by anxiety related problems  
28 (separation related anxiety), as opposed to non-anxious counterparts (Mendl et al.,  
29 2010). Subsequently, the cognitive bias test was used to monitor the treatment  
30 progress of dogs affected by separation related problems (Karagiannis, Burman &  
31 Mills, 2015). Additionally, Kis et al. (2015) proposed the canine cognitive bias as  
32 a measure of overall well-being. The authors tested dogs with a cognitive bias test  
33 after administering them with either a placebo or oxytocin (which has a known  
34 association with psychological well-being in humans; William, Kahloon, Fakhry

1 & Ishak, 2011), in combination with the presence or absence of social stimuli.  
2 Consistent with the human literature, the test results indicated that oxytocin,  
3 especially in the presence of social stimuli, lead to more positive expectations  
4 than the placebo (Kis et al., 2015). More recently, the use of the cognitive bias test  
5 was extended to the assessment of the well-being of dogs affected by a chronic  
6 and putatively painful condition, i.e. syringomyelia (a neurological malformation  
7 that involves the formation of sacs filled with fluid in the spinal neural cord;  
8 Cockburn, et al., 2017). The test results indicated that a group of dogs affected by  
9 syringomyelia had a more negative expectation as opposed to a group of healthy  
10 dogs (Cockburn et al., 2017).

11 It should be noted that there are some limitations in the use of the  
12 cognitive bias test; for example it did not prove to be useful in measuring the  
13 effect of short-term positive events (Burman et al., 2011). On the contrary, the  
14 evidence in the literature indicates that the test is a reliable measure for the long-  
15 term effects on wellbeing that are related with chronic health conditions.  
16 However, to our knowledge, the cognitive bias test has never been used to assess  
17 the decline in the wellbeing of old dogs.

## 18 **Aims of the study**

19 The aims of the present study were: 1) to design a simple and reproducible  
20 version of the reversal learning task, which did not require large apparatuses or  
21 several weeks of training and could detect differences in performance between old  
22 and young dogs; 2) to assess the two groups of dogs with a cognitive bias test (Kis  
23 et al., 2015). For the first goal, the performance of the old dogs was expected to be  
24 poorer (in terms of time required to learn and number of trained dogs) during the  
25 reversal learning task. For the second goal, the old dogs were expected to have a  
26 more negative expectation towards the ambiguous stimulus when compared to the  
27 young dogs.

28 We were also interested in developing tests that could be potentially  
29 repeated over time, e.g. to monitor the progress of the condition. However, both  
30 the reversal learning tasks and the cognitive bias test intrinsically have a large  
31 carryover effect (i.e. during retesting the subjects are influenced by their previous  
32 experience). Therefore, we tested the dogs in this study with different stimuli, in  
33 order to explore whether these would affect the dogs' performance. The two types



1 of stimuli varied in their physical characteristics and relied on slightly different  
2 cognitive tasks and domains, as described by Cotman and Head (2008). For one  
3 group of dogs, the stimuli varied based on their location, as described in the  
4 original cognitive bias protocol (Mendl et al., 2010); therefore, the tasks relied on  
5 egocentric spatial coding (i.e. the animal can rely on the representation of the  
6 objects in space relative to its own body axes, such as left-right and front-back),  
7 specifically relying on learning (spatial function) and reversal learning (executive  
8 function). For the other group of dogs, the stimuli varied based on their physical  
9 characteristics, such as colour and shape; therefore, the tasks relied on visual  
10 learning and reversal learning (executive function). Both tasks also relied on  
11 visual discrimination learning and reward and object approach learning (learning  
12 domain). Previous findings suggested similar effects of age on location and size  
13 discrimination (Tapp et al., 2003b); therefore we expected young dogs to perform  
14 better than old dogs in both tasks.

15 In this study we decided to investigate the normal ageing process, i.e. the  
16 cognitive changes that occur in all individuals as they age, rather than more severe  
17 signs occurring in a smaller part of the population, therefore the subjects were  
18 screened based on symptoms of health issues associated with age. In fact,  
19 knowing the “normal” ageing process is a prerequisite for the subsequent  
20 identification of pathological phenotypes (Szabó et al., 2016).

21

## 22 **Materials and methods**

### 23 **Ethics statement**

24 The procedures applied complied with national and EU legislation and  
25 institutional guidelines. The study received Ethical Permission from the Eötvös  
26 Loránd University, Budapest, Hungary (Permission No.: PE/EA/2019-5/2017).  
27 Owners provided written consent to their participation. Our Consent Form was  
28 based on the Ethical Codex of Hungarian Psychologists (2004). We took special  
29 care to ensure that the consent process was understood completely by the dog  
30 owners. In the Consent Form, participants were informed about the identity of the  
31 researchers, the aim, procedure, location, expected time commitment of the  
32 experiment, the handling of personal and research data, and data reuse. The

1 owners were not informed about the exact aim of the test. The information  
2 included the participant's right to withdraw their consent at any time. Participants  
3 could at any point decline to participate and could request for their data not to be  
4 used and/or deleted after they were collected during the experiments. The study  
5 was performed in strict accordance with the recommendations in the International  
6 Society for Applied Ethology guidelines for the use of animals in research.

## 7 **Subjects**

8 Power analysis was performed using G\*power in order to estimate the  
9 required sample size for the study, aiming for a medium effect size ( $d = .65$ ) and a  
10 power of .08. The analysis yielded a recommended sample of  $N = 35$  per group  
11 (old and young). A group of old dogs ( $N_{old} = 76$ ) had already been recruited and  
12 tested, following the same procedure as the current work, for a different study  
13 (unpublished). Therefore, a matching sample of young dogs had been recruited  
14 following the same inclusion and exclusion criteria, although the sample size had  
15 been kept closer to that calculated *a priori* ( $N_{young} = 43$ ) in order to avoid inflating  
16 the risk of type I errors. For both groups, the inclusion criteria were for the dogs to  
17 be free from overt signs of cognitive decline (as reported by the owner) and/or  
18 medical problems, which might have affected the performance in the tasks (e.g.  
19 untreated neurological conditions, motor-sensory deficits). All dogs were assessed  
20 for their motor-sensory skills by a qualified veterinary surgeon or a  
21 physiotherapist, following on a previously defined procedure (Bognár et al., in  
22 prep). For the young dogs group, dogs between 2 and 6.5 years were recruited; for  
23 the old dogs group, dogs had to be above 8 years of age. The age limits had been  
24 set based on previous findings about the age when the first signs of cognitive  
25 decline were detected (Studzinski et al., 2006; Szabó et al., 2016 for a review).  
26 The sample included 54 mix breeds and 69 pure breeds from 17 different types of  
27 breed. In order to reduce the confounding effect of dogs' size on ageing speed  
28 (see Szabó et al., 2016), only dogs of medium to large size were included in the  
29 sample. Twelve dogs were tested but excluded from the analysis (Supplemental  
30 material) due to procedural mistakes during the data collection ( $N = 11$ ) or due to  
31 technical issues with the electronic spread sheet ( $N = 1$ ). The demographic  
32 characteristics of the final sample ( $N = 107$ ) are described in table 1.

33

34 **Table 1. Demographic information of the dogs included in the analysis.**

	N	Mdn Age [years] (min – max)	M : F (Neutered N)	Mdn Weight [Kg] (min – max)	Mdn Height [cm] (min – max)
Groups					
Young	41	4.5 (2.5-6.5)	1 : 1 (27)	20.2 (9.5 – 44.2)	50.00 (27.00 - 84.00)
Old	66	10.5 (8-14.5)	1 : 1 (53)	18.65 (5.9 – 78)	50.00 (35.00 - 70.00)

1

## 2 **Study design**

### 3 *Stimuli and randomisation*

4 Different sets of stimuli were used to train the dogs to discriminate the  
5 stimuli based on their location (“location” group) or based on their physical  
6 characteristics, i.e. size, colour, and shape (“physical characteristics” group).

7 For the test performed based on location, dogs had to associate the  
8 presence (P) or absence (N) of food with the specific location where the stimulus  
9 was placed. The stimulus was a blue plate (plastic, round shape, 20 cm of  
10 diameter) and it was placed on the floor either on the left or the right hand side of  
11 the experimenter. For about half of the dogs in the location group, the positive  
12 location was on the left and the negative was on the right, while for the other half  
13 the opposite was true; the same balancing method was used for the colour group  
14 (table 2).

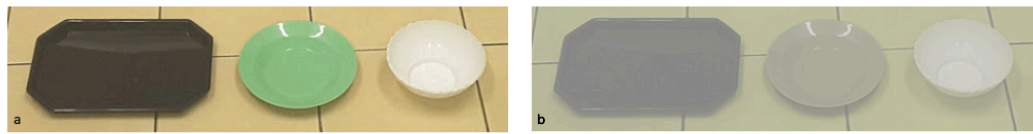
15 **Table 2. Groups composition.** The number of individuals is shown based on the counter-balancing for type of discrimination (based on  
16 location or physical characteristics of the stimuli)

Groups	N total	Location (P = left)	Colour (P = white)
Young	41	21 (10)	20 (9)
Old	66	28 (13)	38 (18)

17 Notes: P = positive

18 For the test performed based on the physical characteristics of the stimuli,  
19 the stimuli were always placed on the floor right in front of the experimenter and  
20 the dog had to learn the association between presence (P) or absence of food (N)  
21 based on the shape and colour of the stimuli. These consisted of a set of 3 plates;  
22 two plates were used as P and N stimuli and the third plate, with intermediate  
23 characteristics between the P and N, was used as an ambiguous stimulus. The two  
24 plates used as P and N (Fig 1) were a large, black, rectangular plate (plastic, 23 x  
25 15.5 cm) and a small, white, round plate (plastic, 12 cm). The ambiguous stimulus  
26 (A) was a plate of a size that was in between the other two and of a colour  
27 (plastic, round, green colour, 15 cm of diameter), which had contrast and

1 chromatic characteristics that are supposed to be perceived as in between black  
2 and white, according to dogs' sensory abilities (Pongrácz et al., 2017).



3  
4 **Figure 1. Stimuli used in the physical characteristics group.** The two images  
5 show the stimuli in the way they are perceived by humans (a) and dogs (b, altered  
6 to dog-vision setting through a dedicated [image processing](http://dog-vision.com) tool, [http://dog-](http://dog-vision.com)  
7 [vision.com](http://dog-vision.com)). The three plates varied in shape, size and colour. The middle plate  
8 (used as ambiguous cue) had intermediate characteristics between the other two  
9 plates.

10

11 All dogs had pre-tested to ensure that they could reliably find a small  
12 object placed on the floor – this was done to ensure that their visual abilities were  
13 sufficient for them to perform successfully in the current test. Additionally, in all  
14 cases, from their starting position the dog could not see the food inside of the plate  
15 as we were interested for the dogs to decide whether to approach a stimulus or not  
16 based on the outcome associated with it. Finally, previous findings indicate that  
17 dogs do not rely on smell in such settings (Szetei et al., 2003); nevertheless, all  
18 plates were smeared with food prior to testing in order to control for odour cues.  
19 A thin slice of sausage or a piece of cheese of equal size was used as food reward  
20 in all conditions (one dog was on a medical diet, so was tested using pieces of  
21 food from their own diet); the dog owners were asked about the dog's preference  
22 and dietary requirements.

23

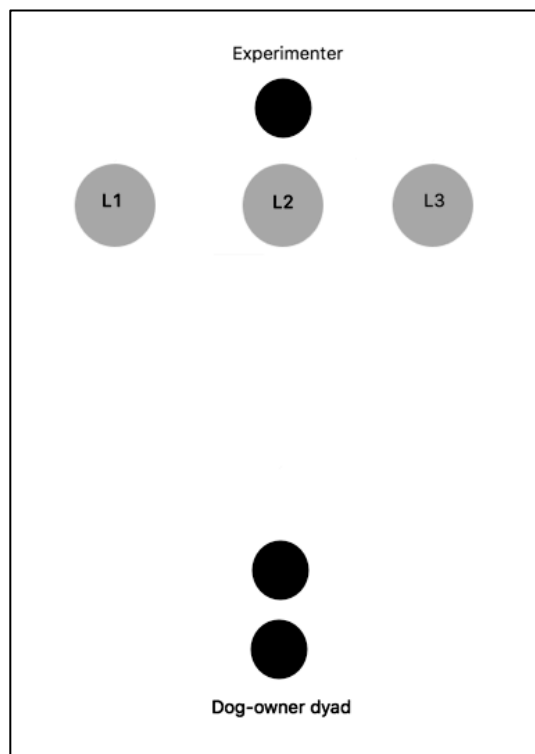
#### 24 *Testing area*

25 The study was performed at the Department of Ethology, Eötvös Loránd  
26 University (Budapest, Hungary), in a small room (2.8 x 5 m). Only the dog's  
27 owner, the dog, and the experimenter were in the room. The room was empty  
28 beside a chair placed at one end of the room (for the owner). The owner held the  
29 dog's collar in order to keep the dog in front of the chair (on a spot marked with  
30 tape on the floor). The experimenter was standing approximately 3 meters in front

1 of the dog-owner dyad. Two cameras were mounted on the ceiling, one behind the  
2 experimenter and the other behind the dog-owner dyad (Fig 2).

3 For the “location” group, the food plates were placed on the floor right in  
4 front of the experimenter (L2) or towards her left (L3) or right-hand side (L1) and  
5 at arm’s length distance from her (P and N). For the “colour” group, the plates  
6 were always placed in front of the experimenter (L2).

7  
8  
9



10

11 **Figure 2. Room set up.** The owner and the dog were at one side of the room  
12 (black circles at the bottom of the figure) and the experimenter was standing  
13 opposite to them (black circle at the top of the figure). The grey circles in front of  
14 the experimenter mark the positions where the plates could be placed based on the  
15 type of the stimuli (L1 and L3 = positions for the P and N stimuli in the “location”  
16 group; L2 = position for the ambiguous stimulus as well as the P and N stimuli in  
17 the “physical characteristics” group).

18

## 1 **Protocol**

2           The study consisted of four different phases. In the “discrimination  
3 learning” (phase 1), dogs were trained to discriminate between the P and N stimuli  
4 (“discrimination learning”), then they were given a break of a few minutes. Kis et  
5 al. (2015) observed that some dogs appeared to not discriminate well the stimuli  
6 after a short delay; therefore, as in their study, the dogs in our study underwent  
7 additional training-like trials (phase 2, “consolidation”). In the “cognitive bias  
8 test” (phase 3), the dogs were then tested with a similar procedure as in Kis et al.  
9 (2015), described below. Finally, the dogs were exposed to a “reversal learning”  
10 (phase 4), where the P and N valence of the stimuli was swapped around. The  
11 order of presentation of the P, N, and A stimuli was identical for all dogs.

12           The discrimination and the reversal learning lasted between 15 and 35  
13 minutes each, depending on the dog, and the consolidation and cognitive bias test  
14 each lasted less than 5 minutes. The whole procedure lasted about one hour.

15

16

### 17 *1) Discrimination learning*

18           The aim of this phase was to teach the dogs that one stimulus was  
19 associated with food (P = positive) and the opposite stimulus was associated with  
20 no food (N = negative). This was achieved by presenting the dogs with the two  
21 stimuli in consecutive trials; the stimuli were presented in a pre-determined  
22 pseudo-random order, with no more than two trials of the same type being  
23 presented consecutively (for the order of presentations see the supplemental  
24 material).

25           At the beginning of each trial, the owner was asked to put the dog on the  
26 leash while the experimenter baited (or did not bait, depending on the trial  
27 valence, N or P) one of the plates. The experimenter then put the plate on the floor  
28 (based on the group type and the trial valence, and according to the pseudo-  
29 random order), and in front of her: for the location group this was placed either  
30 towards the left-hand side or the right-hand side of the dog; for the location the  
31 plate corresponding to that trial valence was placed right in front of the  
32 experimenter.

1           As soon as the plate was on the floor, the owner unleashed the dog.  
2 Owners had been instructed to unleash the dogs exactly as the plate touched the  
3 floor, so to avoid biasing the dog’s behaviour. Dogs had up to 15 seconds to reach  
4 the plate and eat the food, while the experimenter looked straight ahead without  
5 making eye contact with the dog; once the dog ate the food, or after the 15  
6 seconds had elapsed, the experimenter took the plate and the trial was over. If the  
7 dog did not immediately approach the food plates when released, the owner was  
8 allowed to encourage it with short sentences, such as “Go”, or gently touching the  
9 dog. For each trial, the latency to reach the plate was recorded (defined as the  
10 amount of time from when the food plate touched the ground to when the dog  
11 crossed the line on the floor that marked the plates’ position); if the dog did not  
12 approach the plate, the experimenter recorded the no-choice and the trial was  
13 given a latency of 15 seconds. Dogs were deemed to have learned the association  
14 between the stimulus and the food when the longest latency to reach the P plate in  
15 the previous 5 trials was shorter than the latency to reach any of the previous N  
16 trials (“learning threshold”). Dogs underwent a maximum of 50 training trials; if  
17 they did not reach the learning criterion by the 50th trial, they were excluded from  
18 further testing. If the dog refused to participate in the test (i.e. did not leave the  
19 location of the chair), the training was interrupted. For each dog, the experimenter  
20 recorded the latency to reach the food in each trial. These were imported in a  
21 spreadsheet at the time of testing; after the first 10 trials, the spreadsheet  
22 compared the last 5 latencies to P and the last 5 latencies to N for each trial in  
23 order to assess whether the dog had reached the learning threshold. Overall, the  
24 following variables were recorded and calculated:

- 25           -       *number of learning trials*: count variable indicating the number of  
26                    training trials (this could be either the number of trials required to  
27                    learn the task, the number of trials before the task was interrupted  
28                    because the dog refused to participate, or the maximum number  
29                    of trials (50) if the dog did not learn);
- 30           -       *learning success*: binary variable indicating whether the dog  
31                    reached the learning criterion (0 = did not achieve learning, 1 =  
32                    achieved learning).

- 1 - *latency*: time to reach the plate in each trial (continuous variable),  
2 if the dog did not make a choice, the maximum latency (15  
3 seconds) was assigned to that trial;  
4 - *learning mean latency P*; *learning mean latency N*: continuous  
5 variable indicating the mean latency to the last 5 P and 5 N trials;  
6  
7

## 8 **2) Consolidation**

9 The dogs that passed the learning threshold in the discrimination learning  
10 phase, underwent the consolidation phase ( $N = 88$ ). The aim of this phase was to  
11 have a measure of how stable the learning remained after about 5 minute break.  
12 This consisted of 10 trials (5 P and 5 N) identical to the training trials (reported in  
13 the supplemental material). The following variables were recorded:

- 14 - *consolidation success*: binary variable, indicating whether the dog  
15 reached the same threshold as in the learning (0 = fail, 1 =  
16 success)  
17 - *latency* to reach the plate in each trial (continuous variable), if the  
18 dog did not make a choice, the maximum latency (15 seconds)  
19 was assigned to that trial;  
20 - *consolidation mean latency P*; *consolidation mean latency N*:  
21 continuous variable indicating the mean latency to the last 5 P  
22 and 5 N trials;  
23

## 24 **3) Cognitive bias test**

25 Dogs ( $N = 88$ ) were tested following the procedure described in Kis et al.  
26 (2015). The test consisted of 3 trials: one negative (N), one positive (P), and one  
27 ambiguous (A). The trials were presented in a fixed order (N, P, A), which was  
28 identical for all dogs (reported in the supplemental material). The ambiguous trial  
29 was not baited; otherwise, the 3 trials were identical to those in the training. The  
30 following variable was recorded:



1 - *latency* to reach the plate in each trial i.e. P, N, A (continuous  
2 variable), if the dog did not make a choice, the maximum latency  
3 (15 seconds) was assigned to that trial.

#### 4 **4) Reversal learning**

5 This phase was identical to the discrimination learning phase, except only  
6 the dogs that had passed the learning threshold were included ( $N = 88$ ) and the P  
7 and N were reversed. For example, for a dog in the location group, if the positive  
8 stimulus (P) was on the left, now it was on the right; for a dog in the colour group,  
9 if the P was the white plate, now it was the black plate. As in the learning phase  
10 the dogs underwent a maximum of 50 trials; the learning threshold was the same  
11 as in the discrimination learning phase (reported in the supplemental material).

12 The following variables were recorded:

- 13 - *number of reversal trials*: count variable indicating the number of  
14 trials (this could be either the number of trials required to learn  
15 the reversal discrimination, the number of trials before the task  
16 was interrupted, or the maximum number of trials (50) if the dog  
17 did not learn);
- 18 - *reversal learning success*: binary variable indicating whether the  
19 dog reached the learning criterion (0 = did not achieve learning, 1  
20 = achieved learning)
- 21 - *latency* to reach the plate in each trial (continuous variable), if the  
22 dog did not make a choice, the maximum latency (15 seconds)  
23 was assigned to that trial;
- 24 - *reversal learning mean latency P*; *reversal learning mean latency*  
25 *N*: continuous variable indicating the mean latency to the last 5 P  
26 and 5 N trials;

27

28

29

#### 30 **Statistical analysis**

31 Data were analysed using R statistical language (R Core Team, 2017). The  
32 recorded variables were subjected to a Shapiro-Wilk normality test (Supplemental

1 material), which indicated that some of the data were not normally distributed;  
2 therefore, non-parametric and semi-parametric tests were used. All tests were two-  
3 tailed.

4

### 5 *1) Discrimination learning*

6 Our variable regarding the number of trials was right censored (i.e. some  
7 dogs did not reach the learning outcome within the 50 trials or became  
8 uncooperative, leading to interruption of the phase). Therefore a survival analysis  
9 was performed on the discrimination learning using a Cox proportional hazard  
10 regression model (Cox regression) implemented in the R package “survival.” A  
11 Cox regression model for survival-time (time-to-event) was fit to calculate the  
12 effect of the age group upon the time (i.e. number of trials) on the occurrence of  
13 learning; types of stimuli were included in the model as covariate to evaluate their  
14 effect on the learning. The assumption of proportional hazards was tested using  
15 the function “cox.zph” and by plotting the estimates over the time to event  
16 (supplemental material). The analysis provided the Hazard ratios (HRs) for each  
17 parameter, i.e. the ratio of the risk (probability) for the event to occur (i.e. for the  
18 dog to learn) for different levels of the explanatory variables. For each survival  
19 analysis completed, significant results were presented with hazard ratios (HRs),  
20 95% confidence intervals (CIs),  $p$ -values ( $p$ ), and median survival times (i.e. the  
21 time taken to learn). The  $R$  squared of the model and test significance (log-rank  
22 test) were also reported: the  $R$  squared indicates the proportion of the variance in  
23 the dependent variable that is attributable to the variables in the model; the log-  
24 rank test is a non-parametric test which tests the null-hypothesis that the  
25 distribution in the groups under consideration is not different.

26 A delta score was also calculated to measured the difference between the  
27 average latency to the last 5 P and 5 N trials of that given phase ( $\Delta_{\text{discr}} = \text{mean}$   
28  $\text{lat}_N - \text{mean lat}_P$ ). Only the dogs which had reached the learning criterion were  
29 considered when calculating the delta score. A small delta indicates that the dogs’  
30 speeds to the N and to the P are very similar. We then used a Wilcoxon rank-sum  
31 test to look at how the delta varied between the two age groups.

32

### 33 *2) Consolidation phase*

1           In order to assess any age differences in the dogs' ability to remember the  
2 discrimination after a short break, the "consolidation success" variable was  
3 analysed using a Chi-squared test of independence, comparing the success and  
4 failure between old and young dogs.

5           A delta score was calculated for the consolidation phase, using the same  
6 formula adopted for the discrimination learning ( $\Delta_{\text{cons}} = \text{mean lat}_N - \text{mean lat}_P$ )  
7 and a Wilcoxon rank-sum test was used to assess differences between old and  
8 young dogs.

9

### 10 **3) Cognitive bias test**

11           The cognitive bias test was analysed as suggested by Mendl et al. (2010).  
12 Positive and negative expectations were measured using the formula provided by  
13 Mendl et al. (2010), which controls for the possibility that differences in the  
14 latency to the ambiguous cue location (A) was due to differences between the  
15 dogs in the running speeds. This score ("cognitive bias score", CBS) was  
16 calculated by adjusting the A latency by taking into account the baseline latency  
17 to P and to N in the test phase:

18

$$19 \quad \text{CBS} = ((\text{Lat}_A - \text{Lat}_P) * 100) / (\text{Lat}_N - \text{Lat}_P)$$

20

21           This formula varies slightly from the one described in Mendl et al. (2010),  
22 in that in our sample there was one trial per condition, therefore our CBS score is  
23 calculated from absolute values rather than averages. A Wilcoxon sum-rank test  
24 was used to analyse the differences in the CBS between the two age groups and  
25 between types of stimuli ( $\alpha = .025$  to correct for multiple comparisons).

26           Startling et al. (2014) recommended comparing average individual  
27 latencies to P and to N in the cognitive bias test, because the average latency to  
28 reach P needs to be significantly less than the average length to reach N for the  
29 test to be meaningful. However, in our case only one score for each stimulus  
30 valence was available (as our cognitive bias test had only 1 P and 1 N). Therefore,  
31 a delta score was used instead, although in this case it was calculated as the  
32 difference between the latency to N and the latency to P ( $\Delta_{\text{CBS}} = \text{lat}_N - \text{lat}_P$ ).  
33 The main interest was to ensure that the delta was positive for all dogs. However,

1 the difference between young and old dogs was assessed as well using a Wilcoxon  
 2 rank-sum test.

3

#### 4 **4) Reversal learning**

5 The effect of the age group on the time (i.e. number of trials) necessary for  
 6 the occurrence of learning was analysed using Cox regression models, with the  
 7 same modalities followed for the discrimination learning. Two additional Cox  
 8 regression models were calculated for the location and the physical characteristics  
 9 groups separately.

10 Latencies were analysed with a Wilcoxon rank-sum test, after calculating a  
 11 delta score as in the discrimination learning ( $\Delta_{rev} = \text{mean Lat}_N - \text{mean Lat}_P$ ).

## 12 **Results**

### 13 **1) Discrimination learning**

14 A Cox proportional hazard model (Table 3) indicated that, during the  
 15 discrimination learning phase, the number of trials that the dogs required to reach  
 16 the learning criterion was influenced by the age group, with the young dogs  
 17 learning faster when compared to the old dogs (Table 4, Fig 3). The type of  
 18 stimuli did not significantly affect the number of trials required to learn (Table 3).  
 19

20 **Table 3. Cox Proportional Hazards estimates of the determinants of learning in the**  
 21 **discrimination learning phase, by age group and type of stimuli.**

Variable	Coefficient <sup>a</sup>	HR <sup>b</sup>	Test statistics	<i>p</i>
<b>Age group <sup>c</sup></b>				
(Old)				
Young	.6513	1.91	2.99	.003
<b>Type of stimuli <sup>c</sup></b>				
(Physic.)				
Location	-.3952	.67	-1.83	.066
Total N			107	
Wald test			12.25 (2 df), <i>p</i> = .002	
Test for proportional hazards			$\chi^2 = 4.083$ , <i>p</i> = .129	
R <sup>2</sup>			.10	

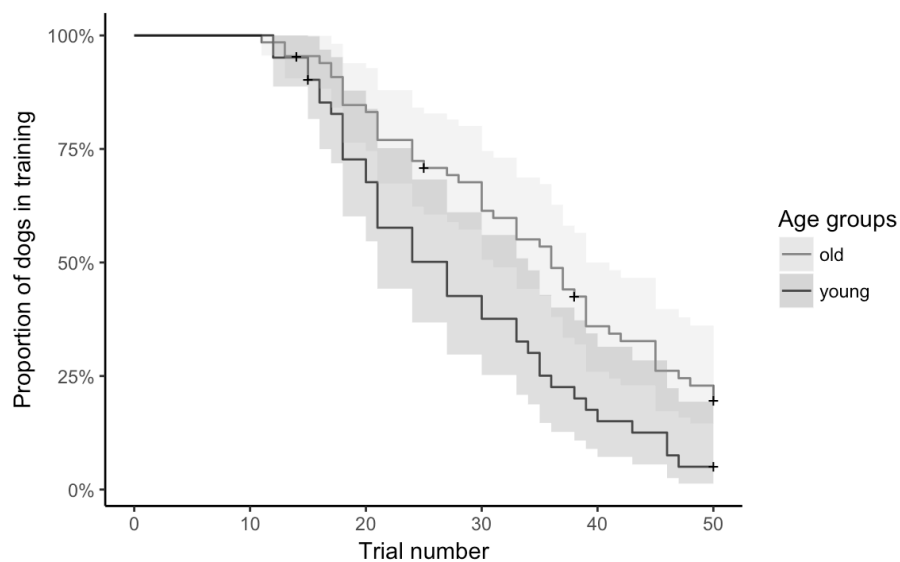
22 <sup>a</sup> Coefficient = log (relative hazard).

23 <sup>b</sup> HR = Hazard Ratio.

24 <sup>c</sup> Reference category in parenthesis.

25

26



1

2 **Figure 3. Survival curve for the number of trials to reach the learning criterion in the**  
 3 **discrimination learning according to the age group.** The darker line represents the young dogs,  
 4 the lighter line represents the old dogs. The shadowed areas reflect the confidence intervals and the  
 5 crosses (+) indicate censored data (i.e. dogs for which the task was interrupted but they had not  
 6 learned).

7

8 **Table 4. Median number of trials necessary to reach the learning criterion in the**  
 9 **discrimination learning phase, according to age groups.**

Variable	N	Events (learning)	Median	95% CI
<b>Age group</b>				
Old	66	50	36	31-39
Young	41	38	27	21-34

1

2

3 The Wilcoxon rank-sum test (Table 12) revealed that there was no  
4 significant difference in the delta score between young and old dogs (Fig 6).

5

6 As table 4 indicates, 82% of the dogs ( $N_{\text{events}} = 50 + 38 = 88$ ) reached the  
7 learning criterion during the discrimination learning phase. The dogs which did  
8 not learn the discrimination were excluded from further testing.

9 **2) Consolidation phase**

10 The Chi-square test of independence indicated that there was no  
11 significant difference between old and young dogs in their success during the  
12 consolidation phase (Table 5),  $\chi^2_{(1)} = 1.36, p = .243$ .

13 **Table 5. Contingency table for the consolidation success variable.**

	Success		Total
	0 (%)	1 (%)	
Old	26 (53%)	24 (47%)	50 (100%)
Young	15 (40%)	23 (60%)	38 (100%)
Total	41 (47%)	47 (53%)	

14 Note: N = 88

15

16 The Wilcoxon rank-sum test (Table 12) revealed that there was no  
17 significant difference in the delta score between young and old dogs (Fig 6).  
18 Additionally, for some of the dogs, the delta score was equal or below 0  
19 ( $N_{\text{consolidation}} = 3$ ).

20

21 **3) Cognitive bias test**

22 Two Wilcoxon rank-sum tests (Table 6) revealed that there was no  
23 significant difference in the CBS between the young and the old dogs or between  
24 the two types of stimuli.

25

26 **Table 6. Results of the Wilcoxon rank-sum test for the cognitive bias score (CBS), as compared between old and**  
27 **young dogs and between type of stimuli (location and physical characteristics).** The effect size is reported ( $r = z / \sqrt{N}$ ),  
28 significance level was corrected for multiple comparisons ( $\alpha = .025$ )

	<i>W</i>	<i>p</i>	<i>r</i>
Old-Young	1043	.433	-.08

Location-Physic. 986 .867 -.02

Note: N = 88

A Wilcoxon rank-sum test (Table 12) revealed that the delta score was significantly smaller in the old dogs compared to the young dogs (Fig 6). Again, for some of the dogs the delta was negative or equal to 0 ( $N_{CB} = 2$ ).

#### 4) Reversal learning

A second Cox proportional hazard model (Table 7) indicated that, during the reversal learning phase, the number of trials that the dogs required to reach the learning criterion was influenced by both the age group and type of stimuli. The young dogs required fewer trials to reach the learning criterion, compared to the old dogs; similarly, the dogs in the location group required less trials to learn, compared to the dogs in the physical characteristics group.

**Table 7. Cox Proportional Hazards estimates of the determinants of learning in the reversal learning phase, by age group and type of stimuli.**

Variable	Coefficient <sup>a</sup>	HR <sup>b</sup>	Test statistics	<i>p</i>
<b>Age group<sup>c</sup></b>				
(Old)				
Young	1.1091	3.03	4.15	<.001
<b>Type of stimuli<sup>c</sup></b>				
(Location)				
Physic.	-1.46	.23	-5.34	<.001
Total N			88	
Wald test			36.10 (2 df), <i>p</i> < .001	
Test for proportional hazards			$\chi^2 = .815$ , <i>p</i> = .665	
R <sup>2</sup>			.37	

<sup>a</sup> Coefficient = log (relative hazard).

<sup>b</sup> HR = Hazard Ratio.

<sup>c</sup> Reference category in parenthesis.

As the Hazard Ratios for the two types of stimuli differ significantly, with the dogs in the physical characteristics having 74% less of probability to learn the task, compared to the dogs in the location group, the two groups were further assessed separately, in order to obtain predictions regarding the effect of age alone for each of them.

Another Cox proportional hazard model (Table 8) indicated that, during the reversal learning phase of the location group, the number of trials that the dogs

1 required to reach the learning criterion was influenced by the age group, with  
 2 young dogs requiring fewer trials to reach the learning criterion, compared to the  
 3 old dogs (Table 9, Fig 4).

4

5 **Table 8. Cox Proportional Hazards estimates of the determinants of learning in the reversal**  
 6 **learning phase in the location group, by age group.**

Variable	Coefficient <sup>a</sup>	HR <sup>b</sup>	Test statistics	<i>p</i>
<b>Age group<sup>c</sup></b>				
(Old)				
Young	.91	2.49	2.658	.008
Total N		42		
Wald test		7.07 (1 df), <i>p</i> = .008		
Test for proportional hazards		$\chi^2 = 1.14$ , <i>p</i> = .285		
R <sup>2</sup>		.15		

7

<sup>a</sup> Coefficient = log (relative hazard).

8

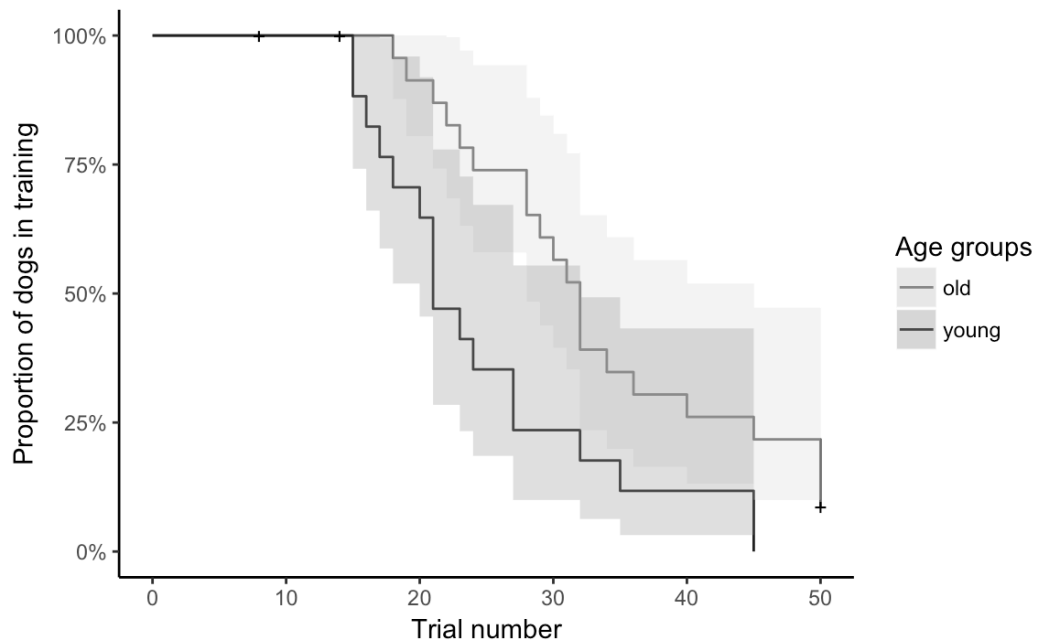
<sup>b</sup> HR = Hazard Ratio.

9

<sup>c</sup> Reference category in parenthesis.

10

11



12

13 **Figure 4. Survival curve for the number of trials to reach the learning criterion in the**  
 14 **reversal learning phase of the location group according to the age group.** The darker line  
 15 represents the young dogs, the lighter line represents the old dogs. The shadowed areas reflect the  
 16 confidence intervals and the crosses (+) indicate censored data (i.e. dogs for which the task was  
 17 interrupted but they had not learned).

18



1 **Table 9. Median number of trials necessary to reach the learning criterion in the reversal**  
 2 **learning phase of the location group, according to age groups.**

Variable	N	Events (learning)	Median	95% CI
<b>Age group</b>				
Old	24	20	32	28-45
Young	18	17	21	20-32

3

4

5 The same analysis was repeated for the physical characteristics group and  
 6 the Cox proportional hazard model (Table 10) indicated that, during the reversal  
 7 learning, the number of trials that the dogs required to reach the learning criterion  
 8 was influenced by the age group, with young dogs requiring fewer trials to reach  
 9 the learning criterion, compared to the old dogs (Table 11, Fig 5).

10

11 **Table 10. Cox Proportional Hazards estimates of the determinants of learning in the reversal**  
 12 **learning phase in the physical characteristics group, by age group.**

Variable	Coefficient <sup>a</sup>	HR <sup>b</sup>	Test statistics	<i>p</i>
<b>Age group<sup>c</sup></b>				
(Old)				
Young	1.351	3.862	3.092	.002
Total N			46	
Wald test		9.56 (1 df), <i>p</i> = .002		
Test for proportional hazards		$\chi^2 = .01, p = .99$		
R <sup>2</sup>		.20		

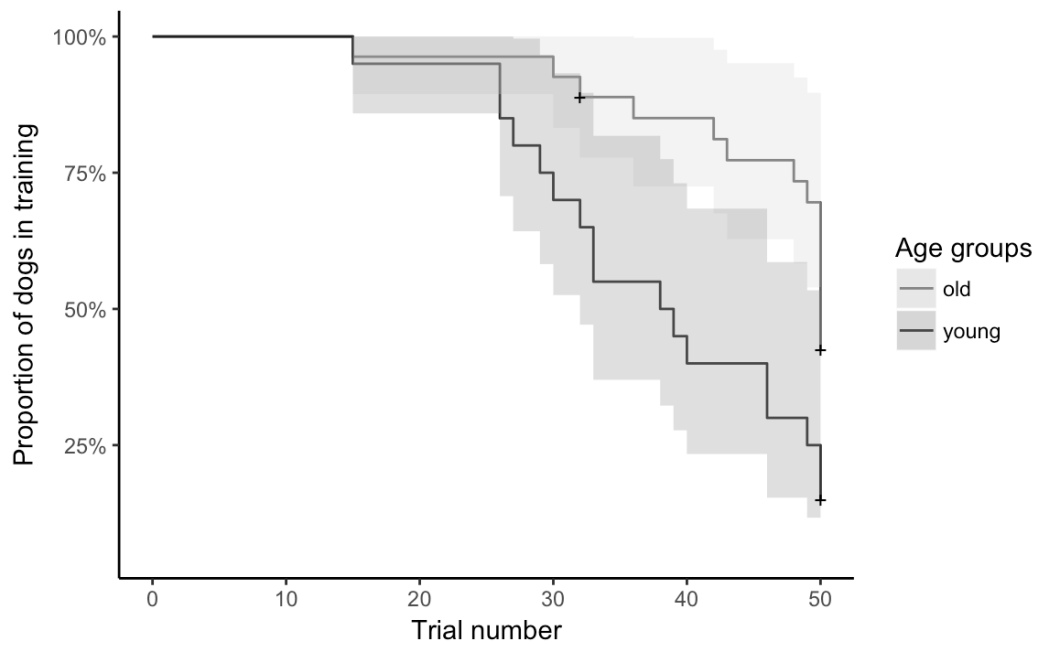
13 <sup>a</sup> Coefficient = log (relative hazard).

14 <sup>b</sup> HR = Hazard Ratio.

15 <sup>c</sup> Reference category in parenthesis.

16

1



2

3 **Figure 5. Survival curve for the number of trials to reach the learning criterion in the**  
 4 **reversal learning phase of the physical characteristics group according to the age group.** The  
 5 darker line represents the young dogs, the lighter line represents the old dogs. The shadowed areas  
 6 reflect the confidence intervals and the crosses (+) indicate censored data (i.e. dogs for which the  
 7 task was interrupted but they had not learned).

8

9 **Table 11. Median number of trials necessary to reach the learning criterion in the reversal**  
 10 **learning phase of the physical characteristics group, according to age groups.**

Variable	N	Events (learning)	Median	95% CI
<b>Age group</b>				
Old	26	8	39	-
Young	20	16	38.5	32 - 50

11

12

13 A Wilcoxon rank-sum test (Table 12) revealed that the delta score was  
 14 significantly smaller in the old dogs compared to the young dogs (Fig 6).  
 15 Furthermore, for several dogs, the delta score was negative or equal to 0 ( $N_{\text{reversal}}$   
 16 = 7).

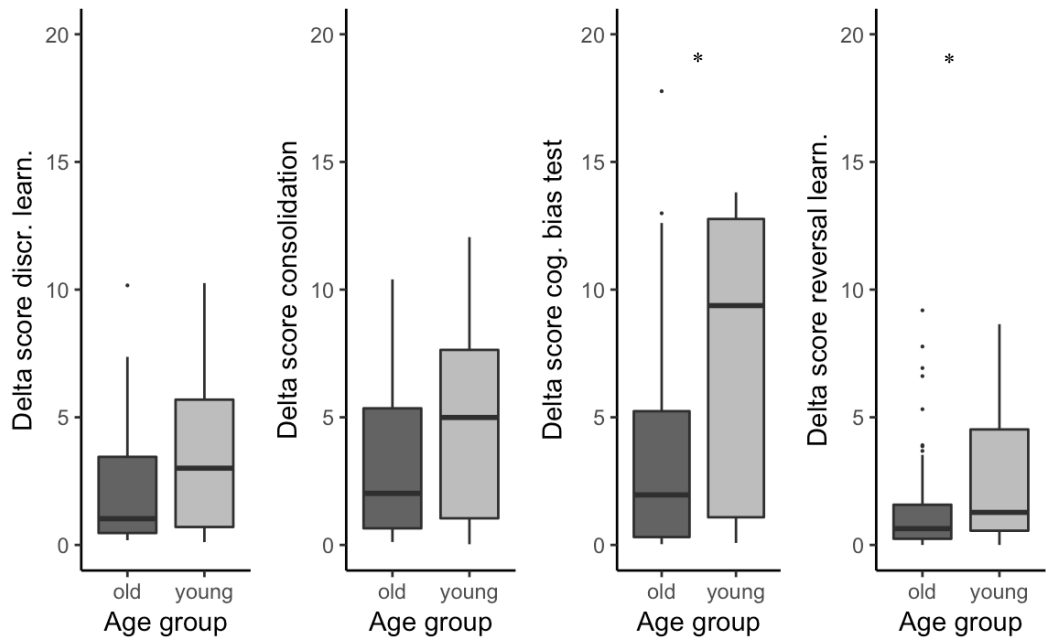
17

18 **Table 12. Results of the Wilcoxon rank-sum test for the delta score, as compared between old and young dogs.** The  
 19 effect size is reported ( $r = z / \sqrt{N}$ ), significance level was corrected for multiple comparisons ( $\alpha = .025$ )

	<i>Mdn (min, max)</i>		<i>W</i>	<i>p</i>	<i>r</i>
	Young	Old			
Discrimination learning	3.01 (.11, 10.26)	1.03 (.19, 10.17)	739	.075	-.19

Consolidation	4.57 (-.58, 12.06)	2.02 (-.23, 10.40)	728	.060	-.19
Cognitive bias test	9.38 (.08, 13.81)	.86 (-.62, 12.99)	567	.001	-.34
Reversal learning	1.27 (.00, 8.65)	.58 (-.18, 9.19)	649	.011	-.27

Note: N = 88



**Figure 6. Box-plot graph for the delta scores of the discrimination learning, consolidation, cognitive bias and reversal learning phases.** The tick bar represents the median score for the group, the boxes are the 25% and 75% quartiles and the error bars represent the minimum and maximum values; \* indicates  $p < .025$ .

## Discussion

The first aim of this study was to develop a reversal learning task which could detect age-related changes in the cognitive function of family dogs. We found that both the reversal learning and the preceding discrimination learning tasks could detect age differences in a group of family dogs without overt medical problems. Younger dogs (2-6.5 years), as a group, required fewer repetitions than older dogs (7-14.5 years) to discriminate between two stimuli; the same was true for the reversal learning task. In contrast to previous discrimination and reversal learning tests designed for the same purpose, our protocol could be performed in a short time frame (about 1 hour).

1           Our second aim was to assess mood differences between the two groups,  
2 old and young dogs, through a cognitive bias test. The two groups did not vary in  
3 their performance in the test, as measured by the cognitive bias score (Mendl et  
4 al., 2010). This suggests that, contrary to our hypothesis, successfully ageing dogs  
5 might not have more negative expectations in the presence of ambiguous stimuli.  
6 However, a delta score (measuring a difference in the speed approaching stimuli  
7 predicting a reward, P, and stimuli predicting the absence of reward, N) showed  
8 that, during the cognitive bias test and at the end of the reversal learning, older  
9 dogs approached the two stimuli (P and N) at a very similar speed. This delta  
10 score may be interpreted as an indirect measure of the contrast or magnitude of  
11 the discrimination between stimuli predicting a reward and stimuli predicting the  
12 absence of reward, and is suggested here as a novel measure in the study of dog  
13 ageing. The small contrast observed in the speed to approach P and to approach N  
14 could be due to lower motivation in old dogs, or cognitive reasons, e.g. decline in  
15 memory function or spatial function. Either way, because the old dogs responded  
16 very similarly to both P and N or were sometimes even faster in reaching the N  
17 than the P, the results regarding the cognitive bias test performed on this sample  
18 are limited in their interpretability in relation to mood. Nevertheless, the  
19 relationship between age and the delta score highlights the fact that cognitive  
20 tasks requiring training might not always be feasible in old dog populations.

21           Another novelty of our study is the indication that the types of stimuli  
22 affect the level of difficulty of the task. Especially during the reversal learning, it  
23 was clear that that the learning was more difficult (required more trials) for the  
24 dogs trained based on the physical characteristics of the stimuli.

25           The literature shows inconsistent evidence regarding age effects on  
26 discrimination learning (detected: Milgram et al., 2002; Studzinski et al., 2006;  
27 Tapp et al., 2003a,b; Tapp et al., 2004; Wallis et al., 2016; not detected: Christie  
28 et al., 2005; Milgram et al., 1994; Mongillo et al., 2014). On the contrary, the age  
29 effect is more stable when reversal learning tasks are employed (Christie et al.,  
30 2005; Milgram et al., 1994; Mongillo et al., 2014; Tapp et al., 2003a,b Tapp et al.,  
31 2004). On the other hand, dog populations, age ranges and types of tasks (as well  
32 as task design) vary largely in the literature (Szabó et al., 2016); therefore, any  
33 direct comparison between tasks should be cautious. Mongillo et al. (2013)  
34 developed a spatial learning task for family dogs. The authors reported no

1 difference in the discrimination learning between young dogs (3-7.3 years) and  
2 old dogs (8-14 years) and concluded that the task is likely too simple (Mongillo et  
3 al., 2013). It should be noted that 25% of the dogs in their sample (young: 23%;  
4 old: 28%) did not learn the discrimination. In our sample the rate in the learning  
5 failure was relatively similar for the old dogs (27%), but not for the young ones  
6 (7%), suggesting that the discrimination learning alone is more difficult for the  
7 old compared to the young dogs. Mongillo et al. (2013) suggested that the  
8 differences in performance that they observed between their discrimination  
9 learning and reversal learning tasks were likely due to variability in the level of  
10 difficulty between the two tasks. However, easier tasks should not be deemed as  
11 not useful; in fact, they allow for measuring a wider range of variability within a  
12 population. For example we observed that the dogs in our study found size, shape  
13 and colour discrimination more difficult than egocentric spatial learning in the  
14 reversal learning task (i.e. dogs in the “physical characteristics” group required  
15 more trials than dogs in the “location” group), although we cannot know which of  
16 these three components were used by the dogs and which were more difficult to  
17 them. Possibly as a consequence of this we observed a ceiling effect in the  
18 “physical characteristics” group, as the median number of trials of the old dogs  
19 corresponded to the maximum number of trials for the task. One might also argue  
20 that older dogs had impaired visual abilities and could not see the plates.  
21 Although, all dogs included in the current study had been preselected to ensure  
22 that they were able to reliably find small objects placed on floor. We cannot  
23 completely exclude that differences in the visual function affected old dogs’  
24 ability to discriminate the stimuli in the “physical characteristics” group.  
25 Regardless of the reason, our results show that excessively difficult tasks might  
26 reduce the variance within the tested population, making it impossible to  
27 investigate within group differences.

28         The focus on the discrimination learning task brings an additional level of  
29 detail in the assessment of dogs’ cognitive function, especially overcoming the  
30 issue of the ceiling effect observed in the reversal learning task, which might be  
31 relevant in the assessment of dogs with a higher deficit. Thus, tasks which are  
32 difficult for successfully ageing dogs and lead to a ceiling effect, cannot be used  
33 for testing dogs with cognitive dysfunction. On the contrary, as previously  
34 mentioned, reversal learning is a very consistent measure of age related decline

1 (e.g. Christie et al., 2005; Milgram et al., 1994; Mongillo et al., 2014; Tapp et al.,  
2 2004). Our findings therefore suggest that the discrimination learning and reversal  
3 learning, based on location or combined with learning based on physical  
4 characteristics, may be an efficient task for the objective investigation of age-  
5 related cognitive decline in family dogs.

6         One possible reason for the discrepancies reported in the literature, in  
7 relation to learning and reversal learning, may be the fact that not all brain regions  
8 are affected by ageing at the same pace and not all subjects are equally affected at  
9 a given age; moreover, different cognitive functions rely on different brain areas.  
10 For example, Tapp et al. (2004) observed increasing atrophy in the frontal lobe of  
11 dogs as their age increased (starting from 8 – 11 years) as well as an inverse  
12 correlation between frontal lobe volume and a discrimination learning and  
13 reversal learning task. Moreover, Studzinski et al. (2006) observed deficits in the  
14 acquisition of a discrimination task in dogs aged 10+ years, compared to dogs  
15 below 8 years of age. However, they also reported that not all dogs in their sample  
16 showed spatial impairment, with 25% of the dogs above the age of 10 showing no  
17 deficit in their performance. Similarly, Head et al. (2000) reported signs of beta-  
18 amyloid accumulation in some brain areas (enthorinal cortex, prefrontal cortex)  
19 from the age of 9 years, but only in subsets of dogs (42% vs 75% respectively),  
20 which was not consistently affected until the age of 14 years. Finally, Siwak-Tapp  
21 et al. (2007) found that hippocampal neurogenesis is significantly lower in dogs  
22 aged 3-5 years, compared to dogs aged 13-15 years. Additionally, hippocampal  
23 neurogenesis was negatively correlated with dogs' performance in a number of  
24 cognitive tasks, including object discrimination, size discrimination, and  
25 black/white discrimination (Siwak-Tapp et al., 2007). The dogs in our sample  
26 were screened for neurological conditions, sensory-motor decline, and general  
27 signs of pathological ageing. Therefore our results could mirror cognitive changes  
28 of successfully aging dogs.

29         One advantage of the use of family dogs as models for the study of ageing  
30 is the large and diverse population available, as long as non-invasive methods are  
31 employed. The discrimination learning and reversal learning tests described in our  
32 study could be used in combination with imaging techniques (e.g. MRI, fMRI,  
33 EEG) to further investigate the role of structural and functional changes in the  
34 brain on cognitive function. Future research should also investigate ways to

1 overcome the issue with the non-learning dogs. This is a limitation of the current  
2 study (as well as any study requiring training), as the dogs that do not learn the  
3 discrimination cannot be assessed in such cognitive tasks. One way to attempt  
4 overcoming this issue could be to increase the number of training trials during the  
5 discrimination learning; however, this strategy has a limitation in that it prolongs  
6 the overall duration of the task.

7         One interesting finding is the variation in the delta score (i.e. difference  
8 between the latency to N and the latency to P, which could be defined as positive-  
9 negative contrast) between old and young dogs. Originally derived from the  
10 cognitive bias test research (Starling et al., 2011), the measure should provide an  
11 indication of dogs' ability to discriminate between the two stimuli. It is therefore  
12 interesting that we could observe two phenomena: 1) based on the delta score,  
13 there was a marked difference between the young and the old dogs, both during  
14 the cognitive bias test and the reversal learning; the young dogs tended to have a  
15 higher delta in terms of central tendency (median value) as well as spread (min-  
16 max range). It is interesting that the difference between the groups appeared in the  
17 two phases where the discrimination may be more difficult for the dogs. Dogs  
18 might have found the discrimination difficult during the cognitive bias because of  
19 the delay from the training (despite of the use of a block of consolidation trials),  
20 and in the reversal learning due to the cognitive conflict with the previous  
21 learning. We did not analyse further delta difference between tests as this was  
22 beyond the scope of the current paper; however, another advantage of measures  
23 such as a delta score is that it allows for comparability between tasks and between  
24 papers.

25         Our findings do not support the hypothesis that old dogs have more  
26 negative expectations than young dogs. However, as previously mentioned, the  
27 fact that the dogs in our sample did not consistently discriminate between the P  
28 and the N, deemed the results of the cognitive bias test to be difficult to interpret  
29 (Roelofs et al., 2016; Starling et al., 2014). Kis et al. (2015) reported that dogs  
30 could not remember the discrimination between P and N after a delay and indeed  
31 we observed that a large number of dogs did not repeat their discrimination  
32 learning performance during the consolidation phase (5 P and 5 N trials). This is  
33 something that should be explored more in the cognitive bias research, especially  
34 when the training protocols or the types of stimuli vary or there is a time gap

1 between training and testing. Another reason for the inconsistent findings that  
2 were observed in the cognitive bias test could be the limited number of test trials  
3 (i.e., 3 trials). The protocol had been previously used and yielded successful  
4 results in detecting differences between groups of dogs with the same number of  
5 trials (Kis et al., 2015). One solid justification for the use of few trials is that, with  
6 repetitions, subjects of the cognitive bias test readily learn that the ambiguous  
7 cues are unrewarded (a phenomenon called ‘loss of ambiguity’), which may lead  
8 to false conclusions (Doyle et al., 2010). In contrast, repeated tests may be  
9 particularly relevant in the case of ageing research (e.g. to monitor changes over  
10 time), therefore further investigations aiming to find a balance between loss of  
11 ambiguity and susceptibility to random errors is necessary. It has also been  
12 pointed out that personality traits (e.g. trait anxiety) might affect the results of the  
13 cognitive bias test (Roelofs et al., 2016), which is particularly relevant for a  
14 between subject design. For example, Starling et al. (2014) reported individual  
15 differences in baseline judgement bias in dogs. This should be taken into account,  
16 for example by matching the cognitive bias results with other behavioural  
17 observations and personality measures of the animal (Roelofs et al., 2016).  
18 Research should also investigate other measures potentially related to welfare,  
19 such as anticipatory behaviour (Clegg & Deflour, 2018).

20 Overall, our findings indicate that a discrimination task based on the  
21 location of two objects, accompanied by a reversal learning task, may be an  
22 efficient way to measure age related decline in learning performance in family  
23 dogs. Further studies are necessary to better understand to which degree variation  
24 in the performance of this test might relate to functional changes in the brain or  
25 whether the test is predictive to cognitive decline. The task may be associated to  
26 colour and shape discrimination, although care should be taken to avoid ceiling  
27 effects, e.g. by increasing the maximum number of trials in the test. Future  
28 research should investigate the stability over time of the learned associations. This  
29 is particularly important when other tests (for example the cognitive bias test) rely  
30 on this association. However, the effectiveness of a cognitive bias test on a  
31 population of aged dogs is yet to be demonstrated.

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33



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