Behaviour and Beyond:

Three Ways to Examine Dog Cognitive Processing

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ADDENDUM AND ERRATA

ERRATA

p. 21, lines 4 and 6: replace 'i.e.' with 'e.g.'
p. 50, line 162 and p. 55, line 287: replace 'principle' with 'principal'

ADDENDUM

p. 11, para 1, line 9, after "...empathy in dogs (Silva & de Souza 2011)", add: Since dogs are social animals and empathy is related to social behaviour in humans (Preston & de Waal 2002), dogs may also experience empathy."

p. 19, para 1, lines 6-10, delete: "This makes intuitive sense...of this phenomenon."

p. 24, line 5, after "as well as other dogs (Pongracz et al. 2008)", add: However, these results could be caused by stimulus enhancement, in which the demonstrator drew attention to the corner of a fence around which the observer must go to obtain a treat (Mersmann et al. 2011). This then provided the observer with an opportunity to learn through trial and error how to detour the fence to get the treat. There is also evidence that dogs can learn to complete a novel task through observational learning (e.g. Range et al. 2007; Slabbert & Rasa 1997), although in other studies they were not successful at learning in this way (Mersmann et al. 2011; Tennie et al. 2009). In Range et al. (2007), dogs learned to pull a lever to open a box containing a toy by watching a demonstrator dog. In Tennie et al. (2009), dogs were unable to learn a new word for a previously learned command (in this case, 'sit') by watching a demonstrator dog perform the command when hearing the word. Tennie et al. (2009) suggest that the use of the box in the demonstration in Range et al. (2007) may have resulted in the different outcome from their study, which did not use any objects in the environment on which the dogs could focus their attention.

p. 24 end of para 2, add: The data from this study were re-analysed by Hare et al. (2010)who determined that the dogs performed equally as well as the wolves in the Udell et al. (2008) study. The re-analysis differed from the original study in that only dogs which made a selection at all were included; in Udell et al. (2008), the subject making no selection at all was considered to be an incorrect response for the purposes of the statistical analysis. Hare et al. (2010) pointed out that this would increase the probability that the subject would choose incorrectly, rather than providing a 50/50 chance that the subject would choose correctly or incorrectly. Excluding non-selectors is also the more conventional method of analysing data in the object-choice test (Hare et al., 2010), although it does raise the question of how best to manage uncooperative subjects in cognition research. It also highlights the importance of appropriate research design and analysis in the interpretation of cognitive studies which aim to demonstrate that animals possess or lack a particular ability.

p. 25 end of para 1, add: This argument was recently answered by a direct comparison of chimpanzees and dogs in their ability to follow human pointing cues (Kirchhofer et al. 2012). The authors used imperative pointing (pointing toward something the experimenter wanted but which was of no interest to the subject), in case chimpanzees were not able to understand cooperative pointing gestures but could understand the referential nature of pointing in other scenarios. Some of the dogs were kept behind a fence in the same way that the chimpanzees were separated from the experimenter. The dogs still obtained the target item more reliably than the chimpanzees, which did not appear able to follow the pointing gesture.

p. 28 under Section 2.2.4, add para: A commonly researched area of animal cognition is 'theory of mind' (ToM) (Heyes 1998; Penn & Povinelli 2007). Premack and Woodruff (1978) defined ToM as the ability to "impute mental states to [oneself] or others (either to conspecifics or to other species as well)". ToM develops in early childhood, ultimately permitting children to engage in a wide range of social behaviours, including persuasion and sympathy (Berger & Thompson 1996). Therefore, much of social cognition in humans is related to the understanding that others experience different thoughts and emotions than oneself. The development of a rudimentary awareness of 'self' and 'other' can be observed in children as young as 2 years old, with children saying things like "Don't be mad, Mommy". This awareness becomes more advanced by age 4 or 5 years, when children understand that their personal reality is subjective (Berger & Thompson 1996). ToM is of interest to animal cognition researchers because an over-arching goal of animal cognition, in the traditional sense of comparative psychology, is often to understand ways in which humans are similar to, and different from, other animals (Shettleworth 2010). While ToM is expansive and covers many topics within animal cognition, two topics of focus for this thesis are empathy and self-awareness.

Empathy is fundamentally a mechanism for "bridging the gap that exists between the self experience and others' experiences" (Hodges & Klein 2001 p. 438). Empathy develops along a continuum in human babies; they demonstrate emotional contagion as newborns (Preston & de Waal 2002), in which they can 'catch' another person's emotional state, but they are unaware that the emotion is being felt by another. This is called affective empathy. By around 2 years of age in typically developing children, this contagion has developed into a full awareness of the other person's emotional state, called cognitive empathy (Zahn-Waxler & Radke-Yarrow 1990). Empathy is an aspect of ToM; it demonstrates that a person is aware that other people can have different emotions than what that person experiences, and it is of interest to animal cognition researchers because it relates to the development of social behaviour in humans (Preston & de Waal 2002). It is possible that animals experience empathy. There is evidence that chimpanzees and crows engage in affiliative, consoling-like behaviours toward conspecifics with whom they have a valuable relationship after the animal receiving the consolation has engaged in antagonistic interactions with other conspecifics (Fraser & Bugnyar 2010; Fraser et al. 2008). Furthermore, mice which observed their cage-mates in pain exhibited more behaviours associated with the experience of pain than when the mice observed unknown mice in pain (Langford et al. 2006). Behavioural measures of empathic responses, such as these, should be expanded into dog cognition research.

p.28 para 1, line 6, after "...precursor to empathy, with humans", add: Further supporting this hypothesis is the finding that children with autism spectrum disorder are less likely to experience yawning contagion than typically developing children(Senju et al. 2007).

p. 29, before para 2, add para: Self-awareness is another common topic in animal cognition (Epstein et al. 1981; Suddendorf & Collier-Baker 2009). According to Gallup (1998), "individuals who are self-aware, as evidenced by being able to become the object of their own attention, experience a sense of psychological continuity over time and space" (p. 240). Like empathy, self-awareness has been suggested to be an element of ToM because it illustrates the ability to differentiate between oneself and others (Gallup 1998), although it is possible that self-awareness does not necessarily extend to a true ToM in the sense of understanding that individual experiences are subjective (Gross 2010). Also like empathy, in human babies self-awareness develops along a trajectory, as illustrated by mirror research. The mirror mark test is one in which the subject secretly has a mark placed on its face, and is then placed in front of a mirror. The subject is able to see the mark on the face in the mirror and, if it attempts to remove it from its body, this suggests that the subject is aware that it is looking at its own reflected image (as opposed to a conspecific). Below 12 months of age, babies tend to view their mirror image as if it was another baby, but, by 24 months, most babies are aware that they are looking at themselves in the mirror (Amsterdam 1972).

p. 33, line 9, delete "higher-order"

p. 55, after line 304, add new para: The MDORS subscale 2, for perceived emotional closeness, predicted the PoDIaCS subscales. However, the proportion of variance explained by perceived emotional closeness was small, ranging from 4.0% for subscale 4, learned awareness of human attention, to 13.0% for subscale 8, general intelligence compared to humans. This study revealed a relationship between the MDORS and the PoDIaCs, but was not designed to detect causality. Furthermore, although the regression was completed with MDORS as the predictor of the cognition ratings, this does not necessarily mean that a strong dog-owner relationship leads to the owner ascribing more cognitive abilities to his/her dog. Given the low proportion of variance explained by the MDORS, it could mean that there are other variables which would have a stronger effect on cognition ratings, such as length of ownership, extent and quality of prior experience with dogs, or the owner's religious, cultural, or personal values regarding human-animal relationships generally.

p. 72, after para 1, add: Many of the survey items were similar, such as 'dogs can learn to recognize themselves in a mirror' and 'dogs can instinctively recognize themselves in a mirror'. This could have impacted the responses as people who agreed with the first item might have then been more inclined to agree with the second one. However, the items were pseudo-randomised among participants to help reduce this possibility. Still, this potential effect cannot be ruled out, especially since much of the survey asked questions along these lines, and many participants probably realised that they should expect items related to both learning and instinct as they progressed further in the survey.

p. 74, line 1, delete "first".

p. 83, line 6, after "...completing this task." add: However, phylogenetic similarities do not always equate to identical cognitive skills because different environments would require different cognitive abilities, and dogs may therefore have evolved different skills than pigs.

p. 91, line 80, after "...in the reflection." add: Another study showed that aged dogs with cognitive impairments spent more time interacting with a mirror than healthy aged dogs (Siwak et al. 2001).

p. 93, line 130, add: The two fans were in each corner of Area 4 (see Fig. 1).

p. 97, line 233, replace "Differences in latency...paired *t*-tests" with: Latency to find the treat was also analyzed using a Cox proportional hazards regression model. This analysis was chosen because the data was censored at 180 seconds; that is, if a dog did not obtain the treat within three minutes, their latency was recorded as 180 seconds, and marked as censored.

p.98, lines 244-247, replace "However, subsequent...(two-tailed)." with: Latency to obtain the treat among dogs in the experimental group also differed significantly from the control group dogs, with dogs in the experimental group finding the treat faster than controls, exp(B) = 2.46 df = 1, SE = 0.42, P = 0.03. Among only dogs which found the treat, there was no significant difference in latency between experimental and control groups (Cox proportional hazards regression, P = 0.59).

p. 109 para 2 line 6, after "...time it took to find the treat.", add: This is a key finding because dogs may have been motivated to search for the treat due to some other reason, and did not use the mirror to find the treat at all. In spite of the fact that there was a difference between groups in likelihood to find the treat, the lack of a group difference in latency (among dogs which found the treat) suggests that there may have actually been no difference between the experimental and control groups. Indeed, it is possible that the successful dogs, regardless of group, were simply more likely to move around the room and thus found the treat by chance.

p. 109 end of para 2, add: Also, if the food bowl had been placed, empty, in view of the mirror, this would reduce the possibility of odour cues. The association with the bowl would remain, having been taught in the association phase, so the dogs should still be motivated to approach it.

p. 130, para 1, line 8: replace 'comprehensive' with 'useful'.

p. 133: delete para 2.

p. 135 end of para 1, add: The inability or lack of motivation to complete the task could indeed be due to the experimental setup itself. For instance, certain studies show that dogs can engage in observational learning (e.g. Pongracz et al. 2005;

Range et al. 2007; Slabbert & Rasa 1997) while others show that they do not (e.g. Mersmann et al. 2011; Tennie et al. 2009). Differences in the research designs of these respective studies could account for these different results, potentially in ways obvious to researchers (e.g. perhaps a v-shaped fence, as used in Pongracz et al. 2005, is more difficult to negotiate than a straight-line fence, as in Mersmann et al. 2011), and potentially in ways that are not noticeable by humans, given that their perceptive abilities differ from dogs (Browne et al. 2006; Miller & Murphy 1995).

p. 138 para 1, line 1, after "...use of this EEG technique." add: Not all dogs would be suited for this type of research. Dogs which behaviourally indicate anxiety when receiving veterinary injections should not be used in studies of this kind due to the needle electrodes required to record the EEG. Also, dogs should have received enough obedience training to 'sit' and 'stay' for long periods of time at their owner's command. This would make developmental research with puppies challenging with currently available technology. Additionally, while this MMN method would be well-suited to discrimination tasks, other types of cognitive studies would see little benefit from an incorporation of this method. For instance, in some observational learning tasks, like the detour task (e.g. Pongracz et al. 2005), the study subject would have to observe the demonstrator's behaviour for far longer than a few hundred msec. While there may be a point in which the dog's cognitive processing results in MMN waveforms during the course of the demonstration, it would be impossible to standardise the timing of this response such that it could be examined in more than one dog. Nonetheless, in the future, wireless EEG technologies may increase the possibilities of incorporating EEG into behavioural studies which require movement. If it is one day possible to reduce the amount of muscle artifact visible in the EEG of a moving animal, the brain activity of dogs in behavioural research which involve walking could potentially be recorded.

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ABSTRACT

Dog cognition research relies heavily on behavioural approaches in order to determine the nature and extent of dog cognitive abilities. These behavioural data have greatly advanced current understanding of dog cognitive abilities. While there has been much research exploring how dogs respond in paradigms which require cooperation or communication with humans, fewer studies have explored their capabilities in non-social cognitive domains. More research of this kind would provide a more comprehensive account of dog cognitive abilities and limitations. Moreover, the use of non-behavioural methodologies may offer additional insights. Towards this end, surveys that explore community beliefs about dog cognition may be informative because dog owners spend time with dogs in non-experimental settings, giving them a different perspective on dog behaviour than what is observable in a scientific experiment. Neurophysiological techniques that index automatic, involuntary responses to stimuli also offer substantial opportunity to evaluate dog cognitive abilities, without the potentially confounding effects of training or motivation.

The aim in this thesis was to advance understanding of dog cognitive abilities through the use of a variety of techniques, which each offer a different perspective on the general question of dog cognition. A survey was developed to determine community perceptions of dog cognition to redress the scarcity in research of this kind in recent decades. Behavioural studies to examine how dogs respond to mirrors were undertaken to further scientific understanding of dog problem-solving abilities. A method for measuring cognitive processing in dogs at the neural level was developed, using electroencephalography (EEG), which may complement behavioural data.

The survey data collected in this thesis illustrate the extent to which scientifically established understanding of dog cognition has infiltrated the community. The findings revealed that community beliefs regarding some cognitive domains, such as comprehension of human communicative gestures, were well aligned with current scientific evidence. Additionally, respondents believed that dogs possess cognitive capabilities in other less-researched domains, such as empathy and deception; these findings offer researchers opportunities for new study areas. The behavioural research is the first to show that, under certain conditions, dogs are capable of using a mirror as a problem-solving tool. This is a unique finding and is significant in that it reveals a capacity in dogs that has been well established in other animals. However, the findings were sensitive to the experimental design and revealed the need for further research in this area. Data arising from the studies that employed neurophysiological techniques were the first to demonstrate the utility of these methods to advance understanding of cognitive processing in dogs in ways that are minimally invasive. This technique is suitable for discrimination tasks, which could complement behavioural studies to determine how well dogs discriminate items in auditory, visual, and olfactory modalities. Collectively, this series of studies offers new insights into dog cognitive abilities. The studies also identify new avenues of research and suggest practical applications for their use in the future.

DECLARATION FOR THESIS BASED OR PARTIALLY BASED ON CONJOINTLY PUBLISHED OR UNPUBLISHED WORK

Monash University
Monash Research Graduate School

In accordance with Monash University Doctorate Regulation 17/ Doctor of Philosophy and Master of Philosophy (MPhil) regulations the following declarations are made:

I hereby declare that this thesis contains no material which has been accepted for the award of any other degree or diploma at any university or equivalent institution and that, to the best of my knowledge and belief, this thesis contains no material previously published or written by another person, except where due reference is made in the text of the thesis.

This thesis includes three original papers published in peer reviewed journals and two unpublished publications. The core theme of the thesis is the use of three different methods for examining cognitive processing in domestic dogs: surveys, behavioural research, and electroencephalography (EEG). The ideas, development and writing up of all the papers in the thesis were the principal responsibility of myself, the candidate, working within the School of Psychology and Psychiatry under the supervision of A/Prof. Pauleen Bennett, Dr. Russell Conduit, and Dr. Samia Toukhsati.The inclusion of co-authors reflects the fact that the work came from active collaboration between researchers and acknowledges input into team-based research. In the case of Chapters 3, 4, 5, 6, and 7, my contribution to the work involved the following:

Thesis chapter	**Publication title**	**Publication status***	**Nature and extent of candidate's contribution**
3	Development of the Perceptions of Dog Intelligence and Cognitive Skills (PoDIaCS) survey	submitted	75% of the development of survey, data collection and analysis, writing
4	Can dogs (*Canis familiaris*) use a mirror to solve a problem?	published	75% of the development of research design, data collection and analysis, writing
5	Dogs use a mirror to find hidden food	submitted	75% of the development of research design, data collection and analysis, writing
6	Development of a minimally-invasive protocol for recording mismatch negativity (MMN) in the dog (*Canis familiaris*) using electroencephalography (EEG)	published	75% of the development of method, data collection and analysis, writing
7	Auditory stimulus discrimination recorded in dogs, as indicated by mismatch negativity (MMN)	published	75% of the development of method, data collection and analysis, writing

Signed: ……………………………………………………………………

Date: ………………………………

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LIST OF ABBREVIATIONS

EEG – electroencephalography/electroencephalogram

ERP – event-related potential

MMN – mismatch negativity

MRI – magnetic resonance imaging

MSR – mirror self-recognition

LIST OF PAPERS PUBLISHED AND SUBMITTED DURING THE COURSE OF THIS THESIS

Howell, T., Toukhsati, S., Conduit, R., and Bennett, P., (under review). Dogs use a mirror to find hidden food. Submitted 11/2012 to *Journal of Veterinary Behavior: Clinical Applications and Research*.

Howell, T., Toukhsati, S., Conduit, R., and Bennett, P., (under review). Development of the Perceptions of Dog Intelligence and Cognitive Skills (PoDIaCS) survey. Submitted 8/2012 to *Journal of Veterinary Behavior: Clinical Applications and Research.*

Howell, T., Conduit, R., Toukhsati, S., and Bennett, P., 2012. Auditory stimulus discrimination recorded in dogs, as indicated by mismatch negativity (MMN). *Behavioural Processes*, 89 (1): p. 8-13.

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CHAPTER 1 – INTRODUCTION

The number of studies exploring dog cognitive abilities has increased considerably in the last decade (Kaminski 2008; Wynne 2009). In particular, social cognitive skills have been studied extensively, with numerous studies showing that dogs possess an ability to effectively communicate with humans to an extent which may be unique in the animal kingdom (for reviews, see Miklosi & Soproni 2006; Reid 2009). This research began in the late 1990s, when two research groups independently began to study whether dogs can comprehend human communicative gestures, such as pointing (Hare & Tomasello 1999; Miklosi et al. 1998). The results were fascinating: dogs could follow human pointing gestures to find hidden food, an ability that even chimpanzees did not appear to possess (Hare & Tomasello 2005). Great apes, being humans' closest living relatives, are generally believed to be 'demonstrably the most intellectually gifted of all animals' (Humphrey 1976, p. 307). Thus, the prospect that dogs could do something that chimpanzees struggled with was intriguing, and other studies exploring dogs' social skills soon followed (e.g. Miklosi et al. 2003; Range et al. 2009; Viranyi et al. 2004). Experimental research has shown that dogs can learn to detour around a fence to find a treat by watching humans (Pongracz et al. 2005a). They also 'show' a naïve human where a treat is located by alternating their gaze between the human and the treat (Miklosi et al. 2000), and they beg from people who are looking at them rather than from people who are looking away (Gacsi et al. 2004).

Since dogs have demonstrated impressive social cognitive abilities, additional research has been conducted to understand whether dogs possess other, non-social, cognitive abilities as well (e.g. Pattison et al. 2010; Range et al. 2008; Range et al. 2011). Unfortunately, the results of these studies have been less conclusive. For example, Osthaus et al. (2005) suggest that failure at a common string-pulling task means dogs do not possess means-end understanding. On the other hand, a different paradigm established recently by Range et al.

(2011), in which dogs were more likely to pull a moveable board closer to them if the treat was on the board rather than beside it, shows that they may exhibit this skill under appropriate conditions. Given this conflicting information, it may be necessary to test the same cognitive ability in several different ways before drawing conclusions about whether or not dogs possess that skill.

These contradictory studies suggest that there is more work to be done in designing experiments to determine dog cognitive abilities. In addition, certain cognitive domains, which have been studied in other species, have yet to be explored in dogs in any depth at all. For instance, empathy research is rare, with the exception of a recent study showing that dogs approached a stranger who was pretending to cry, but not one who was humming (Custance & Mayer 2012). Another study showed that dogs may ‘catch’ human yawns, a possible precursor to empathy (Joly-Mascheroni et al. 2008). Empathy has been studied in mice (Miller 2006), and there is some argument for studying empathy in dogs (Silva & de Sousa 2011). Additionally, mirror use by non-human animals (hereafter referred to as ‘animals’), either as a measure of self-awareness or as a tool, has been studied extensively (e.g. Broom et al. 2009; Epstein et al. 1981; Gallup 1970; Itakura 1987; Suddendorf & Collier-Baker 2009). However, there does not appear to be much research analysing how dogs respond to mirrors, apart from one study which showed that puppies quickly lose interest in a mirror after initially responding to it as if viewing a conspecific (Zazzo 1979).

At least in part, inconsistent findings and limits to empirical investigation in some cognitive domains are attributable to a reliance on behavioural response as the sole measure of dog cognitive skills. While behavioural response is important, to progress this field of study, other methods of investigating dog cognitive abilities are warranted to complement behavioural research. There are existing techniques that may be informative in this respect. For example, surveys of people's perceptions of animal intelligence (e.g. Davis & Cheeke 1998; Rasmussen et al. 1993) have been used to examine how humans view animal cognitive abilities. This approach has proven informative, with those who live and work with animals being uniquely qualified to comment on their capabilities. Such data provide researchers with insights into how dogs behave in everyday situations, which permit completely natural behaviours to emerge without the constraints necessary for experimental research to be conclusive. Owner surveys can also inform researchers about how much their experimental data has been disseminated to the lay community, and potentially give cognition researchers ideas for future studies in cases where there is a clear discrepancy between experimental data (or lack of data) and people's perceptions. Few survey studies exploring people's perceptions of dog cognitive abilities have been conducted since the mid-1990s (but see Maust-Mohl et al. 2012; Pongracz et al. 2001a), which was before the recent surge in dog cognition research. Drawing on recent scientific evidence regarding canine cognitive abilities, new work that explores people's beliefs concerning dog cognitive abilities in particular could therefore be instructive.

Neurophysiological measures of cognitive processing in animals, such as electroencephalography (EEG) (Takeuchi et al. 2000; Ueno et al. 2008), also offer a complementary approach to behavioural cognition research in dogs. EEG has been used extensively in human studies, as well as in many animals which have served as models for human research (e.g. Catts et al. 1995; Ehlers et al. 1994; Glover et al. 1986; Ruusuvirta et al. 1998). There is, however, a recent advance in EEG that enables researchers to use this technology to benefit the animals themselves (Ahlstrom et al. 2005), rather than in the service of research for human advantage. This technique could be adapted to record brain waveforms in dogs, therefore adding another means of measuring cognitive processing. Some neurophysiological measures are already used in dog behaviour research, such as magnetic resonance imaging (MRI) (McGreevy et al. 2004; Roberts et al. 2010). However, techniques such as these are under-utilised. EEG could assist with the measurement of how dogs respond to stimuli in the absence of any overt behaviour. For instance, if a dog in a discrimination study does not show behaviours that indicate successful discrimination of two stimuli, it may not mean that the dog has failed to discriminate the stimuli, but perhaps internal motivations or prior training affected the dog's behaviour. Therefore, observing neurological responses to the different stimuli could provide insights into whether a dog correctly discriminated the two stimuli, even without the appropriate corresponding behaviour.

The aim in this thesis is to advance current understanding of dog cognitive processing through the use of a variety of techniques, each of which offers a different perspective on the general question of dog cognition. To this end, a survey was developed, which examined how people perceive dog cognitive skills. Also, two behavioural studies were undertaken, which each explored how dogs respond to mirrors in different experimental setups. Finally, a minimally-invasive EEG technique was developed, which provides researchers with another tool for measuring how dogs respond to stimuli.

1.1. Overview of the thesis

Chapter 2 comprises an exploration of the literature related to human beliefs regarding animal intelligence, an analysis of behavioural research in animal cognition, and an explanation of the technical and theoretical aspects of neurophysiology. This literature review highlights the advantages and disadvantages of each method when used individually, and illustrates the potential benefits of using all three in order to develop a more comprehensive understanding of dog cognition. It also draws attention to gaps in the existing research, thus setting the scene for the study-based chapters to follow.

Chapter 3 includes the submitted manuscript, ‘Development of the Perceptions of Dog Intelligence and Cognitive Skills (PoDIaCS) survey’, which reports the results of a community-based survey. This survey comprises items relating to perceptions of dog cognitive abilities in a range of cognitive domains, including those which have been well-established scientifically (e.g. comprehension of human pointing gestures), and those which have not been examined experimentally (e.g. self-awareness). This chapter showcases the similarities and differences between lay community perceptions of dog cognition and experimental data that currently exist in demonstrating what dogs can do. It establishes the need for further research in areas such as mirror use, which have not been studied in dogs, in order to build a more rounded picture of dog cognitive abilities. It also illustrates the need for measures other than behaviour alone to study cognitive abilities in dogs, because laypeople tend to ascribe more abilities to dogs, such as deception and empathy, than what has been currently experimentally researched. It is possible that dogs do possess these abilities, but have failed to demonstrate them in behavioural experimental settings due to the research design of individual studies or the dogs’ own inner motivation or prior training.

Building on the research gaps identified in Chapter 2, and the results of the survey from Chapter 3, Chapter 4 is the first of two chapters which focus on behavioural research examining how dogs respond to mirrors. The published article ‘Can dogs (*Canis familiaris*) use a mirror to solve a problem?’ is included in this chapter. Chapter 4 summarises the results of a study investigating whether dogs can use a mirror to find their owner holding their favourite toy. It also demonstrates the difficulty of interpreting behavioural data, even in controlled experimental settings, a problem which the Chapter 5 study attempts to rectify.

Chapter 5 includes a submitted manuscript, ‘Dogs use a mirror to find hidden food’. This chapter expands on the information gained in Chapter 4, but with modifications to the research design in an attempt to facilitate interpretation of the data obtained in the study. The dogs' behaviour in this study can be inferred somewhat more easily than in Chapter 4; however, there are still potentially spurious variables which may have affected the way the dogs performed in this particular setup. This study, along with the findings presented in Chapter 4, expands current knowledge of dog cognition in behavioural experimental settings, thus increasing researchers' awareness of dog cognitive abilities in the less-studied cognitive domain of problem-solving and tool use in dogs. However, both chapters illustrate the dangers of relying on behavioural research as the *only* mechanism for understanding dog cognition.

Chapter 6 includes the published article 'Development of a minimally-invasive protocol for recording mismatch negativity (MMN) in the dog (*Canis familiaris*) using electroencephalography (EEG)'. It is the first in a series of two chapters which attempt to address the need to develop new ways to measure cognitive processing in dogs. This may help researchers understand whether dogs are capable of more than what has been demonstrated scientifically in behaviour paradigms, as suggested in the survey data from Chapter 3. It also helps redress the problem of interpreting behavioural data as noted in Chapters 4 and 5. Chapter 6 briefly explains the function of EEG, as well as how a particular waveform, mismatch negativity (MMN), can be used to study higher-order cognitive processing in dogs. This chapter focuses primarily on development of the minimally-invasive method, which was adapted to record this waveform in dogs, and presents the results of a pilot study using this method.

Following the promising results of the pilot study presented in Chapter 6, Chapter 7 expands on the MMN procedure by confirming its reliability in a small group of dogs. Chapter 7 includes the published article, 'Auditory stimulus discrimination recorded in dogs, as indicated by mismatch negativity (MMN)’, which provides further background information about EEG and MMN in particular, as it has been used in human and animal research. This chapter highlights the advantages and disadvantages of using MMN as a mechanism for understanding cognitive processing in the dog. Chapters 6 and 7 together constitute an increase in the knowledge of how dogs process information at the neurological level. They also provide researchers a means by which to explore dog cognitive processing in a minimally-invasive way, which permits the use of owned pet dogs, a common source of experimental subjects in behavioural dog cognition research (e.g. Gaunet 2008; Pongracz et al. 2005a; Prato-Previde et al. 2008; Soproni et al. 2001).

Chapter 8 is a general discussion of the results of these studies, with consideration of the strengths and limitations of the methods in the context of past research findings. This discussion reveals a strong case for the use of complementary methods of research to advance understanding of dog cognition, as illustrated in Chapters 3 through 7. This chapter also includes suggestions for future directions in research, including further behavioural research to determine under which conditions specifically dogs can use logic to solve problems, and adapting the EEG technique for use with visual and olfactory paradigms in order to expand its use in discrimination tasks.

1.2. A note on ‘thesis by publication’

Monash University strongly encourages PhD candidates to submit a ‘thesis by publication’, including submitted, in press, and/or published articles in conjunction with previously unpublished material written specifically for the thesis. Five refereed journal articles are included in the body of this thesis. Because each article was submitted as a stand-alone publication, there is some overlap and repetition between the papers themselves, and sometimes between the papers and previously unpublished parts of the thesis, in order to maintain the logic flow of the thesis as a whole.

CHAPTER 2 –DOG COGNITIVE ABILITIES

The aim in this chapter is to review existing research that has made use of survey-based, behavioural, and neurophysiological methods in order to study dog cognitive skills and processes. The first section highlights survey research which has explored owners' attitudes toward their dogs, illustrating the (perhaps unfittingly) high levels of intelligence that people perceive in dogs. The second section focuses on the growing body of literature devoted to behavioural studies of dog cognition. It explains how social cognition research in dogs has outpaced other cognitive studies, due to the dog's apparent proficiency at communicating with humans. The third and final section describes a neurophysiological measure of higher-order cognitive processing called mismatch negativity (MMN), a waveform visible on an electroencephalogram (EEG). This has been used extensively in human clinical and experimental research and has also been shown to exist in certain non-human mammals. It could, therefore, potentially be used to explore cognitive processing in dogs, in conjunction with behavioural and survey research.

2.1 Perceptions of dog cognition

Those interested in understanding dog cognition may find it instructive to explore owner perceptions of specific cognitive abilities in dogs, because dogs often live in human homes where owners have the opportunity to observe their natural behaviours. In some cases, this information may even lead to hypotheses which, when tested, increase understanding of dog cognition. For instance, two recent studies have investigated whether dogs experience guilt, and suggest that 'guilty look' behaviours shown by some dogs after misbehaving (in the case of the studies, taking a forbidden treat after the owner left the room) may be more reflective of fear of punishment by their owner than a true feeling of guilt (Hecht et al. 2012; Horowitz 2009). The authors came to this conclusion because dogs which had not stolen the treat, but whose owners believed they had, displayed 'guilty look' behaviours when the owner returned to the room and scolded the dogs. However, these behaviours were not displayed when the owner returned to the room and *greeted* the dog, regardless of whether or not the dog had taken the treat. Both of these studies were borne of anecdotal information received from owners about the attribution of guilt to dogs (Hecht et al. 2012; Horowitz 2009). Evaluating how people's perceptions of dog cognitive abilities correspond with skills established in experimental settings may therefore help researchers develop new areas of focus in future behavioural studies, as well as to understand how much of the scientific knowledge gained through such studies is being transmitted to the lay community.

2.1.1 Perceptions of comparative animal intelligence

Research has been undertaken to explore people's beliefs about animal intelligence, including the intelligence of dogs. In general, people tend to rate intelligence relative to the phylogenetic scale (Davis & Cheeke 1998; Eddy et al. 1993; Rasmussen et al. 1993). That is, the more closely related to humans, genetically and physically, that an animal is perceived to be, the higher its intelligence is typically rated. Therefore, invertebrates and fish tend to receive a lower ranking than birds and mammals (Nakajima et al. 2002). This makes intuitive sense, because the 'lower animals' are believed to rely more on instinct and less on logic or reason than 'higher animals' (Watson et al. 2010). Even without specialised training in neuroanatomy, it is possible that non-scientists have some awareness of this phenomenon.

The phylogenetic scale rankings are contradicted, however, by reports that cats, sheep, and pigs typically rank lower than dogs in studies of human perceptions of intelligence, with some studies showing that people believe dogs are smarter than other domestic animals (Davis & Cheeke 1998; Maust-Mohl et al. 2012), but not humans. For example, Rasmussen et al. (1993) undertook a within-subjects study, in which participants rated the perceived cognitive abilities of several different animals, plus human children. Dogs were rated higher than the other animals, but not the children.

To limit the possibility that participants in Rasmussen et al. (1993) may have used comparative rankings, rather than independent evaluations of the cognitive abilities of each animal, the authors undertook a second study in which participants rated the cognitive abilities of *either* a human boy or a dog, but not both (Rasmussen & Rajecki 1995). The findings revealed that dogs were rated lower on all but two of the twelve ‘mental operations’ categories; sensation/perception and pleasure/displeasure. Nonetheless, the participants showed that they believe dogs possess several mental abilities by rating them higher than the mathematical midpoint (higher than 4 on a scale of 1 to 7). The authors concluded that ‘the dog and boy were seen as *quantitatively different*, but *qualitatively similar* [emphasis in original]’ (Rasmussen & Rajecki 1995, p. 131), suggesting that people perceive dogs to have similar abilities to humans, but perhaps developed to a lesser extent.

It seems, then, that dogs are sometimes considered to possess skills beyond the typical cognitive abilities attributed to other mammals which are phylogenetically similar to dogs (e.g. livestock animals), in both general intelligence ratings and in specific cognitive domains. There are several possible explanations for this, including the possibility that dogs are genuinely more intelligent than these other species.

2.1.2 Why do people think dogs are so smart?

Eddy et al. (1993) suggest that dogs and cats ranked higher in intelligence in their survey than most other mammals as a consequence of the participant’s familiarity with those animals; the authors argued that the bond between companion animal and owner causes owners to anthropomorphise and attribute more cognitive skills to companion animals than is warranted. However, this does not explain why dogs were sometimes ranked higher than cats

(Rasmussen et al. 1993), which, as companion animals, are more populous than dogs in the United States of America (American Veterinary Medical Association, 2002).

The bias towards dogs is so strong that Rajecki et al. (1999) coined a term to describe it: ‘the dog-positivity bias.’ In their survey, respondents were asked to compare the behaviour of a boy and a dog in a play setting and a bite scenario and to attribute the behaviour to either internal factors (such as the disposition of the boy/dog) or external factors (i.e., environmental circumstances). In general, respondents tended to attribute positive dog behaviour (i.e. play) to the dog’s inner states, but bad behaviour (i.e. biting) to situational factors. In the case of the boy, however, both positive and negative behaviours were attributed to his nature (Rajecki et al. 1999). This positive perception of dogs may lead people to ascribe higher levels of intelligence to dogs as well.

Whether this dog-positivity bias extends to the attribution of specific dog cognitive abilities is unknown. However, dog positivity bias or familiarity might affect cognition ratings, since one study showed that owners who were ‘highly attached’ to their dogs reported higher intelligence ratings than those who were ‘moderately attached’ (Serpell 1996). Also, there appears to be a correlation between first-time dog ownership and reported behaviour problems (Jagoe & Serpell 1996; Kobelt et al. 2003), suggesting that new owners may have unmet expectations about dog behaviour, perhaps due to their relative lack of familiarity with dogs.

It is possible that familiarity with dogs and the dog positivity bias belie a simpler truth about dog cognition: maybe dogs *are* actually smarter than other animals that are phylogenetically similar. This possibility is discussed in more detail in section 2.2 of this review, which explains the difficulty of cross-species comparisons in behavioural paradigms.

These studies suggest either that humans are wont to anthropomorphise and therefore attribute greater abilities to some animals than they actually possess, that researchers have not yet established the full extent of animal cognition, or both. Other research also demonstrates a mismatch between what people believe dogs are capable of and what science has shown them to be capable of. For example, in one study, students were asked to watch five videos of dog behaviour and write short descriptions of what they had seen (Fidler et al. 1996). At least 90% of both dog owners and non-owners used mentalistic descriptions in each video and all participants used these types of descriptions at least occasionally. Many of the mentalistic attributions provided were inconsistent with empirical data, confirming the importance of conducting further research in this area. In one sense, this potential for anthropomorphising about dogs can be considered a limitation of survey research. In another sense, however, survey results may provide insight into what dogs are actually capable of in what has become their natural environment, the human home.

2.1.3 Summary

Overall, the results of these studies suggest that there is a relationship between familiarity with dogs and/or a positive attitude toward dogs and perceptions of dog intelligence. People generally tend to believe that dogs are smarter than many other animals, with the exception of primates (Eddy et al. 1993) and humans (Rasmussen & Rajecki 1995). Interestingly, there has been little recent effort to understand what humans think of specific dog cognitive abilities, other than a survey comparing dogs with several other animals (Maust-Mohl et al. 2012). Research of this kind could be useful, given recent results of behavioural studies with dogs which show that dogs appear to possess a unique cognitive skill set, possibly due to their evolution alongside humans.

2.2 Behavioural research in dog cognition

The goal of animal cognition research is generally to understand either the unique cognitive skill set that a species has developed to survive in its environment (Shettleworth 2010), or to study how animals differ from, or are similar to, humans; in particular, whether or not animals experience consciousness (Griffin 2001). Studies exploring topics such as problem-solving and means-end awareness (the awareness that specific actions will result in specific consequences) are useful in helping researchers develop an idea of how animals respond to stimuli in their environment. Likewise, social cognition studies, such as communication and empathy research, help scientists further understand the evolution of social cognitive skills. Studies in all of these domains also provide information about whether humans are unique in their possession of certain skills or whether such skills are shared among several animal species. This helps explain the extensive study of great apes (e.g. Gallup 1970; 1998; Povinelli et al. 1997). As humans' closest relative, it was reasoned that, if a chimpanzee did not possess a cognitive ability found in humans, it would be unlikely to exist in any other species (Humphrey 1976).

This assumption was overturned when findings emerged from the Max Planck Institute in Germany and Eotvos Lorand University in Hungary to demonstrate that dogs respond appropriately to human communicative gestures (Hare & Tomasello 1999; Miklosi et al. 1998). These results were unexpected because great apes, previously considered to possess the highest cognitive skills of any animal (Humphrey 1976), tend not to successfully find hidden food on the basis of communicative gestures such as pointing (Hare & Tomasello 2005). To explain these results it was argued that dogs' unique evolution alongside humans may have provided them with the ability to comprehend communicative cues by humans, heretofore believed only to exist in humans (Hare & Tomasello 2005). Thus began more than a decade of research that continues to this day.

2.2.1 Social cognition and social learning

Much of the dog cognition research to date has focused on social cognitive abilities, such as how dogs communicate *with* humans or interpret communicative cues *by* humans. For example, research suggests that they can learn how to complete a task by watching humans (Pongracz et al. 2001b; Pongracz et al. 2003b, 2004; Pongracz et al. 2005a) as well as other dogs (Pongracz et al. 2008). Several other studies have demonstrated that dogs possess the capacity to interpret human communicative gestures, such as pointing (e.g. Agnetta et al. 2000; Dorey et al. 2009; Miklosi et al. 1998; Riedel et al. 2008; Soproni et al. 2002; Viranyi et al. 2008). Dogs have shown that they are able to follow pointing gestures significantly above chance; research further suggests that this does not appear to be influenced by breed (Dorey et al. 2009) or age (Agnetta et al. 2000; Riedel et al. 2008). Moreover, dogs consistently outperform chimpanzees, humans' closest relative, in pointing studies (Miklosi & Soproni 2006), and can also sometimes outperform wolves, their closest relative (Hare et al. 2002; Viranyi et al. 2008).

These findings have led some researchers to suggest that the domestication of dogs prompted their unusual ability to interpret human gestures (Hare et al. 2002; Hare & Tomasello 2005); however, this theory is contentious and by no means universally accepted. For instance, Miklosi and Topal (2005) explain that, while some domesticated species, such as goats and cats, also perform well on pointing tasks, others, including horses, do not. Additionally, other studies have shown that non-domesticated species, such as wolves, are sometimes better than dogs at following human cues (Udell et al. 2008), although this finding contradicts previous results (Viranyi et al. 2008).

Chimpanzees struggle to succeed at pointing tasks, while dogs appear to interpret human communicative gestures with relative ease, furthering the hypothesis that dogs developed these abilities through domestication (Hare et al. 2002). However, there may be a more parsimonious explanation. A recent argument put forward was that the previous failure of great apes on pointing tasks stems not from an inability to follow the cues, but from differences in the experimental setup (Mulcahy & Hedge 2012). For instance, in object choice tests, whereby a subject chooses one of two containers based on experimenter cues, such as pointing, dogs have customarily been permitted to stay at a farther distance from the containers than great apes, which are held in close proximity. This difference may affect the great apes' performance, as dogs can use more of their entire visual field than great apes, which cannot make use of peripheral vision in this task (Mulcahy & Hedge 2012).

These types of methodological differences make valid comparisons between species difficult, but it now seems likely that dogs are not the only animals with impressive social cognitive capabilities. More research that confirms the validity of testing paradigms across different species, and, if necessary, experimentally testing for the same cognitive ability in several different ways, is needed before conclusions can be satisfactorily drawn. This is important in terms of understanding the evolution of social cognition, and underscores the importance of behavioural studies done with dogs in terms of identifying areas for further study in species that are often more challenging to work with.

2.2.2 Means-end awareness

In certain experimental setups, dogs have been shown to possess the ability to solve a means-end task; that is, to demonstrate an awareness of the relationship between actions and their consequences (Range et al. 2011). This is an important finding, as it contradicts prior studies along the same lines which appeared to show that dogs do not possess this ability (Osthaus et al. 2005). The inconsistencies are most likely attributable to differences in research design, and serve to illustrate again the impact that methodological differences can have in influencing conclusions drawn regarding the possession or otherwise of cognitive abilities in animals.

Osthaus et al. (2005) used a string-pulling task in which a treat was attached to one of two strings and the dog had to pull the correct string in order to obtain the treat. The dogs did not select the correct string above chance. Range et al. (2011) developed a different technique in which a treat was either placed on one of two moving boards, or beside the boards, and the dogs could move the boards toward themselves. In this setup, dogs were more likely to move the board toward themselves if there was a treat on it rather than beside it (Range et al. 2011). Why dogs were more successful in this paradigm is unknown, but the authors suggest that the lack of a ‘cross board’ condition may have resulted in a simpler paradigm than the cross string condition used in string-pulling tasks (Range et al. 2011). Further research using crossed boards would be informative.

The string-pulling task is a well-established paradigm used with several different species (e.g. Halsey et al. 2006; Pepperberg 2004; Schuck-Paim et al. 2009; Tolman 1937; Whitt et al. 2009), so it makes sense that Osthaus et al. (2005) would choose to adapt that research design for use with dogs. However, the Range et al. (2011) board set-up appears to be more similar to research with cotton-top tamarins (Hauser et al. 2002). It is possible that certain paradigms are not well-suited to certain species, and this should be considered whenever attempting to adapt a paradigm for use in dogs. It may be necessary to adapt different existing paradigms, as Range et al. (2011) appear to have done, or to design a completely new method.

These clear contradictions indicate that the experimental design may affect whether dogs are perceived to be successful at these sorts of tasks or not. Another mechanism for measuring cognitive abilities in dogs would complement behavioural research and potentially help to shed light on conflicting results such as these. These contradictory results also show that research design should be a careful consideration whenever adapting a method for use in another species, as it could affect the validity of the study.

2.2.3 Problem-solving

Problem solving in dogs often appears to be affected by the dog-owner relationship. This is important information to know, but the result is that there has been relatively little problem-solving research in dogs that does not somehow involve cooperation with, or mediation by, humans. The dogs’ response to an unsolvable problem has been the subject of research, for example, in which a box with a treat was locked so that it could not be opened by the dog (Marshall-Pescini et al. 2009; Miklosi et al. 2003). In these trials, dogs tended to look back at their owner or another nearby human for assistance (Miklosi et al. 2003). Compared to wolves, dogs were much quicker to ‘request’ assistance in this task and looked back at their owners more often than wolves; even wolves which were hand-reared by, and deeply enculturated toward, humans (Miklosi et al. 2003). Also, Topal et al. (1997) showed that, when trying to access food only available by pulling an appropriate handle attached to a container, dogs which were more anthropomorphised by their owners were more likely to look back at their owners, as if requesting help, than dogs which were less anthropomorphised by their owners. However, when dogs were encouraged by their owners to persist, the anthropomorphised dogs were able to solve the problem just as well as the other dogs.

This, along with a study by Prato-Previde et al. (2008), which showed that dogs were more likely to choose a smaller amount of food instead of a larger amount provided the owner showed a preference for the small amount, illustrates that performance on cognitive tasks can be influenced by owner behaviour or the dog-owner relationship. This research has been very informative in showing that dogs often use humans as their problem-solving ‘tools’.

However, more problem-solving and tool use research is warranted. Topal et al's (1997) study showed that all dogs may be able to solve problems equally well if they are given proper encouragement. Therefore, perhaps dogs also have a greater problem-solving ability than has been demonstrated in social paradigms: if given the chance to solve a problem on their own, perhaps they can succeed.

2.2.4 Empathy and self-awareness

Empathy is an aspect of cognition that has not been explored thoroughly in dogs and, of the limited research available, the findings are open to interpretation. For example, one recent study showed that dogs were more likely to approach a stranger who was pretending to cry than one who was humming a tune (Custance & Mayer 2012). These findings were interpreted as indicating that dogs may experience empathy or emotional contagion. The authors admit, however, that a more parsimonious explanation is that the dogs may have been previously rewarded when approaching their owner when the owner was crying and could have generalised that experience to other humans.

There is also some evidence that dogs may 'catch' human yawns (Joly-Mascheroni et al. 2008). In this study, dogs were more likely to yawn after a human yawned than if that person made a different type of facial expression in which their mouths were opened wide. This is relevant to social cognition because yawning is often attributed to the experience of empathy among humans and great apes (Harr et al. 2009) and, therefore, may suggest that dogs experience empathy, or some precursor to empathy, with humans. A second study contradicts these results, however, and suggests that dogs do not catch human yawns after all (Harr et al. 2009). In this study, dogs were shown videos of people yawning, unlike the first study when the dogs were in the same room with the yawning person. Why these two different approaches may have produced different results has not been determined, but it may have less to do with empathy than with visual perception. Dogs appear to process visual information more quickly than humans (Miller & Murphy 1995), so a video recording may not be viewed as a constant picture for dogs in the way it is for humans, but rather as a series of pixelated images and half-images. It may, therefore, not be clear to the dog that they are viewing a yawning person on the screen, whereas a person who is present in the room and yawning would be clearly visible to a dog.

These results show how important it is to design behavioural studies in such a way that alternative explanations can be systematically tested and ruled out, or to develop measures other than behavioural response to determine whether dogs can experience empathy with humans. More research is needed to determine whether, and under what conditions, dogs catch human yawns and also to determine the relationship between yawning and empathy. Empathy research with dogs is in its infancy; however, given dogs' well-developed social skills and ability to communicate with humans, it is possible that dogs do experience empathy with humans (Silva & de Sousa 2011).

Self-awareness, which has been studied at length in other species, has rarely been studied in dog research. Mirror self-recognition (MSR), which is believed to provide evidence of self-awareness in animals, may exist in a few different species, such as chimpanzees (Gallup 1970), dolphins (Reiss & Marino 2001), and Asian elephants (Plotnik et al. 2006). Although MSR is relatively rare among animals, other studies have examined animals' use of a reflective surface as a problem-solving tool, with species such as pigs (Broom et al. 2009) and Japanese monkeys (Itakura 1987). Apart from one study that explored puppies' reactions to mirrors (Zazzo 1979), there is a paucity of research exploring how dogs make use of reflections. Mirror studies that examine whether dogs can learn the function of reflection and use it as a tool would provide researchers with more information about how dogs solve problems.

2.2.5 Summary

It is clear from this body of research that social cognitive abilities in dogs have been explored to a considerable extent. This work has been very instructive. Dogs are skilled at communicating with humans, perhaps because this is where their cognitive strengths lie, or perhaps simply because this is the area of cognition that has attracted the most attention from researchers. The extent to which dogs possess other aspects of cognition, such as means-end awareness and tool use, is less clear.

The lack of consistent findings in some of the areas of inquiry highlights challenges inherent in this area of research. One problem is that dogs sometimes fail at tasks believed to demonstrate one aspect of cognition, only to excel at an alternative task believed to require the same skills. The means-end studies described above highlight the potential pitfalls in drawing inferences based on studies with other species that utilise the same experimental paradigm, however well-established it may be, in dog research. In these cases, the research design seems to make the difference between whether dogs demonstrate a particular skill or not. This illustrates the need for studies to be carefully designed and the importance of exploiting a range of experimental paradigms in order to establish validity for a particular species before drawing firm conclusions; making broad inferences about cognitive abilities is inherently problematic. Even research paradigms that have been well-established in one species may not necessarily be valid for use in other species. It also cautions against the tendency to rely *solely* on behavioural response when trying to gauge a dog’s ability in a particular cognitive domain. With respect to empathy research, for example, behavioural response can be difficult to interpret, with alternative explanations virtually impossible to rule out (Penn & Povinelli 2007). The argument here is not that behavioural research should be replaced; indeed, it should be expanded, but with a view to confirming validity across species if necessary, and alongside other tools able to complement behavioural studies. An example of such a tool is discussed below.

2.3 Neurophysiological research in dog cognition

While dog cognition research has predominantly drawn on behavioural response to determine how dogs process information, there are some recent moves to incorporate new technologies into cognition and behaviour research. This inclusion is a welcome addition to cognition research, as it provides ways of measuring cognitive processing, and/or the brain structures underlying such processing, which were previously unavailable to researchers. For instance, two magnetic resonance imaging (MRI) studies have demonstrated that there is a correlation between the shape of a dog’s face and the organisation of its brain (Roberts et al. 2010) and eyes (McGreevy et al. 2004). This could mean that dogs with brachycephalic heads, such as pugs, may process visual and other stimuli differently than a dolicocephalic dog like a greyhound. Another study developed a non-invasive eye-tracking method to measure the precise location of a dog’s visual focus (Williams et al. 2011), which will permit a level of observation in future dog attention studies that would not be possible with the naked eye. Finally, a study used computers to develop algorithms allowing researchers to study dog vocalisations in depth (Molnar et al. 2008). This study has led to other research which has been instrumental in making the case that dog vocalisations are context-dependent (Farago et al. 2010; Maros et al. 2008; Molnar et al. 2006), despite previous assertions that they bark for no apparent reason (Coppinger & Feinstein 1991).

An under-utilised, but potentially informative, method of exploring dog cognitive processing is electroencephalography (EEG). In humans, EEG is a widely used measure of brain activity whereby electrical impulses are externally recorded from the scalp and viewed as waveforms (Spehlmann 1981).

EEG can be used to index event-related potentials (ERP), which are electrophysiological responses to a stimulus (Luck 2005). The ERP waveform appears as a series of positive-going and negative-going components (peaks) with amplitudes generally between 1μV and 25μV. Peaks in the ERP waveform can occur as early as a few milliseconds, and usually no later than 500 msec in healthy adults, after the onset of the stimulus (Celesia & Brigell 2005). They help researchers understand how the brain processes incoming information and how it determines what is relevant and what is not (Luck 2005). Mismatch negativity (MMN) refers to a negative-going component of the ERP waveform that is observable after exposure to an unexpected stimulus and is most typically observed 160-220 msec post-stimulus (Luck 2005).

Auditory oddball paradigms are commonly used to elicit MMN (Naatanen et al. 2007). In this paradigm, a series of ‘standard’ identical tones are presented and interspersed with occasional ‘oddball’ tones of a different frequency, duration, or volume. While a negative peak is not observed after presentation of the standard stimuli, it does appear reliably after presentation of the oddball. MMN is believed to reflect detection of a change in pre-attentive echoic sensory memory, or memory of previous environmental events held in the brain on an unconscious, pre-perceptual level (Naatanen et al. 2007). Importantly, it can be elicited when the subject is not explicitly focused on the tones (Naatanen et al. 2005; Naatanen et al. 2007), or even when sleeping (Atienza et al. 2002).

Measurement of MMN has great potential for advancing dog cognition research, since MMN is related to discrimination abilities in humans. MMN can be elicited by stimuli that evoke a response from auditory (Naatanen et al. 2005; Naatanen et al. 2007), visual (Pazo-Alvarez et al. 2003), or olfactory (Pause & Krauel 2000) senses. In humans, the MMN waveform has been shown to be affected by differences in cognitive processing abilities. It has been used to study the effects of neurological disorders such as Alzheimer’s disease (Pekkonen 2000), post-traumatic stress disorder (Menning et al. 2008), and schizophrenia (Catts et al. 1995) on cognitive processing. It has been studied in healthy adult populations to establish a baseline for comparison with diseased populations, as well as in developmental research with young children to determine when and how MMN arises (Cheour et al. 2000). This body of research provides strong evidence that MMN is an appropriate method of studying cognitive processing in humans. Since MMN does not require the subject to pay attention to the task, but appears to be related to higher-order cognitive processes such as memory, it may have useful applications in the study of dog cognition.

2.3.1 Possible uses of MMN in dog cognition research

Because MMN is a neurological measure which demonstrates that a change has been noted in a series of incoming stimuli, this technique could be very useful in discrimination studies with dogs. This could help reduce the need for long training periods required in some behavioural studies, and also assist researchers in understanding the underlying processes that govern how dogs learn and behave. In theory, MMN research should be able to be adapted for use in the visual, olfactory, and auditory modalities.

An example of where MMN may be useful in relation to the study of dog cognition occurs within the visual modality, where the ability of dogs to discriminate photos has previously been tested. A study by Range et al. (2008) showed that dogs were able to discriminate photos of landscapes from photos of dogs. However, this required extensive training with the dogs, incorporating operant conditioning to teach the dogs to touch photographic stimuli on a computer screen. With MMN, this training period should not be necessary. The dogs could be fitted with the EEG electrodes and connected to an EEG system, and several different photos of dogs could be shown interspersed with occasional photos of landscapes (or vice versa). If MMN were recorded immediately after the photos of the landscapes were shown, it would indicate whether dogs (or at least dog brains) could perceive a difference between the two types of photographs. Additional testing could then be used to determine which aspects of the visual scenes contributed to this discriminative ability.

Another potential discrimination study that could be useful in dogs would be scent detection work. In scenting studies, dogs are usually trained through operant conditioning to ‘select’ a target scent in a series of scents, by behaviourally indicating that the target scent is different from the others (Browne et al. 2006). However, if the dog fails to alert, it is often impossible to determine whether this is because the dog failed to detect the scent, or whether it simply chose not to respond. Using MMN could supplement the need for training to behaviourally indicate the target by recording neurological changes which suggest that a dog has discriminated a scent.

Training for behavioural indicators will always be necessary for ‘real world’ use in police or security work, but MMN measures could help trainers and researchers understand where there may be differences in behavioural indicators and neurological indicators, i.e. when and if dogs discriminate a scent based on the EEG recording but do not show a behavioural indicator of discrimination. Trainers could then work with the dogs to develop programs which improve reliability of behavioural indicators. Since it is necessary for detection dogs to go through long training periods, MMN could be used in conjunction with behaviour training to study the neurological foundations of learning and discrimination in these dogs. This would allow researchers to establish ‘baseline’ EEG responses for discrimination of stimuli prior to the training and develop an understanding of how neurological responses change throughout the course of the training process.

MMN has been used to research language processing in humans (Peltola et al. 2003; Pulvermüller et al. 2008) and could potentially be used for similar research with dogs. There has been some behavioural research with dogs which suggests that some individual dogs can learn hundreds of words (Kaminski et al. 2004; Pilley & Reid 2011) and one study which suggests that dogs can discriminate their handler's voice (Coutellier 2006). MMN research along these lines could help dog cognition researchers understand the extent of language comprehension in dogs, which may have practical applications for working dogs which are far enough away from their handlers for olfactory cues from the handler to be muted and, therefore, may need to rely more heavily on auditory cues (Coutellier 2006).

2.3.2 Adapting MMN research for use in companion dogs

MMN has been demonstrated in rats (Ruusuvirta et al. 1998), monkeys (Javitt et al. 1996), and cats (Pincze et al. 2001, 2002). Accordingly, it is probable that this ERP component will occur in dogs, which would give dog cognition researchers a mechanism other than behavioural response for studying stimulus discrimination. A potential difficulty in the application of the methodology, however, is that its use in animals has traditionally been invasive, involving placement of electrodes directly onto the brain itself (Pincze et al. 2001, 2002). In dog cognition research with pet dogs, this would be unsuitable since dogs are considered to be members of the family (Kubinyi et al. 2009) and, correspondingly, owners are unlikely to acquiesce to such treatment. There has been, however, some successful use of minimally-invasive EEG techniques in research with dogs. For example, epilepsy research in dogs has used subdermal needle electrodes which are inserted just under the skin (Pellegrino & Sica 2004) and hearing loss research has used a similar procedure (Ahlstrom et al. 2005); as an ERP study, the latter could be particularly instructive. A minimally-invasive method for recording late-occurring potentials, such as MMN, could provide dog cognition researchers with a new way to measure how dogs process information to complement behavioural research.

2.3.3 Summary

In summary, MMN research with dogs could have many different applications in dog cognition and working dog studies. Cognition studies generally make use of companion dogs living in human homes, because they have often been fully socialised to humans, and therefore may have developed cognitive skills which could be different from animals raised in a laboratory setting with minimal human contact. Before any of those studies can commence, however, there are research design issues that must be considered in developing a measurement technique that is appropriate for companion dogs. This is especially the case when dogs are recruited for use in research from dog-owning members of the general public. While such dogs have proved invaluable in this field of research, employing dogs that live as companions in human homes brings with it additional responsibilities. A minimally-invasive technique used in hearing-loss research should be able to be adapted to recording MMN in dogs, however, and this would provide another, complementary, measure of dog cognitive processing.

2.4 Future Directions

While there have been several studies examining people’s beliefs about animal cognitive abilities, many of them occurred prior to the renaissance of behavioural dog cognitive research in the late 1990s (Eddy et al. 1993; Rajecki et al. 1999; Rasmussen & Rajecki 1995; Rasmussen et al. 1993). Only one study was published recently, which examines specific cognitive abilities across a range of different animals (Maust-Mohl et al. 2012). Previous research suggests that the dog-owner relationship can affect perceptions of dog cognitive abilities (Serpell 1996), so this should be explored further. More knowledge of this kind would provide further insights into how much of the recent dog cognition behavioural research is understood by the lay community, and may even give researchers ideas for future behavioural studies (Hecht et al. 2012; Horowitz 2009).

The dog's social cognitive abilities, particularly evident in cooperative actions with humans, are unusual in the animal kingdom (Reid 2009). Indeed, dogs' skills in this area often appear to exceed those of other species (Miklosi & Soproni 2006). It logically follows, therefore, that scientific research has focused on understanding the limits of these abilities, but there is much more work that needs to be done. There are fewer cognition studies with dogs that explore more general cognitive skills, although dogs can sometimes succeed at these kinds of tasks too. New research, using different ways of exploring the same cognitive domains, is needed in order to understand the full breadth of dog cognitive abilities. This may help increase the possibility of reliable, consistent findings across a range of domains. In particular, studies examining dogs' responses to a mirror would be instructive in developing further knowledge of problem-solving. While fairly common in animal cognition research generally (e.g. Broom et al. 2009; Povinelli et al. 1997; Prior et al. 2008; Rajala et al. 2010; Reiss & Marino 2001), mirror studies with dogs are rare, but could provide further insights into how dogs perceive the world around them.

A method of studying cognitive processing in dogs other than behavioural research could complement the existing knowledge of dog cognition. Some cognitive skills in dogs, such as their interpretation of human communicative gestures, have been studied so exhaustively and with such similar results that a good case can be made that this ability does indeed exist in dogs. However, there remains uncertainty with regard to dogs' capacity for means-end awareness, in which methodological differences may mean success or failure in different studies. A mechanism for measuring the neurological processes which underpin cognitive behaviour, such as electroencephalography (EEG), could give researchers another tool in their quest to understand the extent of dog cognitive abilities. While minimally- or non-invasive EEG has been used to examine hearing loss in dogs (Ahlstrom et al. 2005), and higher-order cognitive processing, such as memory, in humans (Naatanen et al. 2005; Naatanen et al. 2007), there is currently no established method for recording higher-order cognitive processing in dogs using a minimally-invasive technique. Nonetheless, a procedure such as this could be useful in assisting researchers to develop a more thorough understanding of dog cognitive processing.

2.5 Conclusion

Despite the focus on behavioural research to explore the extent of dog cognitive abilities, there are still many questions to be answered, especially where general, non-social cognitive skills are concerned. More behavioural research is needed to help answer these questions, but there are two other potential tools that have not been made sufficient use of in the past: people's perceptions and neurophysiological measures. The use of these two accompaniments to behavioural response could provide the scientific community with more ways to examine dog cognition. Survey research could provide researchers with further understanding of how dogs behave in natural settings, such as the home, possibly opening up new avenues of examination, as well as to develop an understanding of how perceived intelligence or cognitive skills affect perceptions of behaviour, both good and bad. Neurophysiological research would add a measure of stimulus processing to complement the interpretation of behaviour, and allow researchers to explore the neurological underpinnings of behaviour both in working dog training and in cognition experiments.

The aim in this thesis is to advance scientific understanding of dog cognitive abilities by using different techniques which each offer a unique perspective on dog cognition. To this end, the next chapter reports the results of a survey study in which lay participants rated dog cognitive abilities across a variety of different domains. Chapters 4 and 5 then report the results of two behavioural studies that were undertaken to examine the conditions under which dogs may use a mirror as a problem-solving tool. Finally, Chapters 6 and 7 illustrate a new method of recording MMN in dogs using a minimally-invasive technique. Taken together, results reported in this thesis expand the current knowledge of dog cognitive abilities by exploring the general question of dog cognition in various different, but complementary, ways.

CHAPTER 3 – PEOPLE’S PERCEPTIONS OF DOG COGNITIVE ABILITIES

Survey data can be used to understand human beliefs regarding the cognitive abilities possessed by dogs. This could prove invaluable, since dog owners may be best placed to understand what their dogs are capable of. Given the recent increase in behavioural experimentation to examine dog cognitive skills, it is somewhat surprising that there are few recent studies (Maust-Mohl et al. 2012; Pongracz et al. 2001a) which aim to understand people’s perceptions of these skills. An added benefit of using this approach is that it helps researchers explore how much of the current scientific understanding of dog cognition, as demonstrated in behavioural research, has entered public awareness. This is important to understand because attachment levels have previously been shown to correlate with perceptions of intelligence (Serpell 1996). Hence, it is possible that the quality of the human-dog relationship can be affected by dog owner beliefs, thereby affecting dog welfare. The primary aim in this study was to capture people’s beliefs in relation to the cognitive abilities that dogs possess. A secondary aim was to explore whether the level of perceived emotional closeness to one’s dog predicted perceptions of dog cognitive abilities.

Several cognitive domains were chosen for inclusion in this study, similar to previous research exploring different cognitive abilities in animals (Maust-Mohl et al. 2012; Rasmussen et al. 1993). Some cognitive skills have been thoroughly researched in behavioural paradigms and are generally accepted by scientists as being exhibited by dogs, such as comprehension of human communicative gestures (e.g. Hare & Tomasello 1999; Miklosi et al. 1998; Soproni et al. 2001), and social learning from humans (e.g. Pongracz et al. 2001b; Pongracz et al. 2005a; Pongracz et al. 2008). Other skills have been studied in some behavioural studies, but results have been mixed, such as means-end comprehension (Osthaus et al. 2005; Range et al. 2011). Still others, such as empathy, self-awareness and deception, have been studied rarely or not at all in dogs (but see Custance & Mayer 2012; Joly-Mascheroni et al. 2008), but have been explored in other animal species (e.g. Epstein et al. 1981; Gallup 1970; Miller 2006; Suddendorf & Collier-Baker 2009). Additionally, the survey asked whether our respondents believed dogs were capable of these skills from birth, or innately, or whether these skills developed over the course of a dog's development. Questions examining this issue were included because there has been some debate over whether dogs' ability to accurately interpret human communicative gestures is innate or learned (Agnetta et al. 2000; Elgier et al. 2009; Hare et al. 2010; Wynne et al. 2008). An innate ability may suggest that the domestication of dogs has given them a unique cognitive skill set including communication with humans (Hare et al. 2002), while learned abilities would mean that a simpler, associative learning process was underlying this skill (Wynne et al. 2008). Therefore, it was important to ask people whether or not they believed dogs were born with these abilities. Since breeders are with companion dogs from birth, and owners shortly thereafter, they may be uniquely positioned to inform researchers about when they believe dog cognitive abilities develop (see Appendix A for a copy of the survey).

The following journal article, submitted to *Journal of Veterinary Behavior: Clinical Applications and Research* in August 2012, is titled 'Development of the Perceptions of Dog Intelligence and Cognitive Skills (PoDIaCS) survey'.

3.1 Declaration for thesis chapter 3

In the case of Chapter 3, the nature and extent of my contribution to the work was the following:

Nature of contribution	**Extent of contribution (%)**
Development of the survey, data collection and subsequent analysis, writing the journal article	75%

The following co-authors contributed to the work. Co-authors who are students at Monash University must also indicate the extent of their contribution in percentage terms:

Name	**Nature of contribution**	**Extent of contribution (%) for student co-authors only**
Samia Toukhsati	Advising on development and analysis of survey, suggestions for refinement of the manuscript	
Russell Conduit	Advising on development and analysis of survey, suggestions for refinement of the manuscript	
Pauleen Bennett	Advising on development and analysis of survey, suggestions for refinement of the manuscript	

Candidate's Signature		**Date**

The undersigned hereby certify that:

(1) the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.
(2) they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
(3) they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
(4) there are no other authors of the publication according to these criteria;
(5) potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and
(6) the original data are stored at the following location(s) and will be held for at least five years from the date indicated below:

Location(s)	**Monash University, Clayton Campus**

[Please note that the location(s) must be institutional in nature, and should be indicated here as a department, centre or institute, with specific campus identification where relevant.]

Signature 1		**Date**
Signature 2		**Date**
Signature 3		**Date**

3.2 Development of the Perceptions of Dog Intelligence and Cognitive Skills (PoDIaCS) survey

Development of the Perceptions of Dog Intelligence and Cognitive Skills (PoDIaCS) survey

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Abstract

Dog cognition research is expanding, but few studies have examined people's perceptions of specific cognitive abilities in dogs. The aim of this study was to explore owner perceptions of dog cognitive abilities across different cognitive domains and to determine whether these were associated with the dog-owner relationship. We developed an online questionnaire and analyzed the results from 645 participants, of which 565 were dog owners. Dog owners generally indicated the belief that dogs are socially intelligent and possess the capacity to learn social and general cognitive skills. One quarter of dog owners agreed or strongly agreed that dogs were smarter than most people and 45.7 % indicated the belief that a dog's mental ability is equal to '3 to 5 year old human children'. Perceived emotional owner-dog closeness correlated with almost all cognition ratings. Dog behavior is a common reason for relinquishment to shelters, but a better understanding of dog cognitive abilities may help improve the interpretation of dog behavior.

Introduction

Accumulating dog cognition research has shown that dogs are proficient at communicating with humans (for reviews see Miklosi et al., 2006; Reid, 2009). Dogs are also capable of learning from humans by observation (Pongracz et al., 2001b; 2003a; 2003b), and understand when humans are paying attention to them and when they are not (Gacsi et al., 2004). Studies have shown that some dogs can solve means-end tasks in some situations (Range et al., 2011), can understand hundreds of words (Kaminski et al., 2004; Pilley et al., 2011), and understand that one solid object cannot physically move through another solid object (Pattison et al., 2010).

Skills such as those demonstrated in these studies suggest that dogs experience complex inner states. Accordingly, and despite dogs' inability to verbally communicate their feelings and cognitions to humans, many people form perceptions of these inner states. For instance, both children and adults are capable of categorizing dog barks, solely on the basis of auditory information, correctly perceiving the situation the dog was in when the information was recorded. The participants in this study guessed the perceived emotional state of each dog and were quite consistent (both between and within participants) in doing so (Pongrácz et al., 2011).

In another study, a survey asked people to rank several domestic animals (i.e., cow, pig, dog, cat, horse, sheep, chicken, and turkey) in order of intelligence, and dogs were ranked highest (Davis et al., 1998). Studies in the mid-1990s asked people to rate the abilities of dogs in specific cognitive domains, compared to a human child or other animals, and showed that people tend to rate dogs more highly than other animals, but not as highly as children (Rasmussen et al., 1995; 1993). Similar results were obtained by Maust-Mohl et al. (2012), who found that dogs, cats, and wild animals were generally rated higher on several domains of cognitive functioning (such as learning, memory, and awareness) compared to farm animals.

It is not known why dogs are perceived to have higher level cognitive skills than farm animals, but there are indications that a person's relationship with an animal can influence their perception of that animal's inner experiences. For example, perceived emotional closeness between dog and owner is associated with perceptions of dog behavior, with 'moderately attached' owners being less satisfied with their dog's behavior on the whole than 'highly attached' owners (Serpell, 1996). Empathy towards animals is also positively correlated with having a positive attitude toward pets (Ellingsen et al., 2010). When people were shown pictures of dogs in various potentially painful situations, levels of empathy toward animals predicted the level of pain they perceived the dog would experience (Ellingsen et al., 2010). In Serpell's 1996 study, 'highly attached' dog owners rated their dog's intelligence higher than 'moderately attached' owners.

Notwithstanding public interest in whether dogs have 'minds' and are comparatively intelligent, few studies in recent years have systematically asked owners to describe their perceptions of particular cognitive abilities in dogs. We could find only one recent study which asked dog owners how many commands their dog understood (Pongracz et al., 2001a). Dog cognition research has experienced a revival since the late 1990s, thus expanding scientific knowledge of dog cognitive abilities; therefore, it would be worthwhile to know which abilities owners currently ascribe to dogs. The aims in this study were to understand specific cognitive abilities dog owners attribute to dogs, and whether emotional closeness to pet dogs and perceived level of knowledge about pet dogs are associated with cognition ratings.

Methods

Participants

Data were analyzed from 645 participants who completed an online survey. We asked that people be at least 18 years old and fluent English speakers. A total of 828 people participated in the survey. However, due to lack of survey completion in some cases, the total number of participants included in the analyses was 645, including dog owners and non-owners. Of these, 581 (90.1%) were female, and 62 (9.6%) were male. The mean age was 41.9 years (*SD* = 12.8, range = 19 to 76 years). Most (65.2%) had completed a university degree, which is higher than the Australian average of 24%, and 48.8% were employed full time, higher than the Australian average of 36% (Australian Bureau of Statistics, 2012). Most participants (61.5%) were born in Australia; the United States of America and United Kingdom were also well represented at 18.5% and 9.9% respectively. The majority of respondents (65.4%) reported living with a partner and 22.7% also reported living with a child under 18 years of age.

The majority of participants (87.6%) reported that they were currently living with a dog. Ten people (1.6%) had never owned or lived with a dog. Of those currently living with a dog, 87.7% were living with three or fewer dogs and most people (80.9%) had lived with their dog for at least three years. All breed groups were represented.

Materials

The Perceptions of Dog Intelligence and Cognitive Skills (PoDIaCS) survey was developed on the basis of current literature pertaining to the cognitive abilities of non-human species, with particular focus on dogs. A review of the comparative literature revealed domains of cognitive functioning that had been well established in dogs (e.g., responses to human communicative gestures, Reid, 2009) and others for which evidence could be drawn from non-dog species (e.g., mirror self-recognition), but remained to be explored in dogs. The survey was divided into three sections. Section A consisted of demographic questions, Section B included statements about perceived dog cognitive abilities, and Section C was the Monash Dog Owner Relationship Scale, or MDORS (Dwyer et al., 2006) completed by current dog owners. In Section B, 51 survey items were developed to determine respondent beliefs with regard to whether dogs had an instinctive or learned ability to perform certain actions across several cognitive domains, including: communication with humans, understanding of human attentional focus, problem solving, learning and memory, social learning, means-end awareness, tool use, deception, mirror self-recognition, and empathy/emotional recognition. Participants were generally asked to indicate their beliefs using a five point likert-type scale ranging from 1 = 'strongly disagree' to 5 = 'strongly agree'. For example, one statement about tool use was 'dogs can learn to use a mirror to find their owner, a treat, or a toy', and another statement, related to problem solving, was 'dogs can instinctively solve problems like opening a container lid to get a treat'.

Six questions were accompanied by a picture of a string-pulling task designed to examine perceptions of means-end understanding in dogs (see Figure 1). Each picture corresponded to the following statements: 'dogs instinctively know which string to pull', 'dogs can learn which string to pull by watching humans do it first', and 'dogs can learn which string to pull by watching other dogs do it first'.

In Section C, dog owners were requested to complete an additional section of the survey, comprising the MDORS (Dwyer et al., 2006). The MDORS survey rates various dimensions of the dog-owner relationship and is divided into three subscales: dog-owner interactions (e.g. riding in the car and visiting friends with the dog), perceived emotional closeness, and perceived costs (i.e. the financial, emotional, and social disadvantages associated with dog ownership).

Procedure

This project was approved by La Trobe University Human Research Ethics Committee (approval number: FHEC11/R84), and Monash University Human Research Ethics Committee (approval number: 2011001582).

The survey proceeded entirely online, so participants were recruited through the internet. Social media websites and dog-focused online forums were the primary sources of recruitment, and participants were encouraged to send the survey website to their friends and family who might be interested.

Data analysis

Statistical analyses were completed using PASW Statistics for Windows (Version 18) (International Business Machines, Armonk, New York, USA). In Section B, a higher score indicated a higher perceived cognitive ability. As a method of data reduction, using data from dog owners only ($n = 559$ were included after inspecting Mahalanobis distances for outliers), we performed a Principal Components Analysis (PCA) followed by Varimax rotation with Kaiser normalization on all cognition items that had been rated on a likert-type scale. Items with Eigenvalues < 0.4 on any of the eight factors, or that loaded onto more than one factor, were analyzed as stand-alone variables. Scores for items on the MDORS in Section C that were negatively phrased (e.g. 'my dog costs too much money') were reverse scored such that higher scores indicate a higher degree of emotional closeness or interaction and lower perceived costs.

Dog cognition ratings by current dog owners and non-owners, for composite variables and stand-alone items, were compared using *t*-tests. Correlations were used to determine the relationship between cognition ratings and self-reported knowledge of dogs and the MDORS. Finally, multiple regression analyses were used to examine whether the MDORS has any predictive value for cognition ratings among dog owners.

Results

Principle components analysis

An eight factor solution that explained 63% of the total variance was obtained from dog owner ($n = 559$) responses to 40 dog cognition items (component scores and Cronbach's alpha levels are reported in Table 1), which were used to develop composite variables for further analyses. This solution was confirmed when undertaken with the total sample. A ninth factor, including questions related to mirror use and recognition, did not have acceptable reliability values and was therefore excluded. The 10 remaining questions with likert-type scale response options did not load onto any of the eight subscales and were analyzed individually. The eight factors clearly fall into conceptually distinct subscales, and have been individually named based on what each factor represents (e.g., factor 1 is termed 'subscale 1: recognition of human emotions', and factor 2 is termed 'subscale 2: learned problem-solving abilities'). Subscale names and descriptive statistics for each of the eight factors and the stand alone items are presented in Table 2. Data pertaining to the item, 'a dog's mental ability is equal to', which was indexed on a categorical scale, is reported in Figure 2.

Owner and non-owner cognition ratings

Differences between cognition ratings for current dog owners ($n = 565$) and non-owners ($n = 80$) were evaluated using t-tests (see Table 2). In relation to cognition subscale 4, 'learned awareness of human attention', the mean score for owners ($M = 4.45$, $SD = 0.46$) was significantly greater than the mean score for non-owners ($M = 4.33$, $SD = 0.46$), $t\,(643) = 2.28$, $p = 0.02$ (two-tailed). The same was true of cognition subscale 8, 'general intelligence compared to humans', which owners ($M = 2.61$, $SD = 0.86$) also rated more highly than non-owners ($M = 2.38$, $SD = 0.90$), $t\,(642) = 2.26$, $p = 0.02$ (two-tailed). There were also some differences between owner and non-owner groups among individual cognition items. For instance, for the item, 'once a dog has learned the 'sit' command in one area (like the kitchen), it will respond to the command if it is given in another area (like the backyard) or by another person', the mean for non-owners ($M = 3.68$, $SD = 0.96$) was significantly higher than the mean for owners ($M = 3.28$, $SD = 1.30$), $t\ (123) = -3.38$, $p < 0.01$ (two-tailed). This also applied to the item 'the quickest way to house train a dog is to punish it whenever you find a 'mishap' in the house', which owners ($M = 1.45$, $SD = 0.74$) rated less highly than non-owners ($M = 2.15$, $SD = 1.00$), $t\ (92) = -6.05$, $p < 0.01$ (two tailed). Conversely, owners ($M = 4.62$, $SD = 0.55$) rated the item 'dogs quickly learn to associate actions like picking up the car keys with consequences like going for a ride in the car' more highly than non-owners ($M = 4.44$, $SD = 055.$), $t\ (643) = 2.82$, $p < 0.01$ (two-tailed). Finally, owners ($M = 4.08$, $SD = 0.81$) rated 'dogs quickly learn the sit command when they are being trained' more highly than non-owners ($M = 3.83$, $SD = 0.67$), $t\ (641) = 2.67$, $p < 0.01$ (two-tailed).

Correlations between knowledge of dogs, cognition ratings and the MDORs

All participants ($N = 645$) were asked to estimate their knowledge of dogs in relation to other members of the community; 70.3% of people said they were somewhat or very knowledgeable, while 22.1% said they were somewhat or very unknowledgeable. The remaining 7.6% reported that they were neither knowledgeable nor unknowledgeable. This trend was evident among dog owners ($n = 565$), 73% of whom reported that they were somewhat or very knowledgeable, 22% of whom reported being somewhat or very unknowledgeable, and 5% of whom were neither knowledgeable nor unknowledgeable.

Associations between owners' self-reported knowledge of dogs and dog cognition ratings were examined using Pearson's correlation coefficients. These findings revealed that self-reported knowledge of dogs negatively correlated with cognition subscale 7, instinctive problem-solving abilities, $r = -0.08$ ($p < 0.05$), and the item 'dogs can instinctively recognize themselves in a mirror', $r = -0.08$ ($p = 0.04$). No other correlations between self-reported knowledge of dogs and cognition ratings were significant.

Pearson's correlation coefficient was used to examine associations between cognition ratings and the MDORS (see Table 3). The second subscale of the MDORS, which measures levels of perceived emotional closeness, was significantly correlated with each cognition subscale and all of the individual items, except for 'the quickest way to house train a dog is to punish it whenever you find a 'mishap' in the house' and 'dogs learn mostly by trial and error'. The first subscale of the MDORS, related to dog-owner interactions, was also correlated with several of the cognition ratings, including all the subscales except for Subscale 7, 'instinctive problem-solving abilities', while the third MDORS subscale, for perceived costs, was correlated with fewer than the other two subscales. The third MDORS subscale was significantly correlated only with PoDIaCS subscale 8, 'general intelligence compared to humans', and two individual items: punishment of a mishap to house train a dog, and 'dogs quickly learn to associate actions like picking up the car keys with consequences like going for a ride in the car'. All significant correlations were positive, except for the correlation between MDORS subscales 1 and 3 and the house training item, which was negative.

Predicting cognition ratings by MDORS subscales

Multiple regression analyses were conducted to determine whether the MDORS could predict dog cognition ratings. In this regard, the three MDORS subscales were used to predict dog cognition ratings on each of the eight cognition subscales . With one exception (subscale 7, 'instinctive problem-solving abilities'), significant models emerged for all of the cognition subscales, with MDORS subscale 2, related to perceived emotional closeness to one's dog, explaining between 4% and 13% of the variance in cognition ratings. ANOVA results, percentage of variance explained, Beta scores and *p*-values for cognition ratings predicted by the MDORS are presented in Table 4.

Discussion

The aims of this study were to explore owner perceptions of dog cognitive abilities and to determine whether perceived knowledge about dogs and emotional closeness to one's dog were associated with cognition ratings. In general, the participants scored dogs very highly in terms of the possession of complex cognitive skills. Respondents generally seem to agree that dogs possess extensive social cognitive skills, many of which have been established experimentally. However, many participants also seem to believe that dogs are capable of recognizing human emotion and attempting to deceive humans or other dogs. These latter skills have not yet been demonstrated in scientific research, apart from a recent study that suggests that dogs experience some form of empathy (Custance et al., 2012). This may mean that members of the lay community are unfamiliar with, or do not understand what has been demonstrated in behavioral studies with dogs, or that they believe dogs' abilities go further than what has been shown experimentally. Further research is needed to explore the intricacies of this result. Likewise, further experimental research exploring dogs' abilities in the less-explored cognitive domains would be instructive.

Few differences between owner and non-owner beliefs about dog cognitive abilities emerged, although owners with higher self-reported knowledge of dogs were less likely to believe dogs possess instinctive problem-solving abilities. Interestingly, owners and non-owners have different ideas about the best way to housetrain a dog and how dogs make connections between actions and consequences. This could be due to the 'pure positive' method of dog training, championed by trainers such as Jean Donaldson and Karen Pryor, which proposes that dogs learn most quickly through *immediate* positive reinforcement of desired behaviors and by ignoring undesirable behaviors (Donaldson, 1996, 2008; Pryor, 1999). It is also possible that dog owners have learned through experience with their dogs that punishment for toilet training mishaps is ineffective and that dogs learn most quickly by trial and error. The findings further showed that owners who were emotionally closer to their dogs or with a higher self-reported knowledge of dogs, generally perceived dogs as having more cognitive skills than owners who were less knowledgeable or less close. These results are consistent with past research which suggests that people who feel emotionally closer to their pets believe they are more intelligent than people who feel less close (Serpell, 1996). Previous studies have determined that people's beliefs of animal intelligence tend to follow the phylogenetic scale, so that the more 'like humans' an animal is perceived to be, the higher its general intelligence is rated (Eddy et al., 1993). However, this does not explain why dogs are often rated higher than other mammals, including other domesticated animals (Davis et al., 1998; Rasmussen et al., 1993). It is possible that familiarity with dogs can explain this disparity (Eddy et al., 1993), or possibly even a 'dog-positivity bias' as reported in Rajecki et al.(1999). People believe that 'good' dog behavior is attributable to the dog's disposition, but 'bad' dog behavior is primarily a response to environmental events which force it to misbehave (Rajecki et al., 1999). This is an interesting question which deserves more attention, but was beyond the scope of the current study.

Notably, two exceptions with regard to the anticipated direction of associations between dog cognition ratings and emotional closeness emerged: higher self-reported knowledge of dogs in owners was inversely correlated with instinctive problem-solving skills and an instinctive ability to recognize oneself in a mirror, indicating that they perceived dogs to be *less* capable of those abilities. There are no studies, to our knowledge, examining whether dogs can recognize themselves in mirrors, while some studies exploring problem-solving skills in dogs demonstrate that dogs can learn to solve problems which they do not always immediately, and therefore instinctively, solve (Pongracz et al., 2003b; 2005; 2008). Perhaps people with a higher self-reported knowledge of dogs are more knowledgeable about recent dog cognition studies, or perhaps they have more experience with dogs and have learned about their cognitive strengths and weaknesses through observation.

The results of the principle components analysis showed that the individual items loaded into different factors in intuitive ways. For instance, the items related to emotional recognition all loaded onto the same factor. Items related to instinctive and learned problem-solving abilities also loaded onto respective factors. The ability for deception had its own factor, as did both learned and instinctive awareness of human attention. Perhaps unexpectedly, the items related to emotional recognition loaded onto a different factor than items related to emotional contagion, despite the fact that both of these abilities are elements of empathy. Also unexpected was the unreliability of the factor related to dogs' responses to mirrors, which would have been the ninth factor had Cronbach's alpha been acceptable. These items included both instinctive and learned abilities to recognize oneself in a mirror and to use a mirror as a problem-solving tool, so it is possible that the inclusion of both instinctive and learned skills on the same factor caused the lower reliability as the eight reliable factors separated learned and instinctive abilities. Finally, several of the items related to how dogs learn did not load onto any of the factors, such as 'dogs learn mostly by trial and error', and 'dogs quickly learn to associate actions like picking up the car keys with consequences like going for a ride in the car'. It is interesting that these items did not generate their own factor or load onto any other factors since they all appear to be related to general learning styles.

Some limitations to this survey should be considered when interpreting the data. Our survey respondents were primarily tertiary educated, female dog owners. While this is consistent with other surveys exploring attitudes and beliefs about dog behavior (e.g. King et al., 2009), it could nonetheless bias the results. Also, among non-owners, only 10 respondents had *never* owned or lived with a dog. This could mean that even non-owners in our study may have had sufficient experience with dogs to develop ideas about dog cognitive abilities that are more similar to those of owners, than if we had been able to obtain a larger sample of people who had never had much interaction with dogs at all. With only 10 respondents never having owned a dog, statistical comparisons were difficult with this group, so many potential insights were unavailable to us. Finally, because we recruited through social media and online dog-related forums, many of our respondents were probably very interested in dog behavior and cognition, more so than a person who did not spend time on dog forums online may be. Future research in this area should aim to attract more men, and people who are not 'dog lovers', for a more representative sample of the population at large.

Given that this study was concerned with understanding what owners perceive their dogs to be capable of, the results have potentially significant practical implications. Dog behavior is a common reason for relinquishment to shelters and subsequent euthanasia (Marston et al., 2004). It is possible that, in some cases, dog owners believe that dogs are cognitively capable of more than they actually are and misconstrue normal dog behavior as an attempt at 'dominance' or a stubborn lack of obedience. The more information researchers have about dog cognitive capacities, and the more practitioners understand about what dog owners may be thinking with respect to their dog's cognitive skills, the more that can be done to help the general public understand how dog cognition affects behavior.

Conclusion

Experimental research in different cognitive domains can help researchers understand the extent of dog cognitive abilities. Likewise, surveys exploring peoples' beliefs about dog cognitive abilities can help researchers establish where scientific research connects and disconnects with commonly held perceptions. Finally, veterinary behaviorists can assist new owners by using evidence-based scientific research to interpret dog behavior in the most appropriate way, in order to improve understanding between the two species.

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Table 1: The pattern/structure coefficients for the dog cognition subscales created in the eight factor matrix, including Cronbach's alpha levels for each factor. *A drawing of a simple string-pulling task accompanied these questions (see Figure 1). **A drawing of a more complex string-pulling task accompanied these questions (see Figure 1).

Table 2: Descriptive statistics for the eight cognition subscales and the individual questions which did not load onto any of the subscales. [†]The response options for this question were: (1) Newborn to 11 month old human babies, (2) 1 to 2 year old human babies, (3) 3 to 5 year old human children, (4) 6 to 10 year old human children, (5) 11 to 15 year old human children, (6) Humans who are 16 years or older. Therefore, this question could not be analysed with the others.

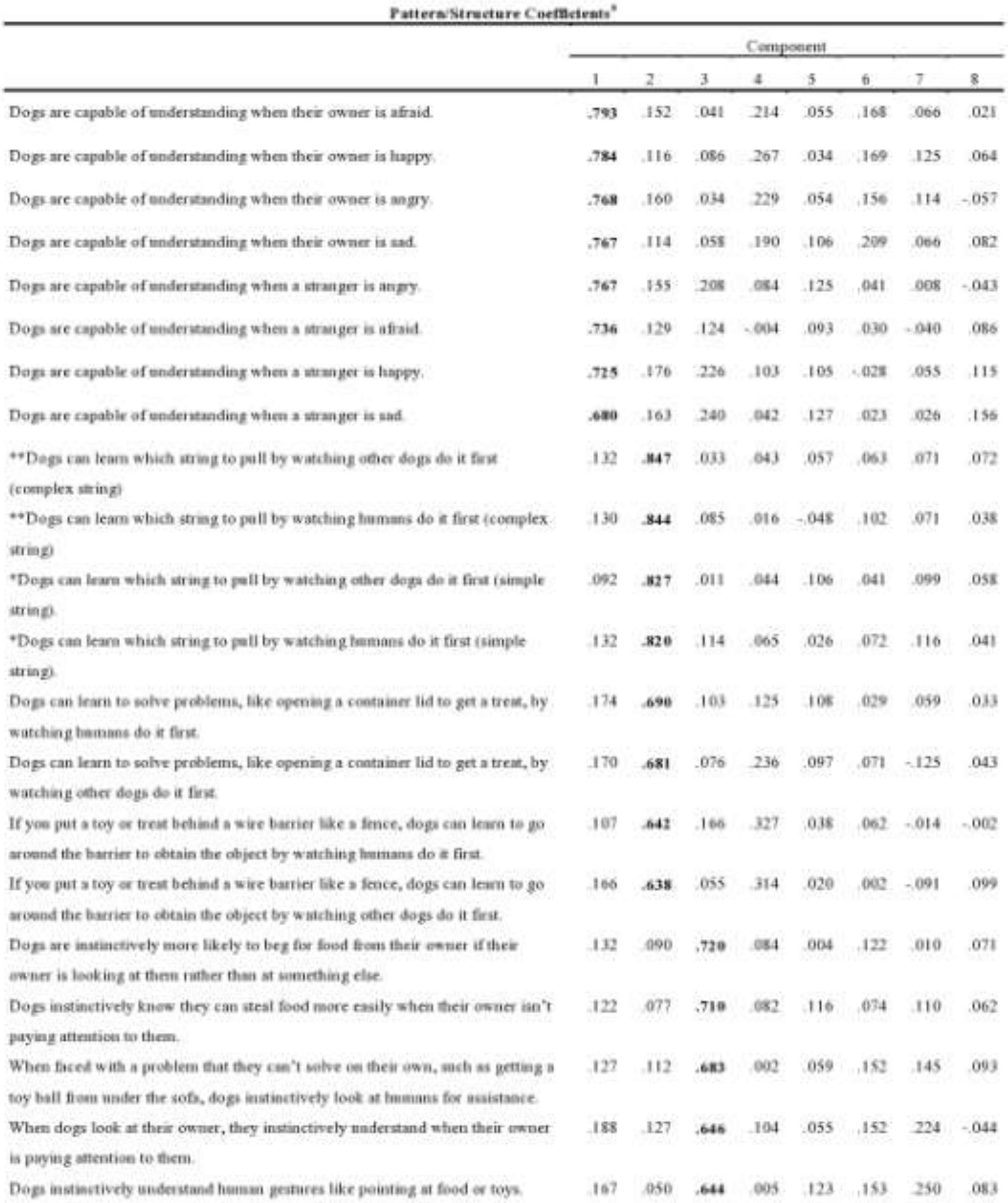
Table 3: Correlation matrix describing relationships between the three MDORS subscales and dog cognition questions. The correlations for the eight subscales and the individual questions which did not load onto any subscale are included. MDORS subscale 1 relates to dog-owner interactions, subscale 2 measures perceived emotional closeness, and subscale 3 measures perceived costs.

Table 4: Results of multiple regression analysis examining whether attachment levels predict cognition ratings for the eight factors in the factor matrix. MDORS subscale 1 is 'dog-owner interactions', subscale 2 is 'perceived emotional closeness' and subscale 3 is 'perceived costs'. Significant variables are in bold. The ANOVA results were significant ($p < 0.05$) for all subscales except for Subscale 7 ($p = 0.059$).

Figure 1: schematic of a simple and complex string-pulling task, each accompanying three of the cognition questions in Section B of the questionnaire. In the simple task, the strings are parallel, and a treat is attached to one of them. The dog must pull the correct string in order to access the treat. The complex task is identical except that the strings are diagonal.

Figure 2: response options and percentage agreement for the item, 'a dog's mental ability is equal to'

Table 1



Pattern/Structure Coefficients[a]

	Component							
	1	2	3	4	5	6	7	8
Dogs are capable of understanding when their owner is afraid.	**.793**	.152	.041	.214	.055	.168	.066	.021
Dogs are capable of understanding when their owner is happy.	**.784**	.116	.086	.267	.034	.169	.125	.064
Dogs are capable of understanding when their owner is angry.	**.768**	.160	.034	.229	.054	.156	.114	-.057
Dogs are capable of understanding when their owner is sad.	**.767**	.114	.058	.190	.106	.209	.066	.082
Dogs are capable of understanding when a stranger is angry.	**.767**	.155	.208	.084	.125	.041	.008	-.043
Dogs are capable of understanding when a stranger is afraid.	**.736**	.129	.124	-.004	.093	.030	-.040	.086
Dogs are capable of understanding when a stranger is happy.	**.725**	.176	.226	.103	.105	-.028	.055	.115
Dogs are capable of understanding when a stranger is sad.	**.680**	.163	.240	.042	.127	.023	.026	.156
**Dogs can learn which string to pull by watching other dogs do it first (complex string)	.132	**.847**	.033	.043	.057	.063	.071	.072
**Dogs can learn which string to pull by watching humans do it first (complex string)	.130	**.844**	.085	.016	-.048	.102	.071	.038
*Dogs can learn which string to pull by watching other dogs do it first (simple string).	.092	**.827**	.011	.044	.106	.041	.099	.058
*Dogs can learn which string to pull by watching humans do it first (simple string).	.132	**.820**	.114	.065	.026	.072	.116	.041
Dogs can learn to solve problems, like opening a container lid to get a treat, by watching humans do it first.	.174	**.690**	.103	.125	.108	.029	.059	.033
Dogs can learn to solve problems, like opening a container lid to get a treat, by watching other dogs do it first.	.170	**.681**	.076	.236	.097	.071	-.125	.043
If you put a toy or treat behind a wire barrier like a fence, dogs can learn to go around the barrier to obtain the object by watching humans do it first.	.107	**.642**	.166	.327	.038	.062	-.014	-.002
If you put a toy or treat behind a wire barrier like a fence, dogs can learn to go around the barrier to obtain the object by watching other dogs do it first.	.166	**.638**	.055	.314	.020	.002	-.091	.099
Dogs are instinctively more likely to beg for food from their owner if their owner is looking at them rather than at something else.	.132	.090	**.720**	.084	.004	.122	.010	.071
Dogs instinctively know they can steal food more easily when their owner isn't paying attention to them.	.122	.077	**.710**	.082	.116	.074	.110	.062
When faced with a problem that they can't solve on their own, such as getting a toy ball from under the sofa, dogs instinctively look at humans for assistance.	.127	.112	**.683**	.002	.059	.152	.145	.093
When dogs look at their owner, they instinctively understand when their owner is paying attention to them.	.188	.127	**.646**	.104	.055	.152	.224	-.044
Dogs instinctively understand human gestures like pointing at food or toys.	.167	.050	**.644**	.005	.123	.153	.250	.083
Dogs can learn to look at their owner to understand when their owner is paying attention to them.	.109	.147	.080	**.713**	.041	.101	.012	-.005

Dogs can learn to beg for food from their owner when their owner is looking at them rather than at something else.	.141	.132	.052	**.695**	.090	-.104	.022	-.134
When faced with a problem that they can't solve on their own, such as getting a toy ball from under the sofa, dogs can learn to look at humans for assistance.	.110	.161	.077	**.665**	.013	-.057	-.112	.042
Dogs can learn that it is easier to steal food when their owner isn't paying attention to them.	.183	.105	-.048	**.654**	.108	-.030	.018	-.061
Dogs can learn to understand human gestures like pointing at food or toys.	.163	.146	.091	**.602**	-.040	.063	-.102	.086
Dogs are capable of trying to trick their owner into doing something like moving from their seat so the dog can sit there.	.159	.104	.117	.043	**.871**	.158	.045	.089
Dogs are capable of trying to trick strangers into doing something like moving from their seat so the dog can sit there.	.200	.130	.102	.049	**.855**	.083	.097	.100
Dogs are capable of trying to trick other dogs into doing something like moving from their seat so the dog can sit there.	.152	.069	.097	.128	**.830**	.088	.016	.129
When a dog owner feels sad, their dog feels sad, too.	.193	.128	.165	.016	.086	**.713**	.119	.116
When a dog owner feels afraid, their dog feels afraid, too.	.118	.118	.132	-.055	.048	**.704**	-.044	.023
When a dog owner feels angry, their dog feels angry, too.	.008	-.025	.126	-.068	.124	**.692**	.163	.046
When a dog owner feels happy, their dog feels happy too	.244	.128	.181	.131	.061	**.668**	.046	.167
**Dogs instinctively know which string to pull (complex string).	.010	.012	.138	-.141	.042	.115	**.813**	.196
*Dogs instinctively know which string to pull (simple string).	.013	-.027	.149	-.127	.084	.131	**.805**	.128
If you put a toy or treat behind a wire barrier like a fence, dogs instinctively understand that they can go around the barrier to obtain the object.	.138	.110	.398	.054	-.027	.091	**.585**	-.093
Dogs can instinctively solve problems like opening a container lid to get a treat	.227	.174	.295	.065	.057	-.057	**.503**	.024
Dogs are smarter than most people	.124	.127	.079	-.019	.010	.093	.103	**.811**
Dogs can solve logic problems better than most humans.	.030	.075	.122	-.079	.112	.076	.227	**.773**
Dogs can solve social problems better than most humans.	.105	.064	.022	.033	.172	.116	-.051	**.729**
Cronbach's alpha	0.914	0.909	0.799	0.753	0.886	0.750	0.737	0.744

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 7 iterations.

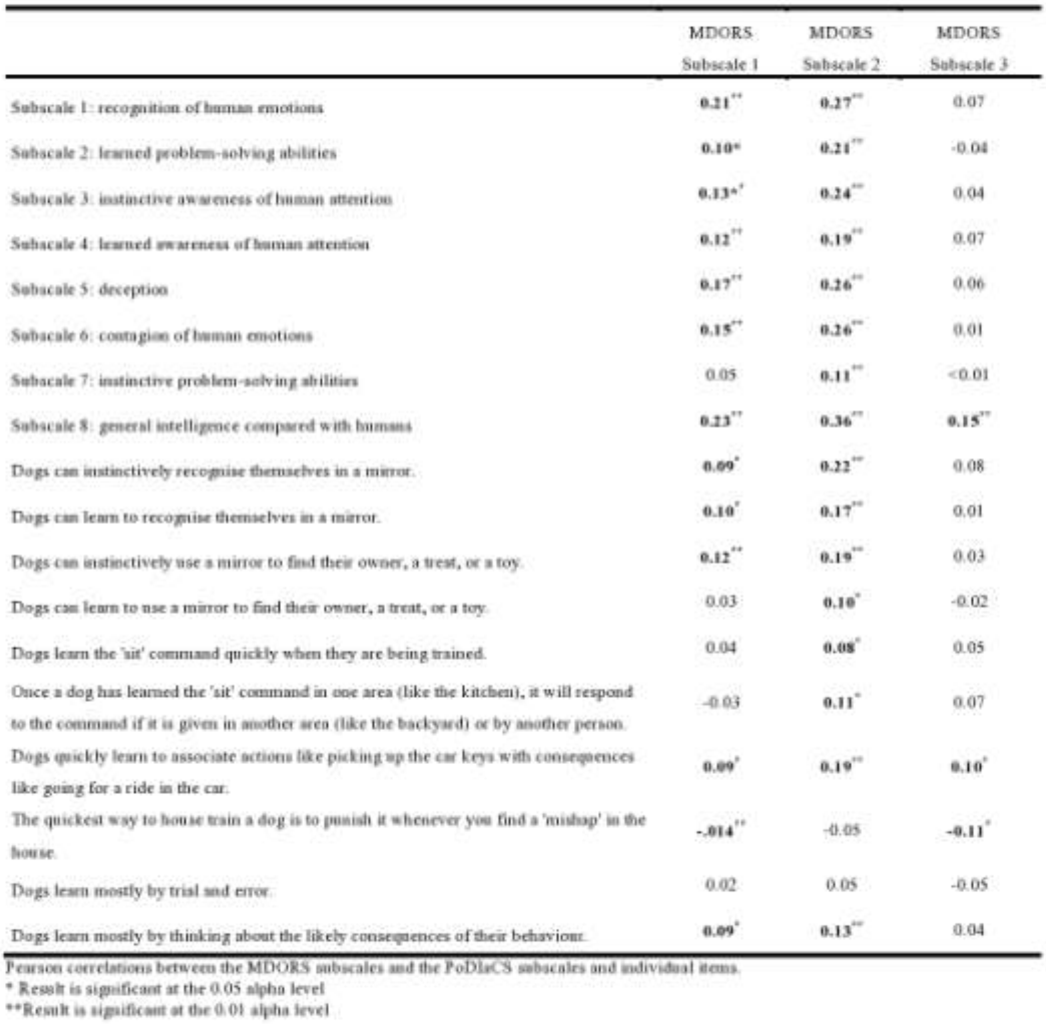
Table 2

Descriptive Statistics

	Owners			Non-owners			p-value
	N	Mean	SD	N	Mean	SD	
Cognition subscale 1: recognition of human emotions	565	4.26	0.58	80	4.18	0.64	0.25
Cognition subscale 2: learned problem-solving abilities	564	3.83	0.69	80	3.95	0.54	0.08
Cognition subscale 3: instinctive awareness of human attention	565	3.33	0.87	80	3.13	0.80	0.05*
Cognition subscale 4: learned awareness of human attention	565	4.45	0.46	80	4.33	0.46	0.02*
Cognition subscale 5: deception	564	3.51	0.98	80	3.33	0.99	0.12
Cognition subscale 6: contagion of human emotions	564	2.90	0.76	80	3.05	0.82	0.10
Cognition subscale 7: instinctive problem-solving abilities	565	2.52	0.73	80	2.55	0.66	0.73
Cognition subscale 8: general intelligence compared with humans	564	2.61	0.86	80	2.38	0.90	0.02*
Dogs can instinctively recognise themselves in a mirror.	563	2.42	0.91	80	2.39	0.79	0.78
Dogs can learn to recognise themselves in a mirror.	563	3.56	0.91	80	3.45	0.88	0.31
Dogs can instinctively use a mirror to find their owner, a treat, or a toy.	562	2.43	0.92	78	2.36	0.79	0.51
Dogs can learn to use a mirror to find their owner, a treat, or a toy.	564	3.61	0.90	80	3.55	0.83	0.06
Dogs learn the 'sit' command quickly when they are being trained.	563	4.08	0.81	80	3.83	0.67	0.01*
Once a dog has learned the 'sit' command in one area (like the kitchen), it will respond to the command if it is given in another area (like the backyard) or by another person.	564	3.28	1.30	79	3.68	0.96	0.01*
Dogs quickly learn to associate actions like picking up the car keys with consequences like going for a ride in the car.	565	4.62	0.55	80	4.44	0.55	0.01*
The quickest way to house train a dog is to punish it whenever you find a 'mishap' in the house.	565	1.45	0.74	80	2.15	1.00	0.01*
Dogs learn mostly by trial and error.	561	3.73	0.93	80	3.59	0.90	0.12
Dogs learn mostly by thinking about the likely consequences of their behaviour.	562	2.50	1.19	79	2.43	0.98	0.59
[†]A dog's mental ability is equal to:	558	4.08	1.14	77	3.10	1.20	0.83

The result is significant at a 0.05 alpha level.

Table 3



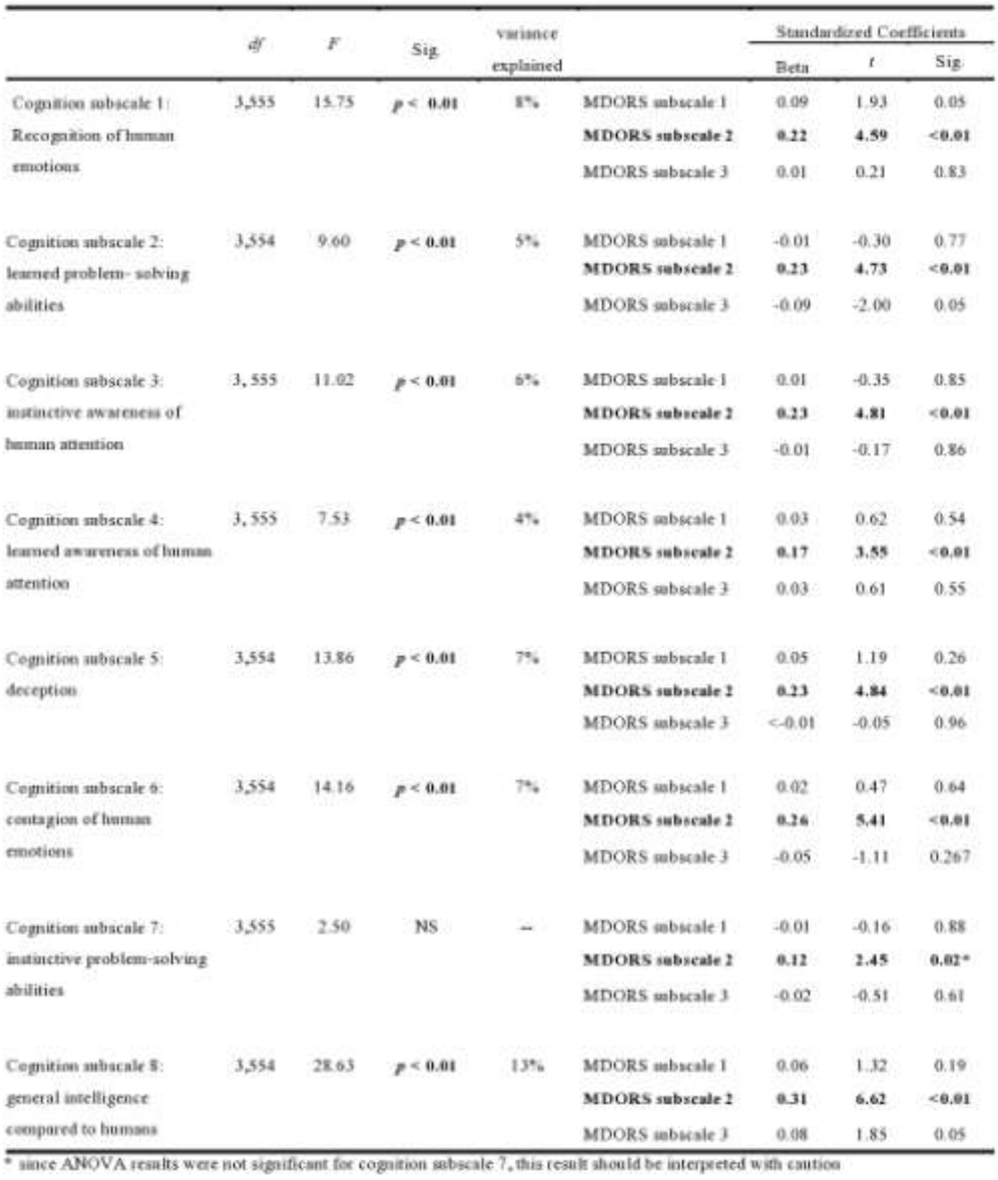
	MDORS Subscale 1	MDORS Subscale 2	MDORS Subscale 3
Subscale 1: recognition of human emotions	**0.21****	**0.27****	0.07
Subscale 2: learned problem-solving abilities	**0.10**$*$	**0.21****	-0.04
Subscale 3: instinctive awareness of human attention	**0.13**$*^{*}$	**0.24****	0.04
Subscale 4: learned awareness of human attention	**0.12****	**0.19****	0.07
Subscale 5: deception	**0.17****	**0.26****	0.06
Subscale 6: contagion of human emotions	**0.15****	**0.26****	0.01
Subscale 7: instinctive problem-solving abilities	0.05	**0.11****	<0.01
Subscale 8: general intelligence compared with humans	**0.23****	**0.36****	**0.15****
Dogs can instinctively recognise themselves in a mirror.	**0.09***	**0.22****	0.08
Dogs can learn to recognise themselves in a mirror.	**0.10***	**0.17****	0.01
Dogs can instinctively use a mirror to find their owner, a treat, or a toy.	**0.12****	**0.19****	0.03
Dogs can learn to use a mirror to find their owner, a treat, or a toy.	0.03	**0.10***	-0.02
Dogs learn the 'sit' command quickly when they are being trained.	0.04	**0.08***	0.05
Once a dog has learned the 'sit' command in one area (like the kitchen), it will respond to the command if it is given in another area (like the backyard) or by another person.	-0.03	**0.11***	0.07
Dogs quickly learn to associate actions like picking up the car keys with consequences like going for a ride in the car.	**0.09***	**0.19****	**0.10***
The quickest way to house train a dog is to punish it whenever you find a 'mishap' in the house.	**-.014****	-0.05	**-0.11***
Dogs learn mostly by trial and error.	0.02	0.05	-0.05
Dogs learn mostly by thinking about the likely consequences of their behaviour.	**0.09***	**0.13****	0.04

Pearson correlations between the MDORS subscales and the PoDIaCS subscales and individual items.

$*$ Result is significant at the 0.05 alpha level

$**$Result is significant at the 0.01 alpha level

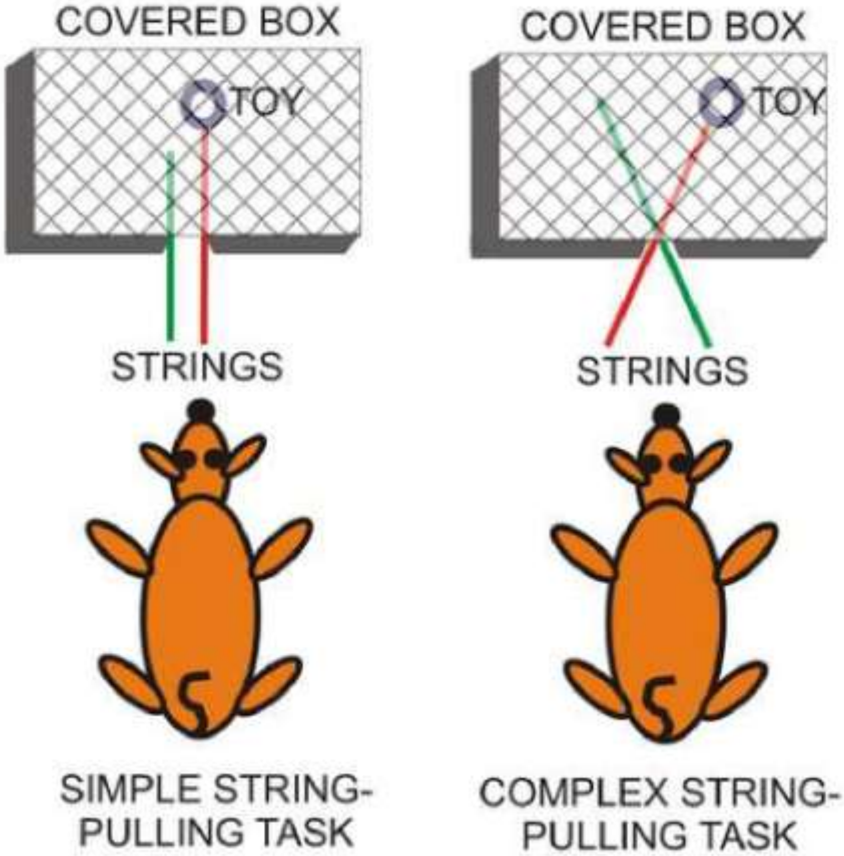
Table 4



	df	*F*	Sig.	variance explained		Standardized Coefficients		
						Beta	*t*	Sig.
Cognition subscale 1: Recognition of human emotions	3,555	15.75	**$p < 0.01$**	8%	MDORS subscale 1	0.09	1.93	0.05
					MDORS subscale 2	**0.22**	**4.59**	**<0.01**
					MDORS subscale 3	0.01	0.21	0.83
Cognition subscale 2: learned problem- solving abilities	3,554	9.60	**$p < 0.01$**	5%	MDORS subscale 1	-0.01	-0.30	0.77
					MDORS subscale 2	**0.23**	**4.73**	**<0.01**
					MDORS subscale 3	-0.09	-2.00	0.05
Cognition subscale 3: instinctive awareness of human attention	3, 555	11.02	**$p < 0.01$**	6%	MDORS subscale 1	0.01	-0.35	0.85
					MDORS subscale 2	**0.23**	**4.81**	**<0.01**
					MDORS subscale 3	-0.01	-0.17	0.86
Cognition subscale 4: learned awareness of human attention	3, 555	7.53	**$p < 0.01$**	4%	MDORS subscale 1	0.03	0.62	0.54
					MDORS subscale 2	**0.17**	**3.55**	**<0.01**
					MDORS subscale 3	0.03	0.61	0.55
Cognition subscale 5: deception	3,554	13.86	**$p < 0.01$**	7%	MDORS subscale 1	0.05	1.19	0.26
					MDORS subscale 2	**0.23**	**4.84**	**<0.01**
					MDORS subscale 3	<-0.01	-0.05	0.96
Cognition subscale 6: contagion of human emotions	3,554	14.16	**$p < 0.01$**	7%	MDORS subscale 1	0.02	0.47	0.64
					MDORS subscale 2	**0.26**	**5.41**	**<0.01**
					MDORS subscale 3	-0.05	-1.11	0.267
Cognition subscale 7: instinctive problem-solving abilities	3,555	2.50	NS	–	MDORS subscale 1	-0.01	-0.16	0.88
					MDORS subscale 2	**0.12**	**2.45**	**0.02***
					MDORS subscale 3	-0.02	-0.51	0.61
Cognition subscale 8: general intelligence compared to humans	3,554	28.63	**$p < 0.01$**	13%	MDORS subscale 1	0.06	1.32	0.19
					MDORS subscale 2	**0.31**	**6.62**	**<0.01**
					MDORS subscale 3	0.08	1.85	0.05

* since ANOVA results were not significant for cognition subscale 7, this result should be interpreted with caution

Figure 1


COVERED BOX
TOY
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SIMPLE STRING-PULLING TASK
COVERED BOX
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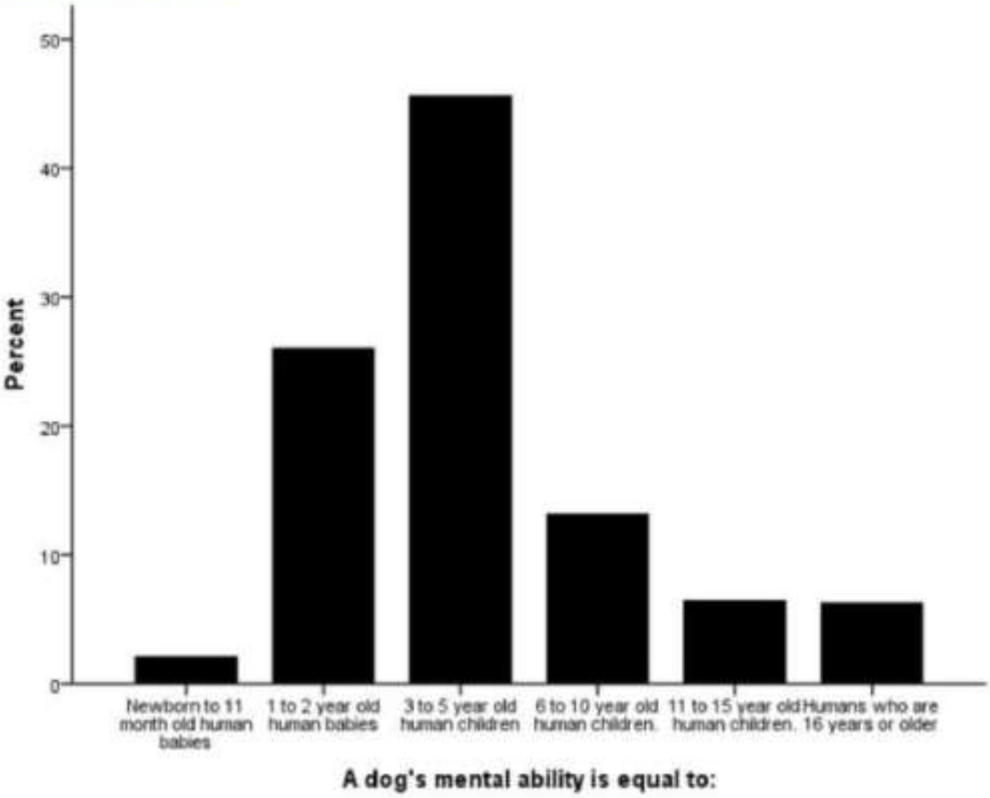
COMPLEX STRING-PULLING TASK

Figure 2


Percent
50
40
30
20
10
0
Newborn to 11 month old human babies
1 to 2 year old human babies
3 to 5 year old human children
6 to 10 year old human children.
11 to 15 year old human children.
Humans who are 16 years or older
A dog's mental ability is equal to:

3.3 Discussion

The main aim in this study was to determine how people rate dog cognitive skills across a variety of cognitive domains, with a secondary aim of determining whether emotional closeness to one's dog is correlated with those ratings. The key finding of the study was that people generally tend to agree that dogs are capable of complex cognitive abilities. The results correspond to experimental behavioural research insofar as people agree that dogs can follow human communicative gestures and engage in social learning, both from other dogs and from humans. However, people's beliefs also appear to go beyond scientifically-established cognitive skills, with respondents generally perceiving dogs to be capable of cognitive skills that have not been thoroughly explored in dogs, such as deception. People also agree that dogs can recognise human emotions, although this has not been tested experimentally, apart from a recent study suggesting that dogs experience empathy (Custance & Mayer 2012). Conversely, respondents were less likely to agree that dogs can innately recognise themselves in mirrors or that they are instinctively proficient logical problem-solvers. Indeed, self-reported knowledge of dogs was inversely correlated with these statements. Given these results, further study is warranted to examine whether dogs are instinctively able to solve logic problems or to recognise themselves in a mirror.

As was established in Chapter 2, the dog-owner relationship has been shown to affect the owner's perception of both dog intelligence and the occurrence of behaviour problems, with higher attachment levels correlating with higher intelligence ratings (Serpell 1996). In this study, positive correlations were identified between most (but not all) cognition ratings and perceived emotional closeness among owners and their dog. The exceptions to this rule were "dogs learn mostly by trial and error" and "the quickest way to house train a dog is to punish it whenever you find a 'mishap' in the house". The "trial and error" statement suggests that owners with higher perceived emotional closeness may believe that dogs are capable of learning beyond just through association. The “mishap” item is slightly more nuanced. This type of house training has been discouraged by modern trainers (Donaldson 1996, 2008; Pryor 1999), and owners may have learned this or generally disapprove of punishment in dog training. However, the ability to understand the basis for a punishment, especially punishment which takes place well after the offending behaviour occurred, would be suggestive of a higher reasoning ability. The item did not specify the time frame for the punishment, but this result provides a more subtle account of people’s perceptions of dog cognitive abilities than has been previously shown, and demonstrates the importance of asking people to rate specific abilities, rather than overall intelligence (Maust-Mohl et al. 2012; Rasmussen & Rajecki 1995; Rasmussen et al. 1993).

The results of the current study demonstrate where scientific understanding converges with, and diverges from, lay community beliefs of dog cognition. Apart from the theoretical importance of this research, as highlighted in the previous paragraphs, there are practical implications as well. Since beliefs of dog cognitive abilities correlate with higher emotional closeness, as in the current study, or attachment levels, as in Serpell (1996), it is possible that beliefs about cognitive abilities in dogs can affect the dog-owner relationship. Behaviour is a common reason for relinquishment to shelters (Marston et al. 2004), so it is important that owner beliefs about dog behaviour and cognition align with actual abilities. Understanding the beliefs of a particular owner may help canine behaviourists work with frustrated owners to train dogs within the limitations of the dogs’ own cognitive abilities, which could reduce the number of dogs surrendered to shelters and subsequently euthanased.

Survey research should be interpreted with caution and does not replace behavioural research in understanding dog cognition. Surveys are, by definition, evaluations of people’s perceptions, and these perceptions may differ from reality. Even if a large group of people believe that dogs can recognise human emotions, this does not necessarily make it so. It could, however, give researchers pause to re-evaluate current scientific understanding of abilities such as empathy. It may even give them useful information in developing experimental paradigms, or adapting neurophysiological techniques to explore such domains.

A limitation of survey research using opportunistic sampling to examine dog-related attitudes and perceptions is the possibility of bias in the sample. This survey included only a small sample of men and only a small sample of people who were not current dog owners. It also focused exclusively on people with access to the internet and was completed almost entirely by people living in Australia, the United States of America, and the United Kingdom, all of which are highly developed Western cultures. Therefore, it is possible that the findings may not generalise well to the wider, global, population. However, it may be representative of the target population, i.e., westerners who are interested in dog behaviour and who own dogs.

In conclusion, the survey research reported in this chapter has been useful in providing information about current human beliefs of dog cognitive abilities. While it would not be an appropriate replacement for behavioural research, it is nonetheless informative and complements behavioural research in dog cognition by providing insights into dog behaviour that have not been established in experimental paradigms.

CHAPTER 4 – BEHAVIOURAL STUDY 1: DOGS USING A MIRROR TO FIND THEIR OWNER

An interesting outcome of the survey reported in Chapter 3 was the general perception of dogs' ability to use a mirror. The mean ratings for statements related to dogs' instinctive abilities to recognise themselves in a mirror, or to use a mirror as a problem-solving tool, were relatively low compared with other questions, indicating that survey participants were generally less likely to agree with those statements. Likewise, agreement ratings for instinctive mirror self-recognition were negatively correlated with self-reported knowledge of dogs. On the other hand, respondents were more inclined to agree that dogs can *learn* to exhibit mirror self-recognition (MSR) or to use a mirror to find a hidden item of interest.

Given the paucity of research examining dogs' reactions to mirrors, abilities such as these should be tested experimentally. This information would further current knowledge of dog cognitive abilities, research of which has predominately clustered around social cognitive domains. The relatively few studies examining non-social cognitive tasks have sometimes produced contradictory results (e.g. Osthaus et al. 2005; Range et al. 2011). Mirror research would add to knowledge of dog cognition in a domain that has been explored extensively in other species (e.g. Broom et al. 2009; Eglash & Snowdon 1983; Gallup 1970; Itakura 1987) but very little in dogs (but see Zazzo 1979). The aim of this study, therefore, was to determine whether dogs could use a mirror to locate their owner, holding their favourite toy, after a very short exposure to the mirror setup.

The study was based on a similar study using pigs (Broom et al. 2009), which was chosen because pigs are phylogenetically similar to dogs. The original study had a five hour exposure. However, our exposure period was very short because many pet dogs live in human homes (Kubinyi et al. 2009), where they may have had extensive access to mirrors throughout their life. The first exploration of mirror-directed behaviour in adult dogs is reported here, in the article titled ‘Can dogs (*Canis familiaris*) use a mirror to solve a problem?’, published in 2011 in *Journal of Veterinary Behavior: Clinical Applications and Research*.

4.1. Declaration for thesis chapter 4

In the case of Chapter 4, the nature and extent of my contribution to the work was the following:

Nature of contribution	**Extent of contribution (%)**
Development of the research design, data collection and subsequent analysis, writing the journal article	75%

The following co-authors contributed to the work. Co-authors who are students at Monash University must also indicate the extent of their contribution in percentage terms:

Name	**Nature of contribution**	**Extent of contribution (%) for student co-authors only**
Pauleen Bennett	Advising on development and analysis of research design, suggestions for refinement of the manuscript	

Candidate's Signature		**Date**

The undersigned hereby certify that:

(7) the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors;
(8) they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
(9) they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
(10) there are no other authors of the publication according to these criteria;
(11) potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and
(12) the original data are stored at the following location(s) and will be held for at least five years from the date indicated below:

Location(s)	**Monash University, Clayton Campus**

[Please note that the location(s) must be institutional in nature, and should be indicated here as a department, centre or institute, with specific campus identification where relevant.]

Signature 1		**Date**

4.2 Can dogs (Canis familiaris) use a mirror to solve a problem?

Journal of Veterinary Behavior (2011) 6, 306-312

ELSEVIER

Journal of
Veterinary Behavior
Clinical Applications
and Research

RESEARCH

Can dogs (*Canis familiaris*) use a mirror to solve a problem?

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KEYWORDS:
mirror;
dog;
self-recognition;
problem solving

Abstract The ability of animals to use a mirror, either as a problem-solving tool or for the purposes of self-recognition, has been tested in several species. However, there are no empirical reports of studies using mirrors with companion dogs, which differ from most animals in that they are from infancy often kept in complex environments containing many reflective surfaces, including household mirrors. We used a simple repeated measures design, with no pre-training, to test whether pet dogs (n = 40) understand the concept of reflection. Each dog accompanied their owner into a room containing a large covered mirror. They were given 1 minute to explore the room, following which the mirror was uncovered. After another minute of exploration, the dog was motivated to attend to the mirror by the owner. A second owner then appeared in an adjoining room displaying the dog's favourite toy. The second owner stood behind the dog but could be seen in the reflective surface of the mirror. Dogs were more likely to attend to the mirror when the second owner was visible than when the owner was not visible in the mirror. Seven dogs turned away from the mirror to look toward the actual location of the owner. Of these, 2 then attended to the owner in the window more than the mirror. It is possible that these 2 dogs understood the real location of the owner and, therefore, the nature of reflection. However, none of these responses was completely unambiguous and most dogs tested showed no evidence of a capacity to spontaneously use the mirror to locate the second owner.

Introduction

The reaction of an animal to its own reflection has been of interest to animal cognition researchers for many years, since chimpanzees (*Pan troglodytes*) were reported to demonstrate mirror self-recognition or MSR (Gallup, 1970). In this initial study, 4 chimpanzees were exposed to a mirror for 10 days, after which a mark was secretly placed on each animal's forehead. The mark was not visible to the chimpanzee, except in the mirror; however, when each animal saw its reflection in the mirror, it began to touch the mark on the forehead, suggesting that it understood that it was looking at its own image. This is called the "mark test." Success is taken to imply that the animal has an idea or expectation of what it looks like from an outside perspective (Nielsen et al., 2006), but it could also mean that the animal is self-aware (Gallup, 1998). Most human children respond similarly to the mirror, when a

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mark is placed on their head, by the age of 24 months (Amsterdam, 1972).

Since this "first experimental demonstration of a self-concept in a subhuman form" (Gallup, 1970, p. 87), several other species have been claimed to have demonstrated an ability to recognize themselves in the mirror, by passing the mark test. For instance, after a period of exposure to a mirror under water, 2 dolphins (*Tursiops truncatus*) were marked with a visible marker and a sham marker, a visible marker only, or left untouched. The parts of the body that were marked were visible only in the mirror, and both dolphins spent more time looking at those particular parts of the body when marked with a real marker than when they had been sham-marked or not marked at all (Reiss and Marino, 2001). Furthermore, one Asian elephant (*Elephas maximus*) has also shown evidence of MSR after exposure to a mirror, by swinging its trunk and continually touching a mark made on the side of its forehead (Plotnik et al., 2006). The reaction of 5 European magpies (*Pica pica*) to a mirror was also studied, and 2 magpies showed clear mark-directed behaviors after being marked in highly visible yellow as compared with a black sham marker that was not visible on their black feathers (Prior et al., 2008). Rhesus monkeys (*Macaca mulatta*) that have been fitted with a head implant for electrophysiological research also show self-directed behaviors in the mirror, contrary to previous reports (Rajala et al., 2010). However, some caution is needed in interpreting results of self-directed behavior that is not clearly mark directed. A 1993 study with chimpanzees showed that there was no strong association between self-exploratory behaviors and passing the mark test (Povinelli et al., 1993).

MSR in the context of the mark test is clearly rare among animal species; furthermore, the results of experiments using this paradigm are difficult to interpret. It is argued that passing the mark test is not definitive evidence that an animal is self-aware because the required response could be based on previously learned behaviors (Epstein et al., 1981). Failing the mark test also does not definitively prove lack of self-awareness. It is possible that many animals are not motivated to attend to themselves in a mirror, in which case they may not successfully demonstrate mark-directed behaviors toward their bodies even if they are self-aware (Suddendorf and Collier-Baker, 2009). This possibility is supported by the fact that less than half of individual great apes tested display mark-directed behaviors in the mirror during this test; the remaining animals may be cognitively capable of displaying mark-directed behaviors but are not motivated to do so (Suddendorf and Collier-Baker, 2009). In an effort to answer these criticisms, one study showed that gibbons (genera: *Hylobates*, *Symphalangus*, and *Nomascus*) were unsuccessful in recognizing their self-image in a mirror, even when they were provided with strong motivation to do so (Suddendorf and Collier-Baker, 2009). Although these gibbons were marked on their faces with white paint that resembled sugar icing, which had been previously eaten by the gibbons when placed on their arms, they did not attempt to remove the paint from their faces after they had access to a mirror. In post-tests, in an attempt to encourage the gibbons to use the information in the mirror to remove the paint from their faces, the authors smeared icing on the surface of the mirror itself. Although the gibbons removed the icing from the mirror and ate it, they never showed any mark-directed behaviors toward their own bodies.

Despite the relative rarity of mark test success in the animal kingdom, an animal's reaction to a mirror can be interesting, even if it does not show MSR. Animals often go through a series of behaviors on exposure to a mirror, before, or instead of, demonstrating self-recognition. When initially exposed to a mirror, animals may react to their mirror image as if they are viewing a conspecific (another animal of that species) for the first time (Plotnik et al., 2006), and human children respond in this way before the age of 1 year (Amsterdam, 1972). In dogs, this behavior may manifest with play bows or staring with raised hackles. However, the "other animal" invariably responds in an unexpected way to the real animal's social cues (Zazzo, 1979), and the animal may then begin to physically inspect the mirror (Plotnik et al., 2006). A dog may therefore look behind it, jump onto it with the front paws, or paw at it. This corresponds to behavior that is observed in human infants at around 12-14 months of age (Amsterdam, 1972). A third response is considered the beginning of understanding the function of reflection, and is categorized by an animal showing self-directed behaviors in front of the mirror (Plotnik et al., 2006). This was noted by Gallup (1970) when the chimpanzees in his study picked their teeth and nose in front of the mirror, made faces at the mirror, and blew bubbles in the mirror. The final developmental step in human infants (Amsterdam, 1972), also demonstrated by certain animal species (Plotnik et al., 2006), is MSR, which is demonstrated by mark-directed behaviors in the mirror during the mark test.

In addition to MSR paradigms, there are studies exploring whether certain species can use a mirror as a tool. This could be evidence of an ability to understand the nature of reflection, and to subsequently use a mirror to locate an item of interest, such as food. For instance, pygmy marmosets (*Cebuella pygmaea*) are able to use a mirror to see hidden conspecifics in a neighboring compartment, separated by an opaque wall (Eglash and Snowdon, 1983). On seeing these conspecifics, the marmosets sometimes engaged in threat displays directed toward the actual location of the conspecific, as opposed to the mirror. This suggests that marmosets were aware of the location of the actual animal, and not just its image. In another study, Japanese monkeys (*Macaca fuscata fuscata*) learned to retrieve a piece of apple from various different compartments visible only in a mirror (Itakura, 1987). Other research showed that, after reinforcement training, pigeons (*Columba livia domestica*) were able to learn to peck a dot on the wall visible only in the mirror, and later they pecked dots on their body that were only visible in the mirror (Epstein et al., 1981). Finally, a recent study explored whether pigs (*Sus scrofa*) could use a mirror to solve a problem (Broom et al., 2009). Pigs were taken to a room which contained food hidden behind barriers, but the food was visible in a strategically placed mirror. It was hypothesized that pigs that understood the nature of reflection and could use the mirror as a tool would take the quickest route to the food based on the information provided in the mirror. While naive pigs were more likely to go behind the mirror in search of the food, pigs with 5 hours of exposure to the mirror were more likely to use it to locate the food (Broom et al., 2009).

MSR has not been reported in dogs (*Canis familiaris*), but Zazzo (1979) studied puppies exposed to a mirror until 4 months of age, and reported that none of them demonstrated any knowledge of the nature of reflection. The puppies never moved beyond the social conspecific response. To extend these observations, we wanted to adapt the idea of using a mirror as a problem-solving tool for use with adult dogs. Healthy dogs should be able to see into a mirror, although they may not see details as clearly as human beings (Miller and Murphy, 1995). Dogs have dichromatic color vision, similar to human beings who are color-blind (Neitz et al., 1989), and although brachycephalic (short-nosed) and dolicocephalic (long-nosed) dogs have different visual streaks (McGreevy et al., 2004), there is evidence that dogs in general cannot see as well in extremely close range (i.e., less than 33-50 cm) as human beings (Miller and Murphy, 1995). Therefore, a distance of 60 cm from the mirror should be an adequate distance for most dogs to obtain a reasonably clear picture of their mirror image.

Because of odor cues from the food used in the task developed by Broom et al. (2009), this exact setup could not be used for dogs. Instead, we tried to motivate the dogs to look into the mirror by the presence of an owner, holding the dog's favorite toy, who stood in a room with a large window connecting to an adjacent room, where the dog and the mirror were located. The owner stood directly behind the window facing the dog, and the dog sat with its back to the owner, facing the mirror (Figure 1). Therefore, the dog could look into the mirror and see the owner through the window. On seeing the owner with the toy in the mirror, if the dog turned around to face its owner, this could indicate that he or she knew the owner's actual location behind them and; therefore, understood the nature of reflection.

Unlike the study by Broom et al. (2009) and other previous studies using mirrors and animals, we did not extensively pre-train the dogs with the mirror before the experimental trial. A rigorous experimental design would require that previous mirror exposure be controlled. However, we were unable to achieve this because the dogs in our sample were like many others kept in western societies, who live in human homes and are primarily kept as companions (Kubinyi et al., 2009). Therefore, we assumed that they would have previously had exposure to a mirror inside the home or at least to other reflective surfaces and, to reduce the time commitment required from our volunteer dog owners and enable inclusion of the greatest number of dogs possible, chose to provide only minimal exposure to the mirror before the test trial. The aim of this preliminary study was simply to determine whether any dog in a sample of 40 spontaneously used a mirror to solve a problem.

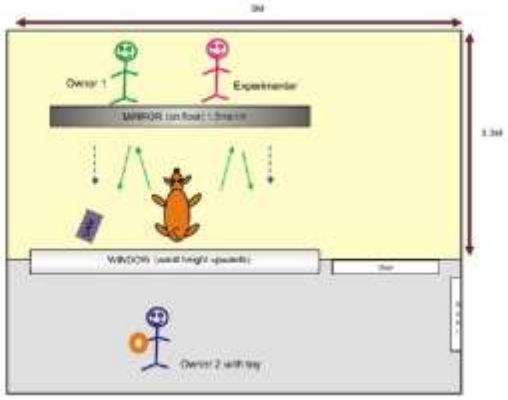

Figure 1 Experimental setup. The dog, experimenter, and owner 1 were in the room with the large mirror on the floor. Owner 2 was in the next room, which was joined by a large window from waist height upwards. Owner 2 held the dog's favorite toy in condition 3, during which time the dog could see owner 2 by looking into the mirror. The solid green arrows indicate the directions in which the dog can see when facing the uncovered mirror, and the dashed blue arrows indicate the direction in which the dog can see when facing the window. For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.

Methods

Participants

Purebred and non-purebred dogs (n = 40) that were at least 18 months of age, and that had 2 adult owners who were both able to come into the university for the study, were eligible to participate. There were 24 male and 16 female dogs; 30 dogs were purebred and 10 were crosses. The dogs had to be able to sit and stay in one place for up to 1 minute, based on the owners' command. Owners reported the breed or combination of breeds of their dog, as well as its sex and age, the number of hours per day that the dog spent indoors, and whether there were low-lying mirrors in their home to which the dog may have had exposure. Windows, pooling water, and other reflective surfaces were not considered because the quality and consistency of the reflection in these surfaces cannot be controlled.

According to their owners, 25 dogs spent more than 12 hours daily indoors, whereas 7 spent 3 hours or less inside the home. All dogs spent at least 1 hour inside per day. Twelve dogs had probably not had exposure to a mirror in the home, with the other 28 most likely having had exposure to a low-lying mirror at home.

Materials

A 3 × 5.5 m^2 room in a building at Monash University Clayton campus held a large (1 × 1.5 m^2) freestanding mirror, facing a window (1.8 × 1.5 m^2) through which the upper half of an adjacent room was visible (Figure 1). The bottom of the window was 1.1 m off the ground, approximately waist height for an average adult, and was fitted with a blind that permitted it to be covered or uncovered as necessary. The mirror was on the floor, 2.5 m from the wall with the window, and was also covered with a removable blanket. A video recorder (Sony Handycam Digital Video Camera Recorder DCR-DVD605E (Sony, Tokyo, Japan) and FLIP Mino Pocket-Sized High-Definition Camcorder, Cisco, Irvine, CA) was used to record the dog's behavior toward the mirror throughout 3 conditions, each lasting for approximately 1 minute only because of the dog's short attention span. In condition 1, the mirror and window were both covered. For condition 2, the mirror's cover was removed and the window remained covered, whereas in condition 3, both the mirror and the window were uncovered.

Procedure

The dog, one owner (owner 1), and the experimenter entered the room with the mirror, whereas the dog's second owner (owner 2) remained in the adjacent room behind the (covered) window. The roles of the owners were determined by asking who among them was most strongly bonded to the dog, and who had most control over the dog. In most cases, this person was the same, and he or she became owner 1 because of the necessity of the dog's obedience during the trial. In a few cases, the most strongly bonded owner was not the one who had most control over the dog; in these cases, owner 1 was the one who best controlled the dog, and owner 2 was the person most strongly bonded to the dog. The door between the 2 rooms was closed to control for sound and odor cues as much as possible. Owner 2 held the dog's favorite toy. If the toy contained a squeaker or other noisemaker, owner 2 was asked to ensure that the toy did not make any noise, so as to control for sound cues. Owner 2 was asked to remain silent throughout the experiment, and to not produce any treats or other food items that could have provided odor cues to the dog. Owner 1 was requested not to bring treats or toys into the room with the mirror because this may have distracted the dog.

On entering the room with the mirror, owner 1 and the experimenter stood behind the mirror, to discourage the dog from looking in any other direction than toward the mirror, thus risking the possibility of seeing owner 2 in peripheral vision. Owner 1 was instructed to ignore the dog for conditions 1 and 2. After condition 2, the experimenter instructed owner 2 to bend out of view of the window, and opened the blind so that the adjacent room was visible from the room with the mirror. During condition 3, owner 1 commanded the dog to "sit" and "stay" facing the mirror, with the owner moving out from behind the mirror if necessary to ensure that the dog was correctly positioned. The dog was placed behind a line on the floor, approximately 60 cm from the mirror. In most cases, the owner was able to return behind the mirror after the dog was in a "stay" position; however, if the dog was consistently disobedient to the command after owner 1 attempted to move back behind the mirror, owner 1 stood next to the dog near the edge of the mirror to encourage obedience by the dog. The experimenter returned behind the mirror, and requested owner 2 to stand up using a hand motion. Owner 2 became visible through the window and could be seen by the dog through the mirror. After the trial began, neither the experimenter nor owner 1 attempted to draw the dog's attention to the mirror, by tapping on it or motioning toward the mirror itself. In the original design, a fourth condition was included, in which the mirror was covered and the window remained uncovered. The dog was commanded to sit and stay facing the window, in which owner 2 was visible with the toy. However, the video data from this condition were lost, thus could not be included in any analyses.

Data analysis

For each condition, we measured frequency of attending to the mirror and window, exploratory behaviors toward the mirror (e.g., sniffing within 60 cm of the mirror, walking around/behind the mirror for <10 seconds at a time, jumping onto the mirror with front paws), the frequency of head turns from the mirror to the window, and the frequency of head turns from the window to the mirror. Video data were coded using a partial interval recording at 5-second intervals, during which time the presence of a relevant behavior was noted if it had occurred at all during the previous 5 seconds. This was necessary because a behavior as quick as a turn of the head from the mirror to the window may not take a full 5 seconds, but would be very important for the purposes of the study. Statistics were analyzed using SPSS (version 18, IBM, Somers, NY). Inter-rater reliability was measured by comparing coding of a naïve observer with that of an experimenter on videos from 10 of the dogs. Percentage agreement was 84%, and Pearson's correlation always exceeded 0.667 ($P < 0.04$).

Results

There was no significant difference in frequency of exploratory behaviors toward the mirror between the 3 conditions, using a Bonferroni-adjusted alpha level of 0.017, Wilks' Lambda = 0.84, $F(2, 38) = 3.56$, $P = 0.038$.

There was a significant difference in frequency of attending to the mirror, with a large effect for condition, Wilks' Lambda = 0.31, $F(2, 38) = 41.86$, $P < 0.001$, partial eta squared = 0.69. After Bonferroni adjustments, dogs attended more frequently to the mirror in condition 3 than conditions 1 ($P < 0.001$) and 2 ($P = 0.002$). In condition 2, they attended more frequently to the mirror than in condition 1 ($P < 0.001$).

There was a significant difference in the frequency of time spent attending to the window per condition, with a large effect size for condition, Wilks' Lambda = 0.75, $F(2, 38) = 6.30$, $P = 0.004$, partial eta squared = 0.25. After a Bonferroni correction, dogs attended more frequently to the window in condition 3 than in conditions 1 ($P = 0.005$) and 2 ($P = 0.007$).

There was a significant difference in the frequency of head turns from the mirror to the window per condition, with a large effect size for condition, Wilks' Lambda = 0.86, $F(1, 39) = 6.35$, $P = 0.016$, partial eta squared = 0.14. With a Bonferroni correction, dogs turned their heads from the mirror to the window more frequently in condition 3 than in condition 1 or 2 ($P < 0.05$). There was no significant difference in frequency of head turns from the window to the mirror between conditions, Wilks' Lambda = 0.95, $F(1, 39) = 1.93$, $P = 0.173$, partial eta squared = 0.05.

Independent samples *t*-tests illustrated that there were no significant differences in any of these behaviors when comparing dogs reported by their owners to have previous mirror exposure and dogs reported by their owners as having no previous mirror exposure in any condition.

In condition 3, 7 dogs (17.5%) turned their head from the mirror to the window at least once. Of these, 2 had a higher frequency of attending to the window than the mirror, and one attended to the mirror more frequently than the window. The other 4 never attended to the window again after the initial head turn. The age range of dogs that performed head turns from the mirror to the window was 18 months to 8 years, and 3 were female and the remaining 4 were male. The breeds were as follows: Japanese spitz, Australian shepherd, Lagotto Romagnolo, rottweiler (2), Labrador retriever, and miniature poodle. Four were reported by their owners as having had previous exposure to mirrors at home.

Of the 2 dogs that performed a head turn from the mirror to the window and then attended to the window more frequently than the mirror, one attended to the mirror, then performed a head turn from the mirror to the window, and subsequently only attended to the window. This 2-year-old male Labrador retriever had a brief (<1 second) pause while turning his head from the mirror to the window. Another dog attended to the mirror, performed the head turn to the window, and attended to the window, then returned to the mirror, and later turned from the mirror to the window again. This 5-year-old female Japanese spitz did not behaviorally show a visibly increased alertness level toward owner 2 in the mirror immediately before turning her head.

Of the remaining 33 dogs, 18 (55%) had a 40% frequency of attending to the mirror in condition 3. Eight dogs (24%) attended to it at less than 23% frequency, and 7 (21%) never attended to the mirror. The 18 dogs that attended to the mirror with at least 40% frequency, attended to the window with less than 17% frequency. However, only 3 of the 18 dogs (17%) attended to the window at all, with the other 15 dogs never attending to it. In all, 25 (76%) of these 33 dogs have had previous exposure to mirrors, according to owner reports.

Discussion

Dogs attended to the mirror more frequently in condition 2 than in condition 1, which is probably because the mirror was covered in condition 1, making it physically impossible for the dog to attend to the reflection within it. There was also a significant effect of condition between conditions 2 and 3, when the primary difference was the visibility of owner 2 with the toy. However, during condition 3, the dog was commanded to sit and stay facing the mirror, whereas the dog was given no commands during condition 2. Although sitting and facing the mirror did not force the dog to attend to the mirror, it could have increased the likelihood of the dog attending to the mirror in condition 3, as compared with condition 2, especially if the dog never approached the mirror in condition 2. Nonetheless, because dogs were significantly more likely to attend to the mirror in condition 2 than condition 1, it is clear that dogs did somewhat attend to the mirror during condition 2. This suggests that dogs were motivated to attend to the mirror in condition 3, when they could see owner 2 in the reflection. There was no effect of condition on exploratory behaviors toward the mirror, and this may be because many dogs have had previous exposure to a mirror, and would have learned that interacting with the mirror is fruitless. Dogs were also significantly more likely to attend to the window during condition 3 than during conditions 1 or 2, and this is probably because the blind was down in conditions 1 and 2, which would have made it impossible to see into the other room or to observe owner 2 in the first 2 conditions. Again, this suggests that the dogs were motivated to see owner 2 and/or the favorite toy displayed by this owner.

Having confirmed that many dogs were motivated to spend time observing owner 2, either directly through the window or indirectly through the reflected image in the mirror, it is of particular interest that 7 dogs performed head turns from the mirror to the window in condition 3. This may indicate that these dogs understood the nature of reflection and were able to use the reflected image of owner 2 to locate the actual position of owner 2—a highly salient social stimulus. However, in arguing against this interpretation, only 2 of the 7 dogs who displayed this head turning behavior subsequently attended to the window more than the mirror. The other 5 dogs turned to the window but then resumed other activities: 4 of them returned their focus to the mirror and never looked at the window again and one alternated its gaze from the window to the mirror several times, but spent more time looking at the mirror than the window. The 2 dogs that did attend to the window more than the mirror after demonstrating head turning behavior may have understood the nature of reflection and used it to locate the owner. They initially attended to owner 2 in the mirror, then performed a head turn from the mirror to the window, and then proceeded to attend to the window, on the other side of the actual location of owner 2.

Although this result may indicate that a small number of dogs spontaneously used the mirror to locate owner 2, an important caveat is that a completely unambiguous response was never observed in any of these 2 dogs. The Labrador retriever briefly paused while turning his head from the mirror to the window. Although this may be inconsequential, it may have meant that the dog was able to notice owner 2 in its peripheral vision, thereby continuing to turn in response to this information rather than to the information obtained through the mirror. The other dog did not show an increased level of alertness toward the mirror after observing owner 2 before turning its head, so there is a small possibility that the dog's head turn was spontaneous and not in response to the visual cue, or that it was cued by some other stimulus of which we were unaware of. We prefer to conclude, albeit tentatively, that the 2 dogs did use the reflected image to infer the true location of owner 2 because they each focused their attention on the window after turning.

Despite these few exceptions, most of the dogs in the study never turned from the mirror to the window. In the case of 7 dogs, this is probably because they never attended to the mirror at all, so they would not have had the opportunity to notice owner 2. However, the other 26 dogs attended to the mirror at least 23% of the time in condition 3, and they still never turned to face the window after the second owner appeared. Although this may be because they did not understand the nature of the reflected image, it remains possible that they did know where owner 2 was, but did not respond in the manner expected either because of obedience to owner 1 (who had directed them to sit and stay facing the mirror) or because they were highly motivated to attend to the reflected image. We believe these explanations to be unlikely. A dog's success at following obedience commands depends greatly on whether its attention is focused on the human being giving the command (Lindsay, 2005). A small number of the dogs never broke eye contact with owner 1, and this meant that those dogs did not focus on the mirror and therefore probably never noticed owner 2. The remainder, however, were not so focused on owner 1 and did appear to be looking into the mirror, particularly when owner 2 became visible. We think that, if the dog was willing to redirect its attention from owner 1's face when owner 2 became visible in the mirror, this would have led to competing motivations and impulses that should have affected the dog's behavior during the stay command.

Several of the owners in this study indicated that their dogs like to play mirror games at home, and the owners of 2 of the dogs stated that their dog used mirrors as a tool to locate them. However, these dogs were unsuccessful in locating owner 2 in our study. This could mean that the dogs that play mirror games or use the mirror as a problem-solving tool at home could be using other cues to find their owner, such as odor or noise. It is also possible that dogs do learn how the mirror works in familiar environments, but they do not generalize that information to a new location. Further research is needed to determine whether dogs can learn the function of a reflection after a certain amount of exposure to a particular research setup in a specified location. This may be possible because other animals studied must be exposed to a mirror for a certain period before they learn how the mirror works (e.g., Broom et al., 2009). We purposely did not expose dogs to this setup because many dogs would have had previous exposure to mirrors or other reflective surfaces during their lives. However, there were no significant differences in mirror- or window-directed behaviors between dogs reported by their owners to have had previous exposure to reflective surfaces and dogs reported by their owners not to have previously been exposed to such surfaces. These results should be interpreted with caution because we relied on owner report for this information and were unable to control for exposure to other reflective surfaces; it is quite possible that many pet dogs have previously been exposed to their mirror image without their owners' knowledge. The response of most dogs in this study indicates that they do not understand how a mirror works, at least not in a novel environment. That there is a high level of individual variation, with 2 dogs (and maybe 7) possibly understanding reflection, may indicate that all dogs are capable of learning the function of a mirror in a particular area, but some may need more exposure than others. Therefore, studying dogs that have received training on the use of the mirror as a tool in the same way that pigeons were trained (Epstein et al., 1981) may be more successful. Dogs have also shown themselves to be proficient in object-choice paradigms (e.g., Hare and Tomasello, 1999; Miklosi et al., 1998), and they might find the prospect of obtaining a treat or toy more interesting than simply observing the owner holding a toy. Therefore, future research could include using the mirror as a tool to locate the baited containers in object-choice paradigms.

Although not specifically tested, we did not observe any obvious breed, sex, or age difference in performance on this task. Although 4 of the 7 dogs that performed a head turn from the mirror to the window had previous exposure to mirrors inside the home, including both dogs that seemed to understand reflection, most of the dogs in the study also had previous exposure but did not complete a head turn, thus conclusions cannot be drawn from this information. More research examining the source of these individual differences in mirror responses would be useful.

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4.3 Discussion

The aim in this study was to determine whether dogs could use a mirror to find their owner holding a toy, following very little exposure to the experimental setup. The study was adapted from a recent study which demonstrated that pigs could use a mirror to find hidden food (Broom et al. 2009). Since pigs are phylogenetically similar to dogs, it was believed that dogs would also be capable of completing this task. Contrary to expectation, the study demonstrated that dogs were generally not able to find their owner using the mirror.

In the experiment, there was a one-minute period in which the dog was able to adjust to the room, and another minute in which the mirror was uncovered but the owner, standing in the next room, behind a window adjoining the two rooms, was hidden behind a blind. This allowed the dogs one minute to adjust to the mirror before beginning the testing conditions. During testing, the mirror remained uncovered, the dog was encouraged to face it, and the blind was lifted such that the owner in the window (positioned behind the dog) was visible to the dog in the mirror for one minute. Of 40 dogs, only seven turned around to observe their owner through the window. Two of these dogs then continued to attend to the window, having appeared to use the mirror to determine that their owner was behind them in the next room. This strongly implies that most of the dogs (i.e., those that did not turn around to face their owner) could not correctly interpret the information in the mirror. However, that two of the dogs did appear to correctly interpret this information appears to provide evidence, in principle, that dogs as a species may be capable of this skill.

Another possible explanation for most of the dogs’ apparent inability to find their owner was the experimental setup itself. There was a very short acclimation period for the dogs before the experimental condition commenced, which may not have been long enough for the dogs to feel calm in their surroundings and focus on the task. Indeed, in Broom et al. (2009), the pigs had a five hour exposure to the mirror before testing. Anecdotal owner reports that dogs can use mirrors at home also support this possibility. Likewise, dogs may not have been motivated to find the toy, as the dogs were not tested for motivation to find the toy prior to commencement of the testing session. Finally, it is possible that, when the dogs saw their owner in the mirror, they knew that the owner was in another room and therefore did not feel compelled to turn around to obtain the toy. These limitations were important, and may explain the null findings. Future study that adapts the research design to include motivation trials, a longer pre-test exposure period to the mirror setup, and positioning the target object in the same room as the mirror and the dog, is needed.

CHAPTER 5 – BEHAVIOURAL STUDY 2: DOGS USING A MIRROR TO FIND HIDDEN FOOD

The study described in Chapter 4 was instructive insofar as it provided the first known evidence to suggest that dogs may possess the capacity to use a mirror to locate a desired item. The results were inconclusive, however, due to a range of possible explanations for the behaviour exhibited by the small number of dogs who did appear to use the mirror to locate their owner, and by the vast majority of dogs who did not display behaviour indicative of this ability. It remains possible that many dogs may have lacked motivation to find the owner holding the toy, that the exposure period to the mirror setup was too short for the dogs to become comfortable in the room, or that the dogs were aware that the toy was in another room and therefore unobtainable even by turning around to face it. It is also possible that the two dogs which appeared to locate the toy just happened to be turning their heads slightly at the time the owner was revealed, thereby having the opportunity to observe movement in their peripheral vision.

The mirror study reported in Chapter 4 was an adaptation of Broom et al.’s (2009) study with pigs, but may have differed too much from the original design. The dogs were expected to locate the owner holding a favourite toy rather than a food treat. It was believed that dogs would be motivated to find the owner and toy, considering the importance of the dog-owner relationship in dog cognition, and the dog’s ability to effectively communicate with humans, as explained in detail in Chapter 2. Also, it was easier to control for odour cues than using food would have been, although Broom et al. (2009) were able to effectively control for these cues in their pig study.

Since the social element was not effective, another cohort of pet dogs was tested on a more straightforward adaptation of the Broom et al. (2009) study. The aim of this study was to determine if dogs could locate food hidden behind a barrier but visible via a mirror. Ultimately, the study described in Chapter 5 provided an opportunity to correct some of the methodological problems encountered in the study described in Chapter 4. First, there were tests to confirm that the dogs were motivated to obtain the treat. Second, there was a longer exposure period to the mirror setup, thereby allowing the dogs plenty of time to adjust to the room and learn how the mirror works. Third, the owner, dog, experimenter and treat were all in the same room during the test condition, to mitigate the possibility that the dog knew where the target object was located but, aware that it could not obtain it, chose not to try to approach it. Finally, a control group was introduced, in which half the dogs were not granted access to the mirror to find the food.

The article reflecting this research is titled ‘Dogs use a mirror to find hidden food’ This manuscript was submitted to *Journal of Veterinary Behavior: Clinical Applications and Research* in November 2012.

5.1 Declaration for thesis chapter 5

In the case of Chapter 5, the nature and extent of my contribution to the work was the following:

Nature of contribution	Extent of contribution (%)
Development of the research design, data collection and subsequent analysis, writing the journal article	75%

The following co-authors contributed to the work. Co-authors who are students at Monash University must also indicate the extent of their contribution in percentage terms:

Name	Nature of contribution	Extent of contribution (%) for student co-authors only
Samia Toukhsati	Advising on development and analysis of research design, suggestions for refinement of the manuscript	
Russell Conduit	Advising on development and analysis of research design, suggestions for refinement of the manuscript	
Pauleen Bennett	Advising on development and analysis of research design, suggestions for refinement of the manuscript	

Candidate's Signature		**Date**

The undersigned hereby certify that:

(13) the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.
(14) they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
(15) they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
(16) there are no other authors of the publication according to these criteria;
(17) potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and
(18) the original data are stored at the following location(s) and will be held for at least five years from the date indicated below:

Location(s)	**Monash University, Clayton Campus**

[Please note that the location(s) must be institutional in nature, and should be indicated here as a department, centre or institute, with specific campus identification where relevant.]

Signature 1		**Date**
Signature 2		**Date**
Signature 3		**Date**

5.2 Dogs use a mirror to find hidden food

Dogs use a mirror to find hidden food

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Abstract

Dog (*Canis familiaris*) cognition research examining whether dogs are able to use a mirror as a problem-solving tool is rare. The aim of this study was to explore whether dogs could find food that was visible only in a mirror. In a laboratory setting, we exposed 44 dogs to a large mirror, attached at a 90° angle to an opaque barrier, for 10 minutes. Dogs were allowed complete freedom of movement. For the first minute of the exposure phase, the owner and experimenter stood against a wall, ignoring the dog; afterwards, both walked around the room for 9 minutes. The dogs could observe their movements in the mirror. Then, dogs were taught to associate a bowl with food, after which the bowl was surreptitiously placed behind the barrier, and the dogs were placed so they could see the reflection of the food in the mirror. Dogs were pseudo-randomly assigned to the experimental group ($n = 22$) as described, or a control group ($n = 22$), which was identical except that the mirror was covered during the testing phase. In the testing phase, dogs that could see the mirror were more likely to find the treat than dogs that could not ($P = 0.032$). While fewer dogs in the control condition found the food, however, those that did were just as likely as those in the mirror condition to locate it within three minutes. This suggests that, while dogs are able to use the mirror's visual cues to locate food, some dogs used other cues which we were unable to control.

Keywords: mirror, dog, problem-solving

Introduction

Dog (*Canis familiaris*) cognition research has highlighted a seemingly singular ability that dogs possess: that of effectively communicating and cooperating with humans (Reid, 2009), perhaps better than any other species of non-human animal. While the dog's social cognitive abilities have dominated the dog cognition research landscape, studies examining non-social cognitive skills in dogs have illustrated that, in addition to their ability to communicate with humans, dogs may be adept problem-solvers in certain experimental settings. For example, some dogs are able to comprehend 2-D referents to 3-D objects (Kaminski et al., 2009), and others can sometimes succeed at means-end tasks (Range et al., 2011). Despite these advances, studies examining non-social cognitive domains in dogs, such as problem-solving and tool use, are relatively rare. In particular, studies exploring whether dogs can use a mirror as a tool are lacking. Although perfect reflections are rare in nature, many dogs in Western societies live in human homes (Kubinyi et al., 2009) where mirrors are common. It is possible that dogs have learned the function of the reflection as a way to find items of interest throughout the home.

Studies exploring cognitive domains in dogs that do not involve communication with humans can sometimes produce conflicting results. For example, a recent experiment showed that dogs possess means-end understanding (Range et al., 2011), contradicting previous research suggesting that they do not (Osthaus et al., 2005). Likewise, object permanence studies in dogs sometimes illustrate that they may understand object permanence (Miller et al., 2009; Pattison et al., 2010), while other studies indicate that they do not (Collier-Baker et al., 2004; Rooijakkers et al., 2009). These different results may be a result of changes in the research design which affect whether or not a dog can complete the given task. A previous study by Howell et al (2011) examined whether dogs can use a mirror to find their owner standing behind them, and only two of 40 dogs tested appeared to be able to understand the actual location of their owner based on the information provided in the reflection. However, since studies exploring other, non-social, cognitive domains have produced different results when the methods were varied, it is possible that a differently designed study with dogs using mirrors as a problem-solving tool would produce different results.

Several species of non-human animal have demonstrated an ability to use a mirror as a problem-solving tool. For instance, pigeons (*Columba livia domestica*) were trained to peck a colored dot on their body that was only visible in a mirror (Epstein et al., 1981), and pygmy marmosets (*Cebuella pygmaea*) that were able to see conspecifics when using a mirror made threat displays toward the actual location of the other marmosets, not just toward the mirror (Eglash et al., 1983). Japanese monkeys (*Macaca fuscata fuscata*) found hidden apples that were only visible in a mirror (Itakura, 1987) and, after 5 h of exposure to mirrors, pigs (*Sus scrofa*) were able to find food hidden behind a barrier but visible in a mirror (Broom et al., 2009).

Dog studies examining responses to reflection are rare. Zazzo (1979) studied the response of puppies younger than 4 months old to a mirror and learned that, after behaving toward the mirror as if witnessing a conspecific, puppies rapidly lost interest in the reflection. Since Howell & Bennett (2011) produced mixed results, we decided to adapt Broom et al's (2009) study with pigs, for use with dogs. The aim of this study was to see whether dogs could find food hidden behind a barrier but visible in a mirror after a 10 minute exposure to the mirror setup.

Methods

Participants

The Monash University Animal Research Platform 2 Animal Ethics Committee approved this study (approval number MARP/2011/123). Pet dogs (*n* = 47) ranging from 18 months to 12 years of age were recruited from greater Melbourne, Australia, through online dog-based forums, social media, and emails to participants in previous dog cognition studies. They were selected based on owner reports that they were at least 18 months old and obedient to the 'sit' command. Over half the dogs (*n* = 27) were purebred, the remaining 20 being cross-breeds. There were 23 male dogs and 24 females. Owners reported their dog's breed or breed combination, sex, age, hours spent inside the home, and whether there were any low-lying mirrors inside the home to which the dog may have had access (details are listed in Table 1). Pooling water and windows were not considered due to the varying quality of those reflective surfaces. In all, 22 dogs had likely had exposure to mirrors in the home. Most dogs (*n* = 41) spent at least 12 h per day inside the house, with the other six spending 6 h or less indoors. All dogs were reported to spend at least 1 h per day inside the family home. Eleven of the dogs had previously participated in a mirror study (Howell et al., 2011) run in the same research laboratory approximately 18 months prior to data collection on the current study. During this previous study the dogs had only a few minutes' exposure to the mirror and received no reinforcement for attending to it, so this was not expected to affect their performance in the current study. Of these 11 dogs, four were in the experimental group and seven were in the control group (described below).

Materials

Dogs and owners entered a waiting room within the laboratory suite together and given a brief explanation by the experimenter of what to expect regarding the amount of time the session would take, instructions for how to behave in the different phases of the study, and the purpose of the study. The predictions were not explained to the owners until after the session ended. Then they were led into the testing room for a 10 minute exposure phase. In total, dogs spent approximately 20-30 minutes in the laboratory suite, of which 13 minutes were in the testing room. Although Broom et al. (2009) had a 5 hour exposure period in their pig study, 5 hours of exposure was not feasible for a large number of dogs whose owners were required to be present throughout the session. Personal communication with Broom (14 July 2011) also suggested that a shorter period of exposure was likely to be sufficient.

The testing room set up was based on Broom et al. (2009), and contained a 1m tall x 1.5 m wide freestanding mirror, positioned on the floor. The centre of the mirror was attached to a 1.5 m tall x 1.5 m wide opaque barrier at a 90° angle to the mirror, also positioned on the floor (see Figure 1). There was a space of 9 cm separating the barrier from the mirror, which was covered with transparent hard plastic. This permitted the dogs to see the reflection of the area on the other side of the barrier, but not to move between the barrier and the mirror. The floor of the room was marked with masking tape to divide the room into four different areas, including the area nearest the door, the area behind the mirror, the area where the treat would be located, and the area where the dog would begin the testing phase, as shown in Figure 1. There were dog treats (You'll Love Coles brand beef liver strips, Coles, Glen Iris, Victoria, Australia) placed in five different and inaccessible locations throughout the room, and two fans in the room were employed to disperse the scent of the treats, thus making it more difficult for the dog to localize the scent of the target treat used during the testing condition. The hidden treats were identical in size and type to the target treat.

Procedure

Exposure Phase

During the first minute of the exposure phase, the owner and experimenter stood against a wall in the laboratory and ignored the dog. The dog was permitted to explore the room and was not given any instructions. After the first minute, the owner and experimenter walked around the room slowly. There was no set pattern required for this movement, but the owner was instructed to approach every part of the room several times. Broom et al. (2009) kept two pigs in the testing room during the exposure period of their study, and watching the movement of the other pig in the mirror may have helped each pig learn how a mirror works.

Since the dogs in our study live in human homes, we believed that they would be more likely attend to their owner in a mirror than a conspecific; therefore, the owner was asked to move around the room so that the dog could see his or her movements in the mirror. A blanket was lying on a countertop running alongside the edge of Area 4.

Association Phase

After the 10 minute exposure phase, the experimenter, owner, and dog returned to the waiting room in the laboratory suite. During this time, the experimenter played a game with the dog to teach the dog to associate a blue bowl with treats. Several small pieces of liver treat, identical to the target treat, were placed in the dog bowl and given to the dog, one at a time. After four or five repetitions of handing the bowl directly to the dog, the owner then held the dog by the collar while the experimenter placed the bowl around a corner of the lab, just out of view of the dog. The dog was released by the owner and permitted to find the bowl; when the dogs approached the bowl quickly once they saw it at least three times in a row, they were deemed to have made the association between the bowl and the dog treats. Most dogs ($n = 39$) made the association in under 10 total trials; however, five dogs took between 10 and 20 trials, and one dog took 24 trials. Two dogs refused to eat the treats when they were offered by the experimenter. Since they appeared to lack motivation for the food, the session was terminated for these two dogs, and data from the exposure phase were excluded from analysis. The total number of dogs who participated in the testing phase was 45.

Testing Phase

After the association between the bowl and the treats was confirmed, the experimenter put a larger piece of liver treat in the bowl, showed the treat in the bowl to the dog, and went inside the testing room for the testing phase. The baited bowl was placed behind the barrier, but visible in the mirror, before the owner was instructed to lead the dog into the room by the collar. The owner was asked to lead the dog to a location in front of the mirror, on an 'x' marked on the floor, which was approximately 60 cm from the mirror and was positioned at a good angle to see the food bowl in the mirror. The owner asked the dog to 'sit' and 'stay', and the owner and experimenter stood in the same location against the wall where they had been during the first minute of the exposure phase; from this position, the owner could only see the treat via the mirror. The owner verbally released the dog from the 'sit' command, and the dog was given 3 minutes to find the treat. Owners encouraged the dog to find the treat using verbal commands such as "where's the treat?" and "find it!", but were instructed not to point to the location of the food. One owner pointed four times, even after being reminded by the experimenter not to point. Data from this dog were excluded from analysis. The total number of dogs included in analysis was 44. Dogs who did not find the treat within the allocated 3 minute period were shown the location of the treat in order to reward the dog for participation, regardless of whether or not it found the treat on its own. All dogs rapidly approached the bowl and ate the treat when they located it, either when they discovered it on their own within the 3 minute period, or when they did not find it on their own and were shown its location.

Half of the dogs (*n* = 22) were able to see the mirror during the testing phase and made up the experimental group, the other half (*n* = 22) constituting a control group in which the mirror was covered by a blanket prior to the dog and owner entering the room for the testing phase. In the control group, the exposure phase and association game were identical to that described above, but the experimenter covered the mirror when she took the bowl of food into the testing room to hide it behind the barrier before the testing phase. The owner was still instructed to place the dog on the 'x' on the floor in front of the mirror, and the dog was given 3 minutes to find the treat with verbal encouragement from the owner and experimenter. The only difference was that the treat was not visible in the mirror for the control dogs. Participation in the experimental or control group was pseudo-randomized such that there would be equal numbers in each group. Dogs received a treat for participation, and owners were offered a candy bar. Water was available for the dogs ad libitum throughout the session.

Analysis

For all dogs, video data were recorded for the exposure phase and the testing condition using FLIP Mino Pocket-Sized High Definition Camcorders (Cisco Systems, San Jose, California, USA) and CMS 3.6.0 Closed Circuit Television software (Shenzhen Winbo Digital Co, Ltd, Guangdong, China). All statistical analyses were performed using IBM PASW Statistics 18 (International Business Machines Corp., Armonk, New York, USA). For the first minute of the exposure phase, we measured the frequency of the dog's presence in each of the four areas of the room. Video data were coded using a 5-second partial interval recording procedure, whereby a dog was noted as having been in an area if the dog's head was present in that area at any time during each 5-second period. This was necessary because dogs were able to move rapidly throughout the room, and could easily (and sometimes did) move through all four areas within 5 seconds. Much relevant data would have been lost had we not used a partial interval recording. We coded the presence of the head instead of the entire body because the dogs often straddled two areas; in order to avoid confusion when coding data, only the presence of the head was considered. Videos from 15 dogs were coded both by the experimenter and by a naïve observer to measure inter-rater reliability. Agreement was 85%, and Pearson's correlation between the two raters for presence in areas 1-4 were 0.981 ($P < 0.001$), 0.567 ($P = 0.028$), 0.989 ($P < 0.001$), and 0.99 ($P < 0.001$) respectively. The relatively low correlation in area 2 was due to one dog that straddled area 1 and 2 for much of the coding period, and whose actual placement was difficult to determine on the video. When correlations were analyzed without this dog, Pearson's correlation for area 2 became 0.891 ($P < .001$).

In order to determine whether dogs in the experimental group had an inherent preference for any part of the room compared to the control group, we analyzed the presence of the dog in each area of the room during the first minute of the exposure phase. Video data from three dogs (one control and two experimental) were lost due to technical difficulties with the camera system. Therefore, video data from the remaining 41 dogs were analyzed. An independent samples, paired *t*-test was conducted to compare the frequency of time spent in each area for the control and experimental groups. Only the first minute was analyzed because, during the remaining nine minutes, the owner and experimenter were moving around the room. This would have likely affected the dog's natural movements, since they would be more inclined to follow their owner.

During the testing phase, we tallied whether or not each dog was able to locate the treat within the 3 minute period, and a Chi-square test for independence with Yates Continuity Correction was used to analyze whether dogs in either the experimental or control group were more likely to find the treat. Latency to find the treat was also analyzed, after being converted from raw time taken (in seconds) into a percentage of the total time allotted in the testing phase (i.e. 180 seconds). For example, in a dog which took 27 seconds to find the treat, this time was converted to 0.15 (as 27 seconds is 15% of 180 seconds) for analysis. Differences in latency to find the treat between groups were analyzed using independent samples, paired *t*-tests.

Results

There was no significant difference in the frequency of the dogs' presence in each area between groups during the exposure phase.

During the testing phase, of the dogs in the experimental group, 17 (77%) were able to find the treat within the 3 minute time frame. Of the control dogs, nine (41%) found the treat within 3 minutes (see Table 1). Dogs in the experimental group were more likely to find the treat than those in the control group, χ^2 (1, n = 44) = 4.601, P = 0.032.

Dogs in the experimental group (M = 0.396, SD = 0.371) also found the treat significantly faster than dogs in the control group (M = 0.677, SD = 0.410), t (42) = -2.386, P = 0.022 (two-tailed). However, subsequent latency analysis that only included dogs that found the treat within the 3 minute time frame revealed no significant differences in latency to find the treat between the experimental group (n = 17, M = 0.218, SD = 0.182) and control group (n = 9, M = 0.210, SD = 0.162), t (24) = 0.106, P = 0.917 (two-tailed).

Discussion

The aim in this study was to determine whether dogs could use a mirror to find hidden food, after being exposed to an experimental setup containing a mirror for 10 minutes. We hypothesized that dogs which could see the hidden food in the mirror would be more likely to find the food than dogs which could not see the food through the mirror. Our results are consistent with this prediction and suggest that dogs are able to use a mirror to find hidden food, even with minimal prior exposure to the mirror. In the same environment, when dogs did not have access to the visual cues provided in the mirror, they were significantly less likely to find a hidden treat within a 3 minute period. This was not due to a pre-test preference for one part of the room over another when comparing the experimental group and the control group, so it is probable that the dogs in the experimental group did indeed use the mirror to locate the food. The ability to use a mirror as a problem-solving tool has not previously been demonstrated in this species (but see Howell & Bennett 2011 for potential evidence of such a skill), and our results therefore add further information to the growing body of knowledge about the general problem-solving abilities of domestic dogs.

There are very few studies involving dogs' reactions to a mirror, but Howell & Bennett (2011) recently explored whether dogs could use a mirror to find their owner holding the dog's favorite toy. The results were different from the ones we report in the current study, with only two of 40 dogs appearing to understand that their owner was behind them. However, this previous study only included 2 minutes of exposure to the room prior to the test condition, and the owner was not asked to spend time in the room with the dog and mirror prior to the test. This difference in methodology may explain the inconsistent findings. Perhaps if the dogs in Howell & Bennett (2011) had been given more time to adjust to the room's setup, and more experience at observing their owner in the mirror, they would have been more successful.

Despite the paucity of previous research exploring mirror use by dogs, this study is consistent with others which suggest that various animals can use mirrors to solve problems. The ability to use a mirror as a problem-solving tool is not limited only to closely related mammals, such as primates, since pigs (Broom et al., 2009) and birds (Epstein et al., 1981) have also demonstrated this ability. Thus it follows that dogs should be able to learn what a mirror represents, being phylogenetically more closely related to pigs and monkeys than birds, although this may represent a case of cognitive convergence in birds. Indeed, cognitive convergence may account for the possibility that dolphins (Reiss et al., 2001) and Asian elephants (Plotnik et al., 2006) exhibit mirror self-recognition, a possible measure of self-awareness in animals, which otherwise tends to cluster within the great ape family (Suddendorf et al., 2009).

Dogs were required to detour around the barrier in order to find the hidden food. During the exposure phase, the owner and experimenter walked behind the barrier several times, and the dog often followed. The ability to detour around barriers in order to obtain a treat has been previously studied in dogs, and results of these studies indicate that dogs are able to learn how to detour the barrier by watching humans (Pongracz et al., 2001; Pongracz et al., 2003; Pongracz et al., 2005). While the dogs in this study were not specifically trained to detour the barrier, the owner's presence in area 3 during the exposure phase usually encouraged the dogs to come into area 3 as well, suggesting that they had ample opportunities to learn how to approach area 3 through observation.

A limitation to this study is the possibility that the blanket which was used to cover the mirror for the control condition created a distraction in its novelty. The dogs were not previously exposed to the mirror covered by the blanket, and the sudden appearance of this new item over the mirror may have been sufficient to make the dogs in the control group forget about the treat. We think this is improbable, because even though the blanket was not covering the mirror during the exposure phase for either group, it was present in the room during this time, lying on a counter along the edge of the room (in area 4). That nine control dogs found the treat regardless of the blanket also suggests this is unlikely.

Many of the dogs in the control group did not find the treat within the three minute testing phase. It is possible that the dispersal of the treat scent throughout the room, via the hidden and inaccessible treats placed all over the room and the use of the fans, made it impossible for dogs to smell the treat. However, in many cases, the dogs in the control group who did find the treat appeared to sniff the floor until they were able to locate the treat. Perhaps they were following the scent trail left by the experimenter when the treat was placed in the room, or were searching for any of the hidden treats using odor cues.

This is an important possibility as, although it is heavily relied upon by humans in police and quarantine work (Browne et al., 2006), the dog's sense of smell remains poorly understood (Walker et al., 2006). Whether some dogs could discern the most recent scent trail left by the experimenter, even among the numerous other scent trails left by the same experimenter during the previous exposure phase, is unknown.

In trying to explain why nine dogs in the control condition were able to locate the treat as quickly as those 17 dogs in the experimental group who did so, we also considered whether the owner or experimenter may have been providing subtle cues, perhaps by gazing in the direction of the treat or making other indications of its whereabouts. We did not observe such behavior during the study but, unfortunately, we were not able to examine the videos of the study post hoc to investigate this possibility as the cameras were focused on the dog rather than the owner. However, because it is well established that dogs are extremely sensitive to subtle non-verbal cues from humans, including eye-gaze (Gacsi et al., 2004), it will be important to confirm our results using an experiment design in which there are no humans visible to the dog during the test phase. Because the owners knew the purpose of the study and were present in the room, it is possible that Clever Hans effects increased the likelihood that the dogs would find the treat. We believe this is unlikely, because the owners of dogs in both the control and experimental group were all present in the room and aware of the study's purpose, but dogs in the experimental group were still more likely to find the treat than dogs in the control group. If Clever Hans effects were present, there should not have been a difference in the likelihood to find the treat between groups, as the stated goal for individuals in both groups was always to find the treat. A final interpretation of these findings is that some dogs, irrespective of scent or visual cues, may be more highly motivated and/or have greater capacity to recall that a treat has been placed in a room for them to find. Future research that explores how long certain breeds or individuals are capable of retaining this sort of information will likely shed further light on this issue.

Conclusion

Pet dogs in our study appear to have used a mirror as a tool to locate hidden food. This is the first study, to our knowledge, which demonstrates the ability to use a mirror as a problem solving tool in a large group of dogs. Further research is needed to examine the conditions under which dogs are successful or not in using the mirror as a tool, as our initial design left several important questions unanswered. Mirror studies may, however, be a good mechanism for understanding when dogs use scent cues and when they rely on visual cues. This information would help researchers understand the extent of dogs' cognitive abilities in non-cooperative or non-social tasks, which is increasing but still less common than research exploring social cognitive skills in dogs.

Acknowledgements

We are grateful for the participation of the owners and dogs who volunteered for our study.

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Table 1

Demographic data for the 44 dogs used in analysis, including the amount of time spent inside the home and likelihood of previous exposure to mirrors. Whether each dog found the treat, and latency to find the treat, are also listed. *Video data of the first minute of the exposure period was lost for three dogs, so they were excluded from that analysis. †Indicates dogs who participated in a previous mirror study in the same laboratory.

Figure 1

Schematic of the laboratory suite. Owners and dogs were received in the waiting room before being taken into the experimental room for the exposure phase. After a 10 minute exposure phase, the owner, dog, and experimenter returned to the waiting room to commence the association game. Then, the owner, dog, and experimenter re-entered the experimental room for the experimental condition. Dotted lines indicate masking tape markings on the floor. The stars represent hidden treats, placed above the dog's reach (approximately 2m off the ground) and out of view.

Table 1

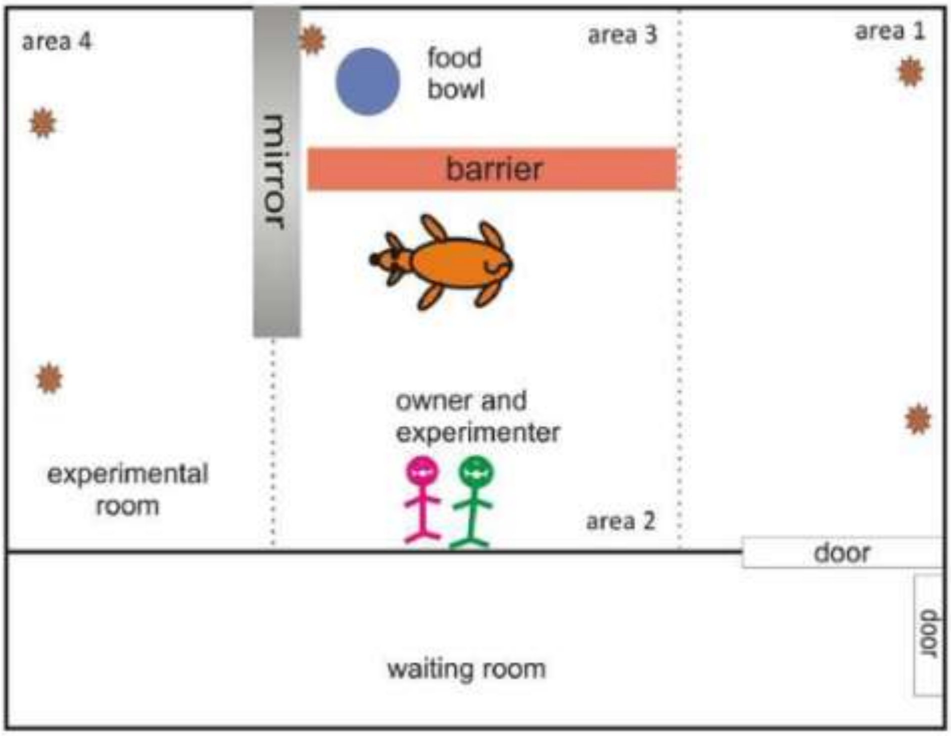
CONTROL GROUP

Age	Breed	Sex	Hrs inside	Prior mirror exposure	Found treat	Latency (sec)
3y	†Rottweiler	F	16	Y	N	--
7y	kelpie	M	15	N	Y	16
6y	†Labrador retriever	M	22	N	N	--
4y	†Labrador retriever x	M	22	N	N	--
3y	†Maltese x shihtzu	M	16	N	N	--
3y	Lhasa apso x poodle	M	23	N	N	--
2y	poodle x	M	16	Y	N	--
18m	pug x Jack Russell terrier	M	22	Y	N	--
2y	Border collie	M	12	Y	N	--
3y	kelpie x	F	12	N	Y	16
4y	papillon x	M	15	Y	N	--
4y	pug x Jack Russell terrier	F	22	Y	N	--
4y	Cairn terrier	F	6	N	Y	70
2y	Staffordshire terrier	F	23	N	Y	60
3y	†Leonberger	F	23	Y	N	--
3y	Chinese crested	M	22	N	N	--
5y	Border collie x kelpie	F	21	Y	Y	16
4y	Jack Russell terrier x	M	14	Y	Y	16
4y	Labrador retriever	M	23	N	Y	27
5y	*†Terrier x	M	15	Y	N	--
3y	Labrador retriever x poodle	M	5	Y	Y	94
8y	*†Labrador retriever	M	22	Y	Y	25

EXPERIMENTAL GROUP

Age	Breed	Sex	Hrs inside	Prior mirror exposure	Found treat	Latency (sec)
9y	Australian shepherd	F	1	N	Y	23
7y	Jack Russell terrier x fox terrier	F	22	N	Y	20
9y	bearded collie	F	12	N	N	--
10y	kelpie	F	22	Y	N	--
3y	toy poodle	F	22	N	Y	96
5y	Shihtzu x poodle	F	22	N	Y	10
8y	German shepherd x kelpie	F	20	Y	Y	28
22m	Labrador retriever	F	12	N	Y	41
5y	Cavalier King Charles spaniel x poodle	M	5	Y	N	--
8y	pug	M	15	Y	N	--
2y	Lagotto romagnolo	F	22	Y	Y	19
3y	Maltese x poodle	F	16	Y	Y	31
6y	Maltese	F	23	N	N	--
3y	†West Highland terrier	M	18	N	Y	6
20m	Border collie	F	2	Y	Y	28
12y	†Staffordshire terrier	M	14	N	Y	27
11y	Samoyed	F	12	N	Y	84
5y	Golden retriever x poodle	M	23	N	Y	7
7y	†Breed type unknown	F	23	N	Y	28
3y	†Rottweiler	M	16	Y	Y	120
21m	Chinese crested	M	22	N	Y	65
2y	*Great Dane	M	18	Y	Y	29

Figure 1


area 4
mirror
food bowl
area 3
area 1
barrier
owner and experimenter
experimental room
area 2
door
door
waiting room

5.3 Discussion

The aim of this behavioural experiment was to determine whether dogs could find food hidden behind a barrier but visible in a mirror. The study described here followed on from the results that were difficult to interpret in the paper from Chapter 4. Methodological differences did appear to redress this problem somewhat. For instance, the dogs were given a longer time to adjust to the room and learn how the mirror works, and they were tested for motivation to find the treat before the testing session commenced. They were also able to approach and obtain the treat once they located it in the mirror.

The results were still somewhat ambiguous. A key finding to emerge from this study was that the dogs exposed to a mirror were more frequently able to find the treat than the control group dogs, which could not see the treat due to a blanket covering the mirror. However, when analysing latency to find the treat using only the dogs in both groups which managed to find the treat within the three minute window, there was no significant difference between groups in the amount of time it took to find the treat. This is of concern because it could mean that it was not the mirror at all, but some spurious variable, such as a Clever Hans effect (an animal's ability to read involuntary, unconscious cues given by humans which encourage the animal to behave in a desired way), which made the difference between whether the dogs could find the treat or not. Clever Hans effects are unlikely because the owners were not made aware of the predictions until after the session ended. However, these possibilities cannot be completely ruled out because owners may have realised the predictions even without being told. Therefore, they (or the experimenter) may have provided involuntary cues indicating preferred behaviours. A scenario in which everyone present is blind to the condition would be ideal, but difficult with this set-up. Instead, covering the heads of the humans would not permit them to view the dog's behaviour, and would therefore help reduce the possibility of Clever Hans effects.

Notwithstanding potential limitations of this study, the research contributes to the growing understanding of dog cognitive abilities, especially in less-explored domains like problem-solving and mirror use. The studies reported in Chapters 4 and 5 constitute another step in developing a deeper comprehension of how dogs perceive the world around them. They also provide insights into how dogs use tools to solve problems such as finding food. Dogs appear to be able to use mirrors as a problem-solving tool, like other animals which are both phylogenetically similar to (Broom et al. 2009) and different from (Eglash & Snowdon 1983; Itakura 1987) dogs.

The problem of interpretation is common in behavioural research (Hare et al. 2010; Ikeda & Matsumoto 2007). It is a rare study indeed that can control for every potential spurious variable and determine unequivocally that the subjects behaved a particular way solely due to the experimental setup. Instead, a cumulative process is followed, with each study building on those before it. Currently, the most common way to evaluate the appropriateness of a particular method is to attempt to replicate it (see Miklosi 2008; Miklosi & Soproni 2006), or to use a different paradigm to study the same cognitive domain (e.g. Collier-Baker et al. 2004; Pattison et al. 2010). This can be time-consuming, and resources may not always be available for replication by the same or other groups. Therefore, another complementary technique that measures a different aspect of cognitive processing, such as neurophysiological measures like EEG, could work in tandem with behavioural research to assist researchers in interpreting how dogs process information.

CHAPTER 6 – DEVELOPING A MEASURE OF DOG COGNITIVE PROCESSING USING ELECTROENCEPHALOGRAPHY (EEG)

The behavioural research in Chapters 4 and 5 examining whether dogs can use mirrors as a tool did not provide unambiguous results. Several changes incorporated into the research design in Chapter 5 were believed to address the problems highlighted in Chapter 4. The exposure to the mirror setup was lengthened, the treat was made fully accessible in the testing condition, and tests were conducted to confirm that the dogs were motivated to find the treat. Nonetheless, it was impossible to establish definitively whether dogs were able to use mirrors as a problem-solving tool because of potential limitations in the research designs of both studies. Therefore, it was important to determine whether there was another way to measure cognitive processing in dogs that did not rely solely on behaviour or people's perceptions of dog cognitive abilities.

Chapter 2 described mismatch negativity (MMN), which is an event-related potential (ERP) or a brain waveform elicited after exposure to a stimulus, that can be measured using electroencephalography (EEG). MMN is observed after exposure to a novel stimulus in a series of expected stimuli, and it has the potential to provide information about how dogs process information, particularly in discrimination tasks. Minimally-invasive EEG methods, involving the use of small, subdermal needle electrodes placed just underneath the skin, have been previously used in the context of hearing loss research with dogs (Ahlstrom et al. 2005). This technique could be useful when working with companion dogs, as it does not require extensive training and does not use invasive methods that would not be possible with pets, which are widely viewed as members of the family (Kubinyi et al. 2009). The aim of this study was to adapt this minimally-invasive method to measure MMN in dogs without the use of sedation or anaesthesia.

The journal article, ‘Development of a minimally-invasive protocol for recording mismatch negativity (MMN) in the dog (*Canis familiaris*) using electroencephalography (EEG)’ was published in *Journal of Neuroscience Methods* in 2011. It describes the development of the technique and its use in a pilot study with one dog, Jaffa. This is the first illustration of MMN in a dog.

6.1 Declaration for thesis chapter 6

In the case of Chapter 6, the nature and extent of my contribution to the work was the following:

Nature of contribution	Extent of contribution (%)
Development of the method, data collection and subsequent analysis, writing the journal article	75%

The following co-authors contributed to the work. Co-authors who are students at Monash University must also indicate the extent of their contribution in percentage terms:

Name	Nature of contribution	Extent of contribution (%) for student co-authors only
Russell Conduit	Advising on development of method, technical EEG advice for data collection and analysis, suggestions for refinement of the manuscript	
Samia Toukhsati	Advising on development of method, technical EEG advice for data collection and analysis, suggestions for refinement of the manuscript	
Pauleen Bennett	Suggestions for refinement of the manuscript	

Candidate's Signature		**Date**

The undersigned hereby certify that:

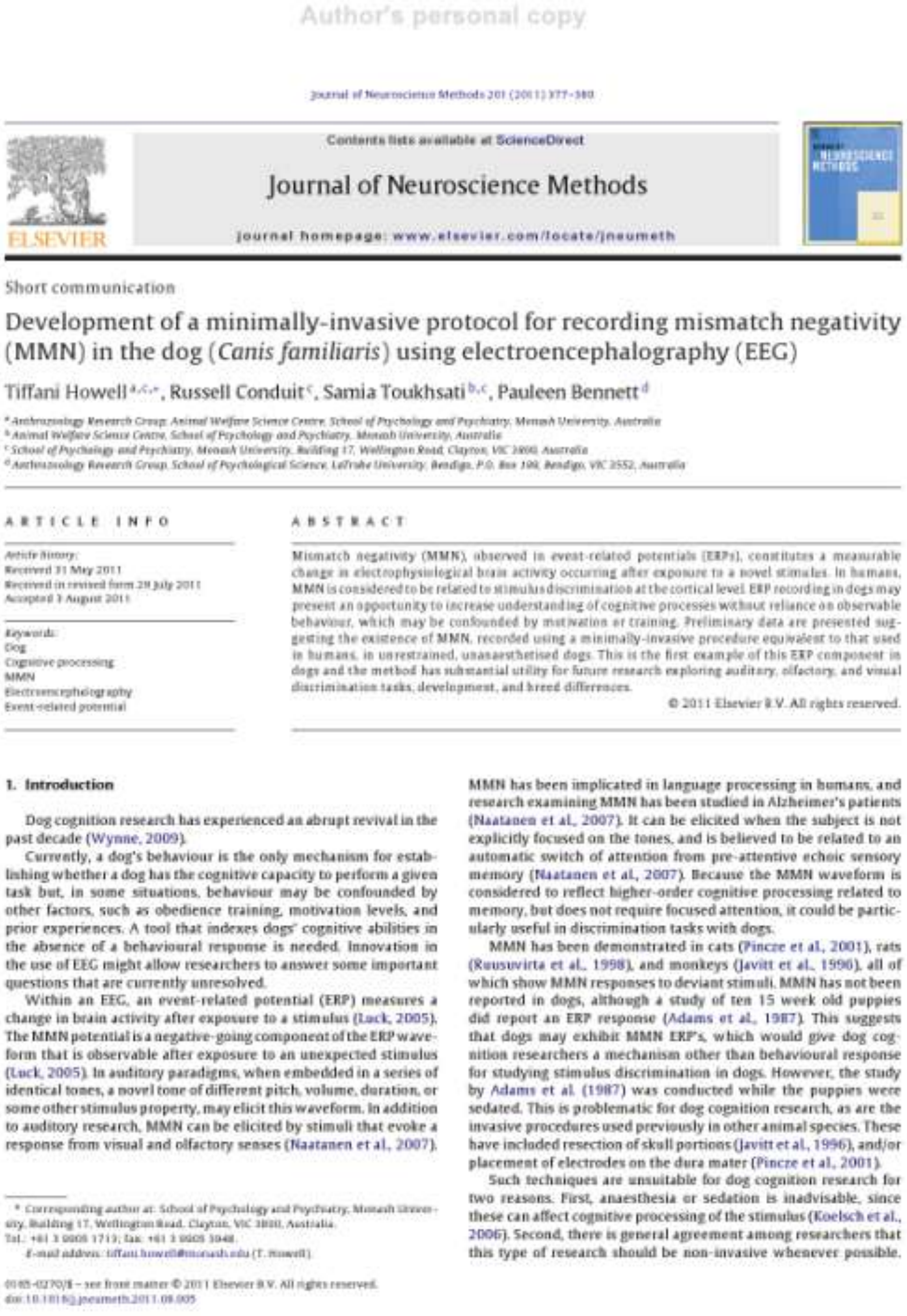
(19) the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.
(20) they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
(21) they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
(22) there are no other authors of the publication according to these criteria;
(23) potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and
(24) the original data are stored at the following location(s) and will be held for at least five years from the date indicated below:

Location(s)	**Monash University, Clayton Campus**

[Please note that the location(s) must be institutional in nature, and should be indicated here as a department, centre or institute, with specific campus identification where relevant.]

Signature 1		**Date**
Signature 2		**Date**
Signature 3		**Date**

6.2 Development of a minimally-invasive protocol for recording mismatch negativity (MMN) in the dog (Canis familiaris) using electroencephalography (EEG)



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Short communication

Development of a minimally-invasive protocol for recording mismatch negativity (MMN) in the dog (*Canis familiaris*) using electroencephalography (EEG)

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ABSTRACT

Mismatch negativity (MMN), observed in event-related potentials (ERPs), constitutes a measurable change in electrophysiological brain activity occurring after exposure to a novel stimulus. In humans, MMN is considered to be related to stimulus discrimination at the cortical level. ERP recording in dogs may present an opportunity to increase understanding of cognitive processes without reliance on observable behaviour, which may be confounded by motivation or training. Preliminary data are presented suggesting the existence of MMN, recorded using a minimally-invasive procedure equivalent to that used in humans, in unrestrained, unanaesthetised dogs. This is the first example of this ERP component in dogs and the method has substantial utility for future research exploring auditory, olfactory, and visual discrimination tasks, development, and breed differences.

1. Introduction

Dog cognition research has experienced an abrupt revival in the past decade (Wynne, 2009).

Currently, a dog's behaviour is the only mechanism for establishing whether a dog has the cognitive capacity to perform a given task but, in some situations, behaviour may be confounded by other factors, such as obedience training, motivation levels, and prior experiences. A tool that indexes dogs' cognitive abilities in the absence of a behavioural response is needed. Innovation in the use of EEG might allow researchers to answer some important questions that are currently unresolved.

Within an EEG, an event-related potential (ERP) measures a change in brain activity after exposure to a stimulus (Luck, 2005). The MMN potential is a negative-going component of the ERP waveform that is observable after exposure to an unexpected stimulus (Luck, 2005). In auditory paradigms, when embedded in a series of identical tones, a novel tone of different pitch, volume, duration, or some other stimulus property, may elicit this waveform. In addition to auditory research, MMN can be elicited by stimuli that evoke a response from visual and olfactory senses (Naatanen et al., 2007). MMN has been implicated in language processing in humans, and research examining MMN has been studied in Alzheimer's patients (Naatanen et al., 2007). It can be elicited when the subject is not explicitly focused on the tones, and is believed to be related to an automatic switch of attention from pre-attentive echoic sensory memory (Naatanen et al., 2007). Because the MMN waveform is considered to reflect higher-order cognitive processing related to memory, but does not require focused attention, it could be particularly useful in discrimination tasks with dogs.

MMN has been demonstrated in cats (Pincze et al., 2001), rats (Ruusuvirta et al., 1998), and monkeys (Javitt et al., 1996), all of which show MMN responses to deviant stimuli. MMN has not been reported in dogs, although a study of ten 15 week old puppies did report an ERP response (Adams et al., 1987). This suggests that dogs may exhibit MMN ERP's, which would give dog cognition researchers a mechanism other than behavioural response for studying stimulus discrimination in dogs. However, the study by Adams et al. (1987) was conducted while the puppies were sedated. This is problematic for dog cognition research, as are the invasive procedures used previously in other animal species. These have included resection of skull portions (Javitt et al., 1996), and/or placement of electrodes on the dura mater (Pincze et al., 2001).

Such techniques are unsuitable for dog cognition research for two reasons. First, anaesthesia or sedation is inadvisable, since these can affect cognitive processing of the stimulus (Koelsch et al., 2006). Second, there is general agreement among researchers that this type of research should be non-invasive whenever possible.

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This is in accordance with National Research Council policies on animal use in research (Guide for the care and use of laboratory animals, 2011) and also reflects the fact that researchers in dog cognition often work with pet dogs, recruited from the community. Many dog owners consider their pets to be members of the family (Miklosi, 2008) and access to these animals requires that the dogs leave the study area in the same physical and affective states as when they arrived; risking even mild pain or distress is unacceptable. In order to be a viable method for studying cognitive processing in dogs, ERP research needs to be conducted with the same level of concern for the subject as is the case in human research: being non- or minimally-invasive and painless. This is made difficult by the fact that dogs have much more hair covering their scalps than do humans, and a thick skin that raises the impedance level to more than 50 kΩ.

Although some EEG research with animals has employed traditional, invasive, methods, other studies have tried to adapt less invasive methods for use in dogs (Greene et al., 1992). One recent study from the field of epilepsy research, for example, aimed to standardise placement of small, subdermal needle electrodes in dogs with different shaped heads (Pellegrino and Sica, 2004). Subdermal needle electrodes are very small, approximately 10–15 mm in length, with a 27–30 gauge width; this makes them comparable in diameter to acupuncture needles (Ceniceros and Brown, 1998). The needles are inserted subcutaneously and do not need to penetrate the skull or muscle underneath the skin. Once underneath the skin, the impedance level drops from more than 50 kΩ to less than 5 kΩ, enabling accurate EEG recording. In an earlier study using subdermal needle electrodes in dogs, the electrodes were placed under the dog's skin while the dog was under anaesthesia (Greene et al., 1992), remaining in place throughout the duration of the recording and easily removed upon completion. Insertion of fine needles such as this should not be associated with pain or distress, making this technique a suitable candidate for use in non-sedated pet dogs. The aim of the current study was to develop a method for recording endogenous ERPs, such as MMN, from dogs using this minimally-invasive technique and without the use of any anaesthesia or pharmaceutical sedation.

2. Methods

This pilot study was approved by Monash University School of Psychology and Psychiatry Animal Ethics Committee: 2010/01-51.

2.1. *Participant*

Our pilot subject was an 8 year old female Australian Shepherd, named Jaffa. The dog was recruited through word-of-mouth and selected on the basis of owner reports that she would relax quickly in novel environments, be obedient to owner commands of 'sit' and 'stay' for up to 10 min, and not be distressed when needles were inserted under the skin. Observations of the dog's behaviour both before and during the testing phase indicated that she could hear the auditory stimuli.

2.2. *Materials*

Testing was performed in a sound-attenuated laboratory at Monash University, Clayton Campus. Viasys Healthcare Disposable Rapid-Pull 12 mm Subdermal Needle Electrodes with 2.5 m cable (San Diego, CA, USA) were attached to a wire connecting the EEG amplifier. These electrodes are 27 gauge needles made of stainless steel. A high-grade D/C amplifier, Compumedics Neuroscan Synamps^2 70-channel (Charlotte, NC, USA), was used to record the dog's EEG. Stimuli were presented using Compumedics Neuroscan Stim2 (Charlotte, NC, USA) and the EEG was recorded using Compumedics Neuroscan Scan 4.5 (Charlotte, NC, USA). Data were analysed using Compumedics Neuroscan Scan 4.5 and MS Excel.

2.3. *Procedure*

2.3.1. *Relaxation protocol*

When the owner and dog arrived at the laboratory, the dog's collar and leash were removed, and the animal permitted to meet the experimenters and explore the laboratory until she appeared ready to settle on a dog bed next to the EEG amplifier. Although pharmaceutical sedation was unnecessary to obtain an accurate EEG recording, it was important that the animal be very relaxed. Therefore, the owner remained present at all times and full relaxation took approximately 40 min. This was determined based on behaviour; Jaffa was deemed relaxed and ready for electrode placement when she lay on the bed, with her head on the floor and eyes closed, for approximately 5 min without attempting to leave the bed, changing position, or fidgeting.

2.3.2. *Needle electrode placement*

When the dog was fully relaxed, electrode placement commenced. The recording electrode was placed at Cz, on the midline 50% of the distance from the stop (the indentation of the bone between the eyes) to the external occipital protuberance. This was selected because human studies often show a large MMN response at midline sites (Luck, 2005), and it is simple to identify, requiring measurement of the distance between two easily visible points on the animal's head. In humans, Cz corresponds to the central sulcus; this is analogous to the canine cruciate sulcus which is located rostral to our Cz placement in dogs (Pellegrino and Sica, 2004). Since MMN can be recorded throughout midline sites in humans, we anticipated that it would be possible to accurately record MMN on the midline in a dog even though the corresponding areas of the brain may differ somewhat.

Because EEG measures electrical impulses occurring in the brain, a reference electrode is necessary to compare electrical activity in the brain to another part of the body. It is important that the reference site has as little electrical activity as possible, and the mastoid or earlobe is commonly used in human research (Luck, 2005). Because the dogs' head has muscles throughout the mastoid and skull (Smith, 1999), this placement was expected to produce too much muscular interference on the EEG recording. Therefore, a midline site was chosen on our pilot subject's neck, 100% of the distance from the stop to the external occipital protuberance, starting from Cz.

A third electrode was necessary to close the electrical loop within the dog's body to reduce electrical interference from outside the body. This ground electrode was placed at Oz, which is 10% of the distance from the stop to the external occipital protuberance, rostral to the external occipital protuberance. Therefore, in this dog, the recording electrode was placed at Cz, 6 cm behind the stop, the reference was placed 12 cm behind Cz on the neck midline, and the ground was placed 1.2 cm rostral to the external occipital protuberance. These three electrodes were the minimum required to record EEG using the Synamps^2 system. See Fig. 1 for illustration of the placement.

The needle electrodes were inserted underneath the skin and were secured with surgical tape. At no time did the dog show any signs of pain or distress upon insertion; in fact she gave no behavioural indication that she had even noticed their insertion at all. Once the recording was complete, the tape and electrodes were removed and disposed of.

2.3.3. *Stimulus presentation*

Once the animal was fitted with the three needle electrodes, an auditory oddball paradigm was run using 50 ms tones. The

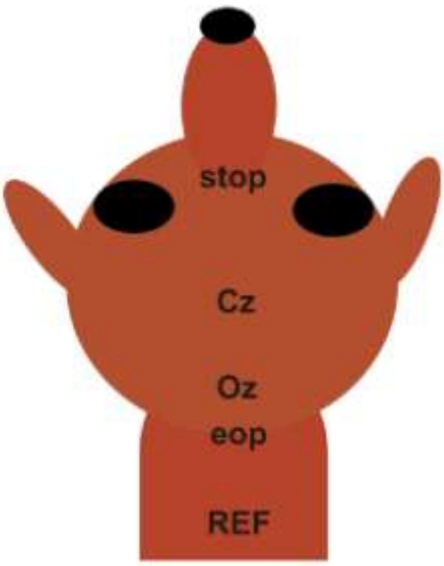

Fig. 1. Schematic of the electrode placement on Jaffa. The stop and external occipital protuberance (as 'eop') are identified. The recording electrode is placed at Cz, 50% of the total distance between the stop and external occipital protuberance on the midline. The ground electrode is at Oz, also on the midline, 10% of the distance between the stop and external occipital protuberance, rostral to the external occipital protuberance. The reference placement is non-standard, at 100% of the total distance from the stop to the external occipital protuberance, starting from Cz on the midline of the neck.

inter-stimulus interval was 2 s. The standard tone was 500 Hz with a probability of 90%, and the deviant tone was 1 kHz with a 10% probability. Each tone comprises a trial, and a total of 209 trials were recorded over the course of approximately 8 min. During this presentation, the dog's EEG was recorded in a continuous D/C format (A/D sample rate: 500; range: ±200 mV; Accuracy: 29.80 nV/LSB; low pass: 100 Hz; high pass: 0.10 Hz; Notch frequency: 50 Hz; 500 sweeps per second).

2.3.4. *Analysis*

Analyses were conducted using Compumedics Neuroscan Scan 4.5 Software. The continuous EEG file was filtered (analogue simulation; low pass: 30 Hz, 6 dB/oct), and epochs were created for waveforms occurring between −100 ms and 600 ms of the stimulus. A baseline correction was performed, as was an artifact rejection in which any epochs with amplitudes higher than 100 µV were excluded from analysis. Epochs occurring around the standard tones were averaged separately from epochs occurring around the deviant tones.

3. Results

Preliminary data from this paradigm are presented in Fig. 2. Averaged responses to the standard tones (188 trials included) and the deviant tones (21 trials included) are reported. There is noticeably higher amplitude of the negative wave after the deviant tone when compared to the standard tone, at approximately 180 ms. To our knowledge, these data are the first to suggest the presence of an MMN-like waveform in a dog using minimally-invasive recording procedures and no sedation or anaesthesia. Importantly, the procedure was such that neither Jaffa nor her owner appeared negatively affected by their involvement. Indeed they appeared to enjoy the outing, the owner offering to return to the laboratory for further testing should this be required. Studies are therefore underway to determine whether this result is reliable over time and across different dogs.

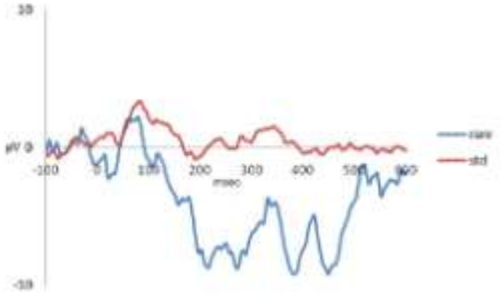

Fig. 2. The event-related potential averages in a healthy adult dog subject during an auditory oddball paradigm. The stimulus presentation is represented at 0.00 ms. After the rare, deviant tone (blue line), there is a large negative peak approximately 180 ms post-stimulus, which could be MMN. This peak is attenuated after the standard tone (red line), because the subject has detected a difference when exposed to the deviant tone. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

4. Future directions in dog cognition research

Our preliminary findings suggest that the MMN ERP, or its species-specific analogue, can be demonstrated in dogs. This represents the first electrophysiological measurement of cognitive processing in dogs, potentially providing a new way to understand the brain processes that underlie dog cognitive abilities. We cannot be sure that the dog MMN waveform is completely analogous to human MMN. Source localization is impossible with this method given the small number of electrodes used for recording the EEG. Notwithstanding these limitations, if an MMN-like waveform can be elicited during the same experimental situations as those used to elicit MMN in humans, this would support the case for a functional dog MMN analogue for use in stimulus discrimination studies. Future research that develops this method will give researchers a means of examining the neural underpinnings of both observable behaviours and their absence, which might provide insights into why dogs sometimes fail to respond to stimuli as expected.

In a discrimination task, the production of an MMN response to a stimulus likely means that the subject has recognised that there is something unique or special about that stimulus that makes it noticeable, even if only for a few hundred milliseconds, regardless of whether there is a behavioural response. These data may therefore provide important insights regarding cognitive processing in dogs, without sole reliance on behavioural responses to stimuli. Furthermore, in cases where there is an MMN response but not a behavioural one, researchers may be able to explore why the dog chose not to respond behaviourally, and try to improve the study such that the dog will provide a reliable behavioural response to all discriminated stimuli. This would be especially helpful in scent detection tasks, because dogs' sense of smell is so superior to that of a human (Miklosi, 2008), that researchers studying scenting abilities in dogs cannot use their own senses to help guide their understanding of dogs' abilities.

Developmental studies with MMN could also help researchers understand how cognitive processing changes both as the dog matures into adulthood and as the dog experiences cognitive decline associated with old age. The cognitive effects of canine cognitive dysfunction, similar to dementia in humans, could be studied using MMN research methods. Dogs are used as models of human Alzheimer's Disease research (Head et al., 1995), so this method could give researchers another tool for understanding the relationship between canine cognitive dysfunction and human Alzheimer's Disease. Breed differences in cognitive processing could also be examined. Because MMN is associated with language processing, studies examining dog comprehension of human language could also utilise this technique.

5. Conclusion

While behavioural response remains the current gold standard for measuring cognitive abilities and cognitive processing in dogs, technological advances in behavioural neuroscience have made available new tools that are unaffected by obedience training levels, prior experience or subject motivation. To this end, ERPs such as MMN, observable in EEG studies after the subject is exposed to a rare stimulus in the context of commonly occurring standard stimuli, offer a new method for gaining insights into canine cognitive abilities. Our demonstration of an MMN ERP in a dog, particularly using a minimally invasive induction protocol, is a first step in developing electrophysiological methods in dog cognition research.

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6.3 Discussion

The aim in this study was to develop a minimally-invasive technique for measuring MMN in a companion dog without the use of sedation or anaesthesia. This pilot study demonstrated that, using three subdermal needle electrodes, similar in size to acupuncture needles, it is possible to record late-occurring ERPs such as MMN. Since MMN is believed to be related to higher-order cognitive processes such as memory, this technique could be useful in dog cognition tasks in the future. It is particularly well-suited to discrimination tasks, and could be used in place of long training periods in visual discrimination of two-dimensional stimuli (Range et al. 2008). It also could be used in auditory and olfactory discrimination tasks. Scent discrimination would be especially beneficial in scent detection work, to help handlers understand whether dogs do not indicate a target scent because they lack motivation or because they do not discriminate the scent.

The current study measured MMN waveforms during an auditory stimulus paradigm. It should be theoretically possible to extend this sort of research to visual and olfactory paradigms; however, there would need to be more studies in all different modalities and with many different dog populations in order to determine that MMN in dogs is indeed a functional analogue of human MMN. If a relationship between human and dog MMN is established, then MMN could be used as a predictor of discrimination in cognitive processing across various domains and modalities. The first step in advancement of the technique, therefore, was to establish reliability of the waveform in a group of dogs using an auditory paradigm similar to the one used in the current study.

CHAPTER 7 – RELIABILITY OF THE EEG METHOD IN A GROUP OF DOGS

The technique developed and described in Chapter 6 holds promise for adding a complementary mechanism for studying cognitive processing in dogs. However, before its utility could be confirmed, it was necessary to determine the reliability of the method by testing a larger sample of dogs. This chapter includes the journal article, ‘Auditory stimulus discrimination recorded in dogs, as indicated by mismatch negativity (MMN)’, published in *Behavioural Processes* in 2012. The aim in this study was to test six dogs with this newly developed technique to confirm reliability in a group of dogs. A secondary aim, by way of validation, was to further test two dogs in a separate experiment to see if changing the probability of the unexpected stimulus from 10% to 50% affected the MMN waveform. MMN research in humans has shown that when the deviant stimulus has a high probability, the amplitude of the MMN waveform is usually lower (Naatanen et al. 2007). It was hypothesised that MMN would be attenuated in these two dogs for this experiment.

7.1 Declaration for thesis chapter 7

In the case of Chapter 7, the nature and extent of my contribution to the work was the following:

Nature of contribution	**Extent of contribution (%)**
Development of the method, data collection and subsequent analysis, writing the journal article	75%

The following co-authors contributed to the work. Co-authors who are students at Monash University must also indicate the extent of their contribution in percentage terms:

Name	**Nature of contribution**	**Extent of contribution (%) for student co-authors only**
Russell Conduit	Advising on development of method, technical EEG advice for data collection and analysis, suggestions for refinement of the manuscript	
Samia Toukhsati	Advising on development of method, technical EEG advice for data collection and analysis, suggestions for refinement of the manuscript	
Pauleen Bennett	Suggestions for refinement of the manuscript	

Candidate's Signature		**Date**

The undersigned hereby certify that:

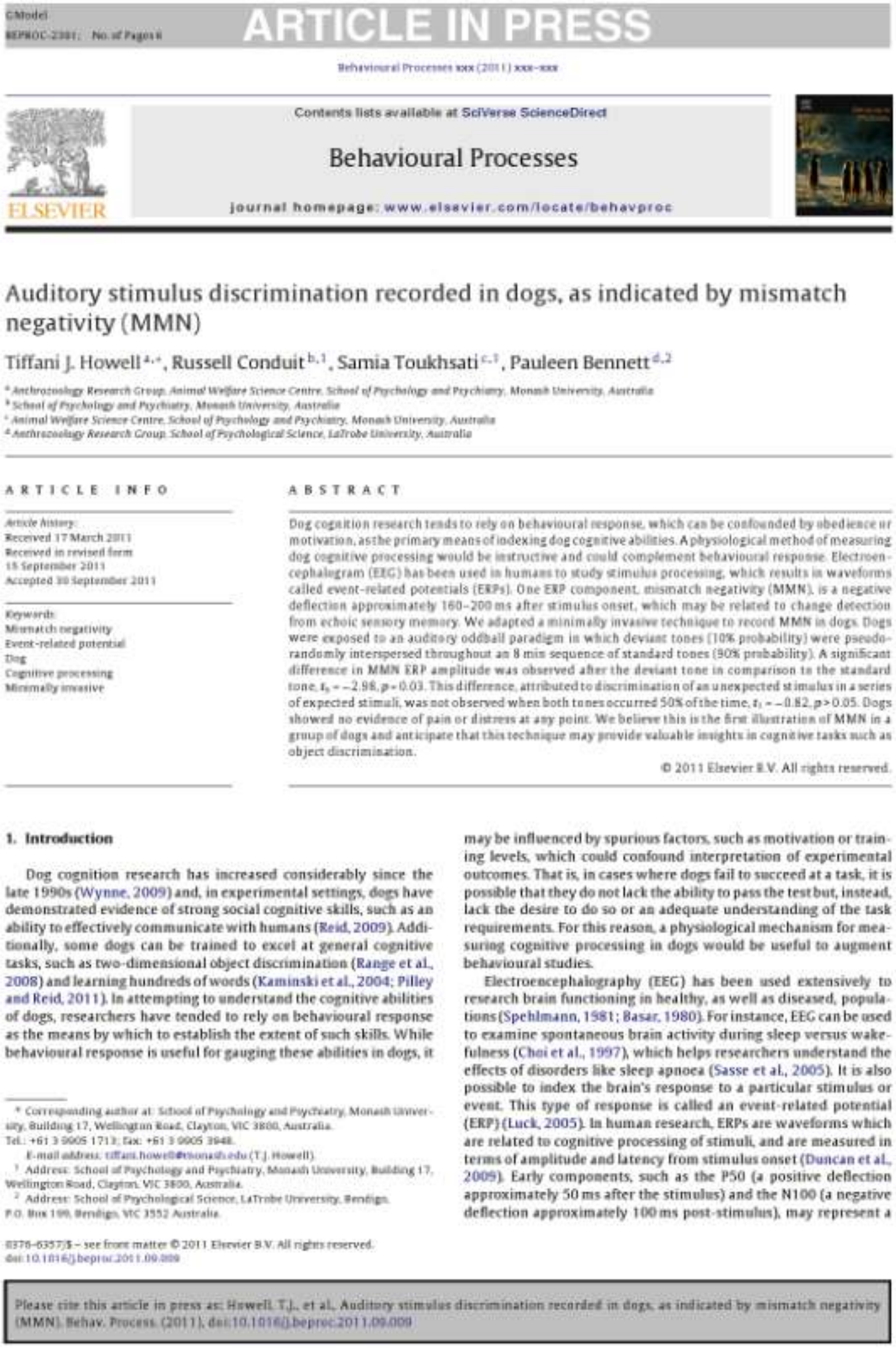
(25) the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.
(26) they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
(27) they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
(28) there are no other authors of the publication according to these criteria;
(29) potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and
(30) the original data are stored at the following location(s) and will be held for at least five years from the date indicated below:

Location(s)	**Monash University, Clayton Campus**

[Please note that the location(s) must be institutional in nature, and should be indicated here as a department, centre or institute, with specific campus identification where relevant.]

Signature 1		**Date**
Signature 2		**Date**
Signature 3		**Date**

7.2 Auditory stimulus discrimination recorded in dogs, as indicated by mismatch negativity (MMN)



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Auditory stimulus discrimination recorded in dogs, as indicated by mismatch negativity (MMN)

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ABSTRACT

Dog cognition research tends to rely on behavioural response, which can be confounded by obedience or motivation, as the primary means of indexing dog cognitive abilities. A physiological method of measuring dog cognitive processing would be instructive and could complement behavioural response. Electroencephalogram (EEG) has been used in humans to study stimulus processing, which results in waveforms called event-related potentials (ERPs). One ERP component, mismatch negativity (MMN), is a negative deflection approximately 160–200 ms after stimulus onset, which may be related to change detection from echoic sensory memory. We adapted a minimally invasive technique to record MMN in dogs. Dogs were exposed to an auditory oddball paradigm in which deviant tones (10% probability) were pseudo-randomly interspersed throughout an 8 min sequence of standard tones (90% probability). A significant difference in MMN ERP amplitude was observed after the deviant tone in comparison to the standard tone, $t_9 = -2.98$, $p = 0.03$. This difference, attributed to discrimination of an unexpected stimulus in a series of expected stimuli, was not observed when both tones occurred 50% of the time, $t_7 = -0.82$, $p > 0.05$. Dogs showed no evidence of pain or distress at any point. We believe this is the first illustration of MMN in a group of dogs and anticipate that this technique may provide valuable insights in cognitive tasks such as object discrimination.

1. Introduction

Dog cognition research has increased considerably since the late 1990s (Wynne, 2009) and, in experimental settings, dogs have demonstrated evidence of strong social cognitive skills, such as an ability to effectively communicate with humans (Reid, 2009). Additionally, some dogs can be trained to excel at general cognitive tasks, such as two-dimensional object discrimination (Range et al., 2008) and learning hundreds of words (Kaminski et al., 2004; Pilley and Reid, 2011). In attempting to understand the cognitive abilities of dogs, researchers have tended to rely on behavioural response as the means by which to establish the extent of such skills. While behavioural response is useful for gauging these abilities in dogs, it may be influenced by spurious factors, such as motivation or training levels, which could confound interpretation of experimental outcomes. That is, in cases where dogs fail to succeed at a task, it is possible that they do not lack the ability to pass the test but, instead, lack the desire to do so or an adequate understanding of the task requirements. For this reason, a physiological mechanism for measuring cognitive processing in dogs would be useful to augment behavioural studies.

Electroencephalography (EEG) has been used extensively to research brain functioning in healthy, as well as diseased, populations (Spehlmann, 1981; Basar, 1980). For instance, EEG can be used to examine spontaneous brain activity during sleep versus wakefulness (Choi et al., 1997), which helps researchers understand the effects of disorders like sleep apnoea (Sasse et al., 2005). It is also possible to index the brain's response to a particular stimulus or event. This type of response is called an event-related potential (ERP) (Luck, 2005). In human research, ERPs are waveforms which are related to cognitive processing of stimuli, and are measured in terms of amplitude and latency from stimulus onset (Duncan et al., 2009). Early components, such as the P50 (a positive deflection approximately 50 ms after the stimulus) and the N100 (a negative deflection approximately 100 ms post-stimulus), may represent a

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reflexive response to the stimulus properties, while later components are believed to be related to higher-order processing of the stimulus (Luck, 2005). One of these, called mismatch negativity (MMN), is a negative deflection with a peak in amplitude occurring between 160 and 220 ms after exposure to a novel stimulus (Luck, 2005). For instance, when a subject is listening to a series of identical tones, a tone of a different pitch or volume may elicit MMN (Naatanen et al., 2007). The probability of the differentiated tone affects the presence of MMN (Naatanen et al., 2007); if a differentiated tone occurs less than 20% of the time, MMN is more likely to be elicited than if it occurs 50% of the time. This ERP component is therefore believed to be related to discrimination of an unexpected stimulus in a series of expected stimuli. It may represent change detection from pre-attentive echoic sensory memory (Naatanen et al., 2005, 2007), which is the 'mental picture' that the subject holds of his/her environment (Grivas et al., 2004), reflecting an automatic process which detects the difference between an incoming stimulus and the sensory memory trace of preceding stimuli. In humans, MMN is affected by cognitive disorders such as dementia of the Alzheimer's type (Pekkonen, 2000) and schizophrenia (Catts et al., 1995), as well as alcohol use (Jääskeläinen et al., 1996). It has been implicated in language processing (Pulvermüller et al., 2008), so patients with aphasia have also been studied (Becker and Reinvang, 2007). Because it likely reflects higher-order cognitive processes, such as memory, but can be elicited without the focused attention of the subject, MMN could be a particularly useful instrument in dog cognition research.

Animal studies with ERPs have traditionally focused on understanding the mammalian brain, and have used animals as models of human capabilities when invasive techniques, unable to be used with human subjects, were employed (Buchwald, 1990). Such techniques are not suitable for modern canine cognition research, where the research subjects are generally much loved family pets (Kubinyi et al., 2009) and are not expected to be harmed in any way. The aim of this study was to adapt a minimally invasive ERP recording technique to determine whether MMN could be elicited in pet dogs.

2. Experiment 1

2.1. Methods

The Monash University School of Psychology and Psychiatry Animal Ethics Committee approved this research (AEC number 2010/01-S1). Pet dogs ($n = 10$), ranging from 18 months to 8 years of age, were recruited from metropolitan Melbourne, Australia. They were selected on the basis of owner reports that they were able to settle quickly in novel environments in the presence of their owner, as well as not being distressed while receiving injections during visits to the veterinarian. While there were no specific breed requirements, all dogs were medium to large and had mesocephalic head shapes, rather than long-nosed or short-nosed heads, in order to maintain size and shape standardisation. The participating breeds included: German Shepherd (2), German Shepherd cross, Labrador Retriever, Labrador Retriever x Poodle, Irish Wolfhound cross, Siberian Husky, Standard Poodle, Maremma, and Rottweiler.

All EEG recording took place in a 3 m × 3.3 m sound-attenuated laboratory at Monash University Clayton campus. Dogs were permitted to explore the laboratory for up to 1 h, until they appeared ready to settle on a pet bed placed on the floor. The owner sat on the floor with the dog, or in a chair next to the dog, to maximise relaxation in the dog. Three sterile single-use needle electrodes (Viasys Healthcare Disposable Rapid-Pull 12 mm with 2.5 m cable; San Diego, CA, USA) were inserted underneath the skin of the dog's head in order to obtain an EEG recording. No pharmaceutical sedation was required for needle insertion, and no dog showed any signs of pain or distress during insertion or removal of the needle electrodes, or at any other time throughout the trial.

The recording electrode was placed at Cz, 50% of the distance from the stop (bridge of the nose corresponding to the human nasion) to the external occipital protuberance (bump at the back of the head corresponding to the human inion), caudal to the stop. The ground electrode was placed at Oz, which is 10% of the distance from the stop to the external occipital protuberance, rostral to the external occipital protuberance. The reference electrode was placed on the midline of the neck, 100% of the distance from the stop to the external occipital protuberance, starting from Cz (see Fig. 1). Impedance levels were below 5 kΩ. All electrodes were secured with surgical tape.

A Compumedics Neuroscan Synamps^2 70-channel DC amplifier and Compumedics Neuroscan SCAN 4.5 software (Compumedics Limited, Abbotsford, VIC, Australia) were used to record the dogs' EEG (band pass: 0.1–100 Hz; sampling rate: 500 Hz). Stimuli were delivered using Compumedics Neuroscan Stim 2 software, using a paradigm adapted from Polich (1989). The stimuli were a series of two different tones presented via computer speakers; each tone constituted one trial. The standard tone was 500 Hz and occurred with 90% probability delivered at 48 ± 2 dB. The deviant tone was 1 kHz and occurred with 10% probability delivered at 56 ± 2 dB. The stimuli were presented at this volume to reduce the risk of arousing the dogs with louder stimuli, and are audible according to a dog audiogram (Van der Velden and Rijkse, 1976). All dogs oriented towards the stimuli during the trials, indicating that they could hear the stimuli. The inter-trial interval was 2 seconds, and sequences ranging between 7 and 14 trials were presented consecutively, with 4–5 s breaks between sequences. A total of eight sequences were presented within the first block, seven in the second block, and five in the final block. Three blocks in total were presented with 20 s breaks between blocks. Presentation of the stimuli was pseudo-randomised, with the deviant tone occurring no earlier than the 4th trial in each sequence. The total recording took approximately 8 min, and obtained 200 total trials (180 standards and 20 targets per dog). The maximum time per session was 90 min; however, most dogs finished in less than 1 h. This variation was due to the amount of time required for the dog to fully relax.

After the recording was complete, the needle electrodes were removed and disposed of in a sharps container. The dog received a treat and the owner received a small cash incentive for participation. Two dogs, the German Shepherd cross and the Rottweiler, did not settle in the room within 1 h and the session was terminated without inserting the needle electrodes or obtaining data. We were able to record the EEGs of eight dogs in total.

ERP data were analysed using Compumedics Neuroscan SCAN 4.5 software. EEG blocks with visibly consistent EKG (cardiac activity) or EMG (muscle activity) greater than 50 μV were excluded from analysis. Data from two dogs had to be wholly excluded for this reason. The total number of dogs included for analysis was six. Subsequently, individual data points with amplitude peaks higher than 100 μV were excluded from analysis. There was some variation in the amount of data remaining for each dog following artifact removal. For instance, out of 200 total data points collected per dog, 47 data points were included for one dog, while 185 were included for another. Across all six dogs, a total of 767 artifact free data points were extracted, including 690 for the standard tone and 77 for the deviant tone. Mean amplitudes of all the standard and deviant tone data were extracted and averaged separately for each dog using Compumedics Neuroscan SCAN 4.5 software. The results were then aggregated to produce grand average standard and deviant tone mean amplitudes for the same ($n = 6$). Values are expressed as means, standard errors, and p-values. Peak amplitude detection was established for three components of the deviant and standard

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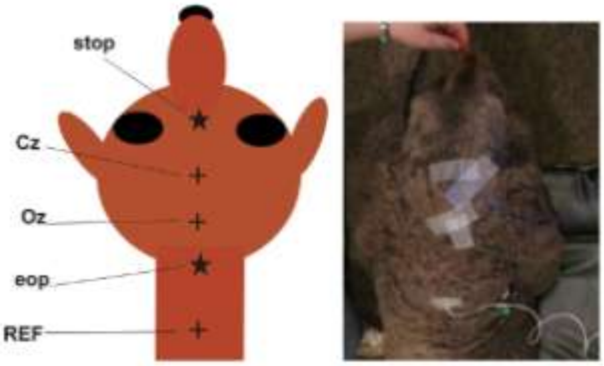

Fig. 1. Schematic and photo of the placement of needle electrodes on the dog's head. The stop is the bridge of the nose, and the external occipital protuberance (eop) is the bump at the back of the head. The recording electrode is placed at Cz, located 50% of the total stop–eop distance. The ground electrode, at Oz, is 10% of the total stop–eop distance, in front of eop. The reference electrode is placed the total stop–eop distance, on the neck starting from Cz. For instance, in a dog with a 15 cm stop–eop distance, Cz would be 7.5 cm rostral to eop, Oz would be 1.5 cm rostral to eop, and the reference would be on the neck, 15 cm caudal to Cz. All electrodes are on the midline.

ERP waveforms: P50 was the positive deflection of highest amplitude within the 30–70 ms post-stimulus time window (Winterer et al., 2001). N100 was the negative deflection of highest amplitude within the 80–120 ms time window (Winkler et al., 1993), and MMN was the negative deflection of highest amplitude within the 180–220 ms time window (Alain et al., 1998). Significant differences in peaks between the standard and deviant tones at these three time windows were determined using *t*-tests in Microsoft Excel 2007.

2.2. Results

The P50 mean amplitude peak detection of $X \pm SE = 2.32 \pm 3.41$ µV, $n = 6$ was recorded in the deviant tone at 64 ms. In the standard tone, the P50 mean amplitude peak of $X \pm SE = 2.85 \pm 3.85$ µV, $n = 6$ was at 54 ms. No significant difference was observed between the standard and deviant P50 amplitude peak, paired two-tailed *t*-test: $t_5 = 0.26$, $p > 0.05$.

The N100 amplitude peak detection of $X \pm SE = -6.84 \pm 8.06$ µV, $n = 6$ occurred at 120 ms in the deviant tone, and $X \pm SE = -2.74 \pm 2.89$ µV, $n = 6$ at 80 ms in the standard tone. No significant difference was observed between the standard and deviant N100 amplitude peak, paired two-tailed *t*-test: $t_5 = -1.25$, $p > 0.05$.

At the MMN amplitude peak, however, the difference was significant. The amplitude peak detection in both the standard and deviant tones was 180 ms; the deviant tone had an amplitude of $X \pm SE = -10.18 \pm 7.15$ µV, $n = 6$, and the standard tone had an amplitude of $X \pm SE = 0.31 \pm 2.29$ µV, $n = 6$, paired two-tailed *t*-test: $t_5 = -2.98$, $p = 0.03$. Grand average waveforms and standard error for the deviant tones and standard tones are presented in Fig. 2.

3. Experiment 2

3.1. Methods

German Shepherd dogs ($n = 2$) that had participated in Experiment 1 were brought in two weeks after their initial session, for an additional EEG recording. To indirectly validate the findings from Experiment 1, we used identical methods and analyses to those used previously, except that the probability of the standard and deviant tone was changed to 50% each; we expected the difference between standard and target tone ERPs observed in Experiment 1 to be attenuated. A total of 360 data points were analysed in this preliminary data set, including 163 standard tones and 197 deviant tones.

3.2. Results

The P50 amplitude peak detection was recorded as $X \pm SE = 2.12 \pm 0.14$ µV, $n = 2$ at 56 ms in the deviant tone, and $X \pm SE = 1.45 \pm 0.32$ µV, $n = 2$ at 58 ms in the standard tone. No significant difference was observed between the standard and deviant P50 amplitude peak, paired two-tailed *t*-test: $t_1 = 3.83$, $p > 0.05$.

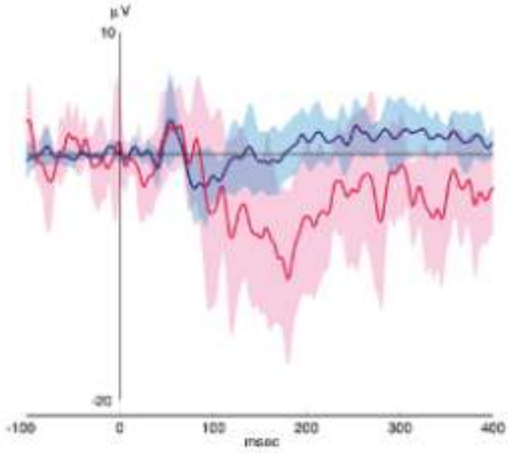

Fig. 2. Grand average event-related potentials for standard and deviant tones ± standard error. The solid blue line is the standard tone, and the solid red line is the deviant tone. The blue shading is the standard error for the standard tone, and the pink shading is the standard error for the standard tone (overlap is shown in purple). There is a significant difference ($p < .05$) between the amplitude of the waveforms at approximately 180 ms, which may be evidence of MMN. (For interpretation of the references to color in figure legend, the reader is referred to the web version of the article.)

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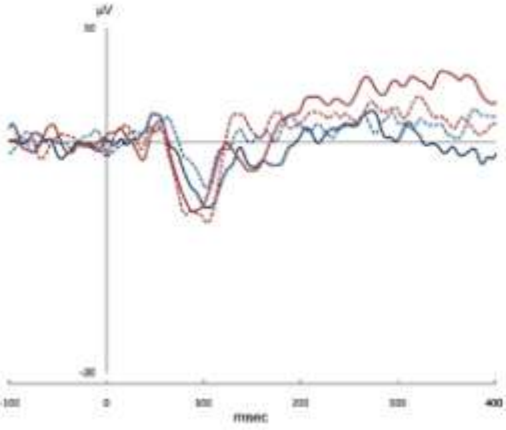

Fig. 3. Average waveforms for the standard and deviant tones per dog, when both occurred 50% of the time. The solid blue line is the deviant tone, and the dashed blue line is the standard tone, for the first dog. The solid red line is the deviant tone, and the dashed red line is the standard tone, for the second dog. There was no significant difference ($p > .05$) in the amplitude of the waveforms during any of the latency periods analysed (P50: 30–70 ms; N100: 80–120 ms; MMN: 180–220 ms). (For interpretation of the references to color in figure legend, the reader is referred to the web version of the article.)

The N100 amplitude peak was $X + SE = -5.45 + 0.01\ \mu V$, $n = 2$ at 100 ms in the deviant tone and $X + SE = -5.41 + 1.52\ \mu V$, $n = 2$ at 104 ms in the standard tone. No significant difference was observed between the standard and deviant N100 amplitude peak, paired two-tailed t-test: $t_1 = -0.03$, $p > 0.05$.

Finally, the MMN amplitude peak was $X + SE = 0.09 + 1.9\ \mu V$, $n = 2$ at 180 ms in the deviant tone and $X + SE = 1.55 + 0.11\ \mu V$, $n = 2$ at 198 ms in the standard tone. No significant difference was observed between the standard and deviant MMN amplitude peak, paired two-tailed t-test: $t_1 = -0.82$, $p > 0.05$. Results are illustrated in Fig. 3.

4. Discussion

To the best of our knowledge, this research represents the first illustration of MMN in a group of dogs. The negative peak of the ERP at 180 ms after the infrequent deviant stimulus, but not after the standard stimulus, is consistent with typical recordings of human MMN in passive auditory paradigms (Naatanen et al., 2007). This component, as in humans, suggests that the subjects detected a difference between the two tones. Also consistent with human recordings, there was no statistically significant difference in the standard versus target P50 or N100 waveforms, which suggests that the physical properties of the stimuli were not responsible for the differences observed in the MMN component; rather, the difference observed in the latter appears to be related to stimulus probability. Further indirect evidence in support of this interpretation was shown when the MMN was completely attenuated in two animals following exposure to a sequence where the probability of the deviant tone was increased from 10% to 50%. To this end, no difference in amplitude, at any latency window measured, was observed between the waveforms occurring after exposure to a sequence that comprised 50% standard and 50% deviant tones (i.e. equal probability of tone occurrence). This corresponds with MMN research in humans, which shows an inverse correlation between MMN amplitude and stimulus probability.

These results collectively suggest that the negative component of the ERP at approximately 180 ms may be attributed to cognitive processing of stimulus change (i.e. MMN). This is an important finding although further research is needed to understand whether these results are reliable in a larger sample of dogs and in samples including different breeds, sizes and head shapes. Data from six dogs were analysed in this study, which is consistent with the small samples in some other MMN studies in animals. For instance, Pincze et al. (2001) use six cats, and their 2002 study uses four cats. Ueno et al. (2008) use one chimpanzee, and Javitt et al. (1996) use five monkeys. It is difficult to observe significant differences in small groups; if anything, this should make the findings more conservative due to the corresponding large effect size necessary to product such a difference. In our case Cohen's d is 1.8, indicating a large effect.

Also, it will be important to determine if the findings are related to age, since healthy aging affects MMN in humans (Ruzzoli et al., 2011). Although some of the dogs in our sample could be considered to be 'aged' we did not specifically explore this issue; it will be of interest to determine in future research whether our findings generalise to younger dogs. Different tones and stimulus intervals will also need to be evaluated to determine the reliability of the result we obtained.

The significance of our finding lies in the fact that previous research examining MMN with animals has often been invasive, involving the use of electrodes implanted into the skull under anaesthesia (Roger et al., 2009; Farley et al., 2010; Javitt et al., 1996; Pincze et al., 2001, 2002; Ruusuvirta et al., 1998, 2010). To our knowledge, only one recent study recorded MMN in a chimpanzee using non-invasive scalp electrodes (Ueno et al., 2008). This technique, similar to that used in humans, is not suitable for use in dogs. Human EEG research employs scalp electrodes; electrophysiological activity is able to be recorded via the scalp because of the thin skin on the human head. Dog scalps are, however, thicker than human scalps (Young et al., 2002; Laurent et al., 2007). To enable an accurate EEG recording through thick skin, the dog's head would need to be shaved to reduce overall impedance between the brain and the scalp, which could distress the dog. To address these issues, a minimally invasive technique was developed for use in veterinary research. It has been employed in epilepsy (Pellegrino and Sica, 2004) and hearing loss (Ahlstrom et al., 2005) research with dogs. This method, which we adapted for use in the current study, uses subdermal needle electrodes that are inserted just under the scalp to measure electrical activity in the brain. This technique reduces impedance without the need for more invasive EEG procedures, such as those that require electrodes implanted into the skull, which would not be appropriate for community dog populations.

A second innovation we employed was to reduce the number of electrodes required. In humans, the International 10–20 system is commonly used to record EEG (American Electroencephalographic Society, 1986). In this system, up to 256 electrodes are placed all over the head, with references often occurring at the earlobes or mastoid. We opted to use just three needle electrodes, the minimum number required to obtain an EEG recording in our system and in brainstem auditory evoked potential (BAER) studies examining deafness in dogs (Holliday et al., 1992; Webb, 2009). Because electrodes in the central midline area show high response levels to MMN paradigms (Luck, 2005), the recording electrode was placed at Cz, halfway between the stop (which corresponds to the nasion) and external occipital protuberance (which corresponds to the inion) according to the International 10–20 system. The ground electrode was placed at Oz, 10% of the distance from the stop to the external occipital protuberance, toward the external occipital protuberance. A P300 study with adolescents also used Oz as the location for the ground electrode (Jocoy et al., 1998).

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The reference electrode was placed on the midline of the neck, the distance from the stop to the external occipital protuberance, starting at Cz (see Fig. 1). We initially attempted to use a mastoid reference and ground; however, unlike humans, dogs have muscles throughout the top of the head (Smith, 1999), which caused too much muscular artifact and would not permit an accurate EEG recording. Therefore, we placed all electrodes on the midline, because the muscle structure is less pronounced than it is on the side of the head and mastoid. While this electrode placement is not standard for the reference in human research, there is some argument in favour of using neck references (Pethe et al., 1998).

Further research exploring MMN in dogs is needed to determine the extent to which this procedure will be useful for dog cognition studies. Source localization is not possible with our method of using only one active electrode; however, if MMN is consistently recorded using this method in contexts that elicit human MMN, it would make the case for a functional MMN analogue. More studies are needed to understand the extent to which the dog MMN reported here is truly analogous to human MMN. Discrimination tasks may be very well-suited to MMN paradigms, as MMN provides a physiological measure of discrimination without any behavioural response required by the dog. For example, MMN in humans is higher in amplitude when the participant is exposed to a sound that is present in their native language versus a sound that is not present in the native language (Peltola et al., 2003). MMN has also been elicited in humans when a grammatical error is detected in the subject's native language (Pulvermüller et al., 2008). Research involving electrophysiological responses to elements of language could be explored in dogs to evaluate how they process relevant stimuli. For example, one possibility would be to examine the ERP response of dogs when hearing their name spoken by their owner or a stranger. Dogs may behaviourally show a preference for responding to their owner, but whether that is based on the owner's tone of voice, or the words being spoken by the owner, is not known. From a veterinary behaviour point of view, the effects of canine cognitive dysfunction on cognitive processing of stimuli could also be studied, similar to dementia of the Alzheimer's type research in humans.

Although MMN is commonly explored in the auditory modality (Naatanen et al., 2005, 2007), it can also be elicited in visual (Pazo-Alvarez et al., 2003) and olfactory (Pause et al., 1996) paradigms. Studies of this kind would be useful if further research demonstrates a reliable MMN response in dogs to auditory stimuli as presented in this study. A better understanding of olfactory abilities in dogs may be particularly beneficial, because these abilities are heavily relied upon by military, police, and government agencies (Browne et al., 2006), yet the dog's sense of smell is not well-understood (Walker et al., 2006). That is, because the dog's scenting abilities are so far beyond those of humans, trainers are unable to rely on their own sense of smell to determine whether a dog has detected a target scent. A mechanism that enables us to explore the extent of scent discrimination abilities in dogs would allow scent detection dog handlers to understand whether lack of a behavioural response is indeed based on lack of discrimination, or on other factors such as motivation levels. In visual paradigms, two-dimensional discrimination could be examined without the extensive training required to obtain a behavioural response (Range et al., 2008). The dog would only be required to sit calmly while being shown the pictures; no operant conditioning would be needed.

Overall, then, we have shown that it is possible to elicit and record MMN in dogs, in response to a deviant auditory tone, using an adaptation of a minimally invasive method previously used in veterinary research. We anticipate that this methodology will provide dog cognition researchers with an additional mechanism for assessing dogs' cognitive abilities, enhancing behavioural studies and contributing to a rapid increase in knowledge about the cognitive capabilities of our closest animal companion.

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7.3 Discussion

The aim in this study was to determine whether MMN could be reliably elicited in a group of dogs using the minimally-invasive technique developed in Chapter 6. The results suggest that MMN can be reliably observed using this method. This is helpful for dog cognition researchers, because it could provide another measure of cognitive processing to complement behavioural and survey research. This technique could potentially be adapted for use in other auditory discrimination paradigms, including whether dogs differentiate their owner’s voice from a stranger’s voice and other language processing studies. It could also be used in visual and olfactory paradigms to explore discrimination within those modalities. The potential could range from the theoretical, such as how dogs discriminate two-dimensional objects as in Range et al. (2008), to the practical, such as whether scent detection dogs which fail to behaviourally indicate the location of a target do not discriminate the scent or simply lack motivation.

A potential limitation of this method is that there is no possibility for source localisation to determine in which part of the brain a particular stimulus response has originated. This is possible in human research with electrode caps because there are many places from which the brain activity is being recorded, and the frequency of the waveform can then be compared across several electrode sites to determine the likely source of the wave (Luck 2005). The method used in the current study, however, utilises only the minimum number of electrodes required to obtain any recording at all. There is only one recording electrode, along with a reference electrode and a ground electrode, so source localisation is not possible. Perhaps using more recording electrodes would assist in source localisation, which could be useful for research groups who would like to explore which parts of the brain are activated during particular tasks. Source localisation could also help to make the case that dog MMN is truly analogous to human MMN, as MMN source localisation in humans has been studied extensively (Naatanen et al. 2005; Naatanen et al. 2007). However, it is difficult to justify inserting more than a minimum number of electrodes into fully conscious animals, and the technique tested in this study can still be used in cognition studies which do not require an intricate understanding of where in the brain a particular response originates.

Chapters 6 and 7 together constitute a new method for measuring cognitive processing in companion dogs. Although behavioural research has dominated the dog cognition landscape for the past 15 years, there are recent moves to utilise new technologies to measure how dogs process information. For instance, some research makes use of eye-tracking software which measures dogs' visual focus at any given moment (Williams et al. 2011). Also, veterinary research has determined that the shape of a dog's face correlates to differences in the shape of the brain, as evidenced by MRI imaging (Roberts et al. 2010). Additionally, dog vocalisations were sampled and analysed in order to establish that vocalisations are context-dependent (Molnar et al. 2008; Molnar et al. 2006; Pongracz et al. 2006; Pongracz et al. 2005b). The use of new technologies to understand dog behaviour and cognition is relatively recent, but it appears to be increasing rapidly. The studies reported in Chapters 6 and 7 provide new ways to measure brain activity in awake dogs without the need for extensive training, therefore opening up a new branch of dog cognition research that still makes use of companion dogs with a typical developmental experience and lifestyle.

While there is still need for more research to explore under what conditions MMN presents in dogs, the findings presented in this study offer a new method by which to measure cognitive processing in dogs without reliance on behaviour.

CHAPTER 8 – GENERAL DISCUSSION AND FUTURE DIRECTIONS

Great apes were long believed to possess the most complex cognitive skill set of any non-human animal (Humphrey 1976). However, in the late 1990s, dogs demonstrated that they were capable of succeeding where great apes had failed: they could accurately interpret human communicative gestures (Hare & Tomasello 1999; Miklosi et al. 1998). Since those two studies were reported, the field of dog cognition has grown considerably (Wynne 2009), particularly regarding social cognition research which suggests that dogs are very good at communicating with, and learning from, humans (Agnetta et al. 2000; Gacsi et al. 2004; Kubinyi et al. 2003; Miklosi et al. 2003; Pongracz et al. 2008; Topal et al. 2006; Wobber & Hare 2009).

Along with social cognition research, some studies have examined other, non-social, cognitive abilities to try to understand how dogs perceive the world around them (Osthaus et al. 2005; Pattison et al. 2010; Range et al. 2008; Range et al. 2011; Topal et al. 1997). However, these results have been less conclusive than the social cognition studies. For instance, one study suggested that dogs do not possess means-end awareness (Osthaus et al. 2005), using a string-pulling paradigm that has been well-established in other species. However, a more recent study, using a paradigm similar to research with cotton-top tamarins, suggested that they may possess such an awareness (Range et al. 2011). It is possible that the different research design was the cause of these disparate results, which highlights the need to confirm the validity of a particular paradigm for each species tested before drawing conclusions about whether or not an animal possesses a given ability. Paradigms which are suitable for great apes and other primates may not be suitable for dogs, and vice versa.

Behavioural research such as that described above has been extremely informative. However, the need to confirm validity of a behavioural paradigm in different species illustrates the need to incorporate other measures beyond behaviour into dog cognition research. For instance, surveys that examine people's perceptions of dog cognitive abilities provide researchers with insights into dog behaviour that is not readily observable in experimental settings, as well as possible avenues for future research based on anecdotal information received by owners (Hecht et al. 2012; Horowitz 2009). Likewise, neurological research, such as electroencephalography (EEG), provides a complementary tool for measuring the neurological underpinnings of observed behaviours, permitting researchers to explore a deeper level of cognitive processing in dogs. Complementary methods, such as these, offer new avenues for understanding how dogs perceive the world.

The aim in this thesis was to advance current understanding of how dogs process information through the use of various techniques which each offer a unique perspective on dog cognition. Chapter 3 reported the results of a survey-based study which asked lay community members about their perceptions of dog cognitive abilities. Chapters 4 and 5 described two behavioural research studies undertaken to explore how dogs respond to mirrors and whether they can use a mirror to solve a problem. Finally, Chapters 6 and 7 reported the results of a new minimally-invasive EEG method developed to record brain activity related to stimulus discrimination. This comprehensive body of work is the first to consider these methods collectively. There are advantages and disadvantages to each method, as discussed in detail below.

8.1 Survey-based research

The first of the three methods utilised in this thesis, survey research, involved the development of a questionnaire to explore people's perceptions of dog cognitive skills. This was the first survey to comprehensively explore owner and non-owner perceptions of a variety of cognitive domains and how they might be associated with dog ownership and/or perceived emotional closeness to a pet dog. Other surveys have asked about dog intelligence in different cognitive domains (Maust-Mohl et al. 2012; Rasmussen & Rajecki 1995; Rasmussen et al. 1993), and still others have explored whether general perceptions of intelligence correlated with perceived emotional closeness (Serpell 1996). This survey was the first to combine the two.

The results did not always correspond to the current scientific understanding of dog cognition. People generally appeared to believe that dogs are capable of complex social cognitive skills, including some established in recent scientific settings, such as interpretation of human communicative gestures (Miklosi et al. 1998; Miklosi & Soproni 2006) and social learning (Pongracz et al. 2003a; Pongracz et al. 2003b, 2004), and others which have not been established scientifically, such as empathy and deception. Respondents were less likely to agree that dogs possess an innate ability to solve logic problems or exhibit mirror self-recognition (MSR), but they tended to agree that dogs can learn these skills. In fact, ratings of innate abilities in these two domains were *inversely* correlated with self-reported knowledge of dogs. Logic-based scientific experiments such as means-end awareness have had mixed results (Osthaus et al. 2005; Range et al. 2011), and there is no research examining whether dogs demonstrate MSR.

As expected, perceived emotional closeness correlated with almost all cognition variables, and predicted several. These results correspond to other research that has demonstrated a relationship between attachment and ratings of intelligence (Serpell 1996). However, there were two exceptions to the general rule of correlation: the statements “dogs learn mostly through trial and error”, and “The quickest way to house train a dog is to punish it whenever you find a 'mishap' in the house”. This illustrates the benefit of including a variety of different domains and specific cognitive statements in survey research rather than general intelligence levels, and comparing individual items to levels of perceived emotional closeness. The result is a more nuanced understanding of the relationship between beliefs about dog cognition and the dog-owner relationship.

While survey research is informative, it must be interpreted carefully. First, it does not replace behavioural research in determining cognitive abilities in dogs, because people's beliefs are not necessarily based on rigorous experimental data. They are likely formed by their own experiences and mediated by their values (Waters 2000). Second, survey research related to dogs tends to be biased toward females (e.g. Bennett & Rohlf 2007; King et al. 2009; Serpell 1996). As such, there is a strong argument that the survey respondents are not representative of the population at large. Dog owners were more likely than non-owners to believe that dogs exceed humans in general intelligence, which was unexpected and demonstrates that there is probably a sampling bias inherent in the survey.

Despite these limitations, survey research is useful because it offers researchers insights into the discrepancies between scientifically established abilities and people's perceptions of dog abilities. For instance, veterinary behaviourists can teach owners what scientific evidence exists for dog cognitive abilities and align these with owner expectations which could improve the dog-owner relationship. Furthermore, survey research can provide insights into elements of dog behaviour that should be experimentally researched, as in 'guilty look' research that was based on owner anecdotes that dogs feel guilty when they misbehave (Hecht et al. 2012; Horowitz 2009); the ambiguity among the survey respondents about mirror use in dogs provided an impetus to explore this in the behavioural studies reported in Chapters 4 and 5 of this thesis.

8.2 Behavioural research

While behavioural studies have dominated dog cognition research, few studies have examined logic and problem-solving behaviour, with most focusing on social cognition instead. Chapters 4 and 5 helped close the research gap in dog problem-solving abilities by examining whether they could make use of a mirror to solve a problem. In Chapter 4, most of the dogs did not indicate an awareness that their owner, holding their favourite toy, was standing behind them in an adjoining room, which was visible in a mirror. However, in Chapter 5, when treats were hidden behind a barrier but visible via a mirror, dogs were more likely to find the treat compared to dogs without access to the reflection in the mirror. These findings suggest that under certain conditions, dogs do appear able to use the mirror to find hidden items of interest. While these results are promising, successful dogs with access to the mirror did not complete the task faster than successful dogs without access to the mirror. Therefore, more research is needed to validate these claims.

From a phylogenetic standpoint, dogs should be able to use a mirror as a tool, since this ability has been shown in many different species of animals, including pigeons (Epstein et al. 1981), pigs (Broom et al. 2009), and Japanese monkeys (Itakura 1987). Moreover, there is no obvious reason why a dog should not possess a cognitive ability that has been clearly demonstrated in pigs. That the Chapter 4 study produced very different results from the Chapter 5 study highlights the importance of research design in the success or failure of animals in cognition research.

There are many variables which could have produced the different results in Chapters 4 and 5, including length of exposure to the mirror, motivation to find the target item, or even the presence or absence of the target item in the same room as the dog and mirror. It is impossible to determine which of these may have caused the conflicting results, and indeed, it may be that several or all of these design issues contributed equally. However, the period of exposure may have played a crucial role because many previous mirror studies involved extensive exposure to mirrors before beginning testing (Broom et al. 2009; Eglash & Snowdon 1983; Gallup 1970). Chapter 4 did not include this extensive exposure because it was believed that many dogs would have already had much access to mirrors in human homes. However, perhaps this belief is incorrect, or perhaps dogs do not easily generalise knowledge gained from mirrors at home to mirrors in novel environments. Future research should examine under what conditions dogs are able to use mirrors as a problem-solving tool, to try to understand whether motivation, exposure length, or the presence of the target item in the same room has a greater effect on these results.

It is also possible that the dogs in Chapter 5 were successful not due to the research design, but due to some spurious variable. For instance, the blanket was always in the room with the dogs, but placing it over the mirror for the control group may have been so unexpected that the control group dogs lost focus of the task and forgot that there was a treat to find. It is also possible that Clever Hans effects caused the dogs to find the hidden treat, if owners in the experimental group were more encouraging than owners in the control group. Predictions were not told to the owners until after the session, but owners may have realised what the predictions were even without being told. Ideally, future research of this kind should be designed such that the owner and experimenter are blind to the experimental group, or perhaps their faces should be covered so that they cannot see how the dog is behaving or provide unintentional cues to the dog about expected behaviours.

Behavioural research is the primary method of exploring dog cognitive abilities. It is instructive and can be done relatively cheaply, depending on the experimental setup. However, there are some limitations that should be considered when interpreting behavioural research. For instance, the owned pet dogs which participate in behavioural research, as anecdotally reported during discussions with the owners in the mirror studies of Chapters 4 and 5, are generally owned by people who are very interested in dog behaviour and cognition. They often participate in obedience training, agility, schutzhund, etc with their dogs. Therefore, these dogs may receive more stimulation and socialisation than many other dogs in the community, so their response to these behavioural tasks may not be easily generalisable to the pet dog community at large. Ideally, studies would include dogs with different life experiences and socialisation levels; however, people who are not deeply interested in dog behaviour may be less likely to volunteer to participate in the research. Nonetheless, pet dogs are a good population for cognition studies because they are raised in human homes (Kubinyi et al. 2009) and therefore are likely to receive more socialisation to humans than many laboratory dogs, racing greyhounds, or working dogs.

Behavioural research requires that dogs respond to a particular set of stimuli in a particular way, or in one of several possible ways. Unfortunately for researchers, dogs do not always behave in these expected ways, and it can be impossible to understand whether the dog lacks motivation to complete the task, or whether the dog is not focused on the task, or whether the dog is motivated and focused, but lacks the cognitive ability needed to complete the task. Therefore, it is important to consider these limitations when interpreting dog behaviour in experimental settings, especially with a view to demonstrating an underlying cognitive ability (or lack thereof).

Notwithstanding the limitations highlighted above, behavioural experimentation will continue to play an important role in dog cognition research. The research to date has been invaluable in helping researchers understand what dogs are capable of, and has made a strong case that dogs are particularly effective at communicating with humans. They also may be good problem-solvers in certain situations, as illustrated in Chapters 4 and 5 of this thesis, but more research will be needed to determine the extent of those capabilities.

8.3 Neurophysiological research

There has been some recent use of technologies which permit new ways of exploring dog cognition, without reliance on behaviour. For instance, eye-tracking software was developed to allow a precise measure of where a dog’s attentional focus lay at a given moment (Williams et al. 2011). Dog vocalisations have been computed into algorithms for use in determining the contextual basis of different types of barks (Farago et al. 2010; Maros et al. 2008; Molnar et al. 2008), and magnetic resonance imaging (MRI) studies of dog brains have demonstrated that the shape of the brain (Roberts et al. 2010) and the visual field (McGreevy et al. 2004) are related to the dog’s head shape.

Another potential mechanism to help researchers interpret unexpected behavioural data is to incorporate neurophysiological measures in cognitive assessment testing in dogs. Chapter 6 showcased the development of a method of using minimally-invasive electroencephalography (EEG) to measure mismatch negativity (MMN) in dogs. MMN is a component of an event-related potential (ERP), which is an electrophysiological response to a stimulus. MMN is elicited after exposure to an unexpected stimulus in a series of expected stimuli, and it is believed to be related to memory. After developing this method, its reliability was confirmed in a group of dogs, as reported in Chapter 7. These studies confirmed that MMN can be reliably measured in dogs using this minimally-invasive technique, which may be especially useful in discrimination tasks, in which dogs are expected to differentiate between two or more stimuli.

Visual discrimination tasks could use MMN to explore how dogs discriminate different types of photos. One behavioural study has already confirmed that dogs can differentiate between photos of landscapes and photos of other dogs (Range et al. 2008), but MMN research of a similar kind would reduce the need for the long training periods required by the dogs in the Range et al. (2008) study, permitting larger samples.

Olfactory research could use MMN to determine the strength of a dog's sense of smell. It could also be used with detection dogs in training, to ascertain when a dog's behavioural indication does not correspond with a neural detection of a target odour. That is, if a dog did not behaviourally indicate that it has discriminated a target stimulus, the presence of an MMN waveform would suggest that the dog lacked motivation or training to indicate the stimulus, while no MMN waveform would imply that the dog did not discriminate the scent at all. This could assist handlers in understanding whether the dogs need more training or other motivators to improve responses, or whether the task is beyond the cognitive capabilities of the animals in question.

An example of auditory research that could incorporate MMN would be to determine how dogs process language information. Since MMN research has been used to study language processing in humans (Peltola et al. 2003; Pulvermüller et al. 2008), similar research could be used in dogs to explore whether they can discriminate their name as spoken by their owner versus a stranger. Since dogs have evolved alongside humans (Coppinger & Coppinger 2002), it could mean that they may be attuned to human language in a way that other animals are not. It could also have a practical application among working dogs, which work relatively independently of their handler, to determine whether the handler should be the only person issuing commands to the dog, or whether others could also participate in situations in which the handler is far away (Coutellier 2006).

In theory, this technique could be adapted for other animal species, so comparative studies could be done to explore whether dogs process visual, olfactory, or auditory stimuli differently from other species. This would allow researchers an opportunity to explore the effect of possible effect of domestication on cognitive processing. This has been attempted in behavioural research with conflicting results, with some suggesting that domestication has improved dogs' ability to communicate with humans (Hare et al. 2002; Hare et al. 2010; Hare & Tomasello 2005), and others suggesting that domestication alone cannot account for this ability (Miklosi & Topal 2005; Udell et al. 2008; Wynne et al. 2008). Another tool for measuring cognitive processing in different animal species, including other domesticated animals, and dogs' wild progenitor, the wolf, would give researchers further insights into the role domestication may have played in providing dogs with their skill set.

There are some practical challenges in the use of this EEG technique. Compared to survey and behavioural research, EEG research is relatively expensive; however, for veterinary and psychology departments which have access to an EEG system, this sort of research could be useful to complement behavioural research. Perhaps more importantly, because the EEG requires that subjects remain relatively still, it would be difficult to incorporate this method directly into a behavioural study which required much movement by the dogs. However, it would be possible to use MMN studies in conjunction with behavioural studies to determine the underlying processes behind learning in experimental settings or training environments. For example, in scent detection work, MMN measures of target scent detection before training would allow researchers to determine whether individual dogs have discriminated a target scent; those that did not discriminate it (if any) would not need to go through the training and detection programs could focus their resources on dogs which could discriminate the scent from the beginning.

An auditory study of owner versus stranger voices could be also used in conjunction with behavioural research. The behavioural research could include the owner and a stranger both speaking directly to the dog, while the MMN research could use the playback of owner and stranger voice recordings delivered by the EEG software which makes note of the precise moment of the delivery of the stimulus.

A visual photographic discrimination study (Range et al. 2008) could potentially be completed at the same time as an MMN recording, provided the dogs were not required to move around much. While a behavioural indication of photo discrimination would affect the EEG recording, as muscle movement decreases the possibility to record brain activity, MMN is typically observed within the first 250 msec of stimulus onset, and any behavioural response would likely come much later, after the MMN response would have already been recorded.

8.4 Conclusion

This thesis contributed to the current understanding of dog cognitive processing in three ways. First, a survey determined community perceptions of dog cognitive abilities and established correlations between those beliefs and perceived emotional closeness to one’s dog. Second, two behavioural studies explored how dogs use mirrors as a problem-solving tool, which advanced the knowledge of dogs’ use of logic and problem-solving, an under-researched area of dog cognition relative to social cognitive studies. Third, a minimally-invasive method for recording EEG waveforms in dogs was developed, which permits use of companion dogs living in human homes and allows researchers to record brain activity related to higher-order cognitive processes including memory.

Future research using surveys to examine what people think about dog cognitive abilities should aim to use a large cross-section of the population, including men and people who neither own dogs nor are interested in dogs. This would reduce the possibility of sampling bias and give a more accurate idea of what people in general believe dogs can do.

Future behavioural studies should continue to explore logic and problem-solving skills in dogs, in addition to the ubiquitous social cognitive research being undertaken. The dog's social cognitive skills are impressive, but they may also be good problem-solvers when given the opportunity. It is also important to confirm validity of behavioural paradigms in different species before making conclusions about their cognitive skills based on the results of those studies. Spurious variables, such as the Clever Hans effect, should always be a consideration in any research design.

Neurophysiological research in dog cognition studies is in its infancy, but it is quickly growing and offers further insights into how dogs process information about the world around them. MMN research should be used alongside behavioural research to study the neural underpinnings of behaviour. More studies should be completed to help establish whether MMN in dogs is truly analogous (or at least a functional analogue) to human MMN, which has been researched extensively.

To conclude, there are different ways to examine cognitive processing in dogs. Although behavioural response has been the primary method for understanding how dogs perceive and interpret the world around them, this thesis has demonstrated the utility of combining this approach with survey and neurophysiological methods to develop a deeper, multi-faceted knowledge of dog behaviour. Each technique has its advantages and disadvantages, but taken together, they provide rich insights into dog cognition. This understanding is important not just for academic and theoretical reasons, but also for the practical benefits of improving communication between dog and owner.

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APPENDIX A: Perceptions of Dog Intelligence and Cognitive Skills (PoDIaCS) survey

Section A

Background Information About You

1. Gender
☐Male
☐Female

2. What year were you born?
(*write*) __________

When responding to the following questions, if you currently spend time living in two different places because of work or study demands, please answer with respect to the location you would describe as your 'real' home.

3. Which of the following people usually live with you in your home? (Tick more than one box if appropriate)
☐Partner (spouse or defacto)
☐Other adults over 65 years
☐Other adults between 18 to 65 years
☐Children between 12-18 years
☐Children under 12
☐Other *(write*) ____________________

4. Which of the following best describes the area in which your home is located?
☐Urban (Inner city)
☐Suburban (over 10km from city)
☐Regional city (population 50,000 or more)
☐Country town/Island (population less than 50,000)
☐Rural

5. What kind of dwelling is your home?
☐House
☐Semi-detached, terrace house, townhouse
☐Flat, unit, apartment
☐Other (*write*) ____________________

6. Does this dwelling include the following?
☐Large outside space (farm, acreage)
☐Medium outside space (large house yard, small acreage)
☐Small outside space (small yard, patio, balcony)
☐No outside space

7. What is the highest level of education you have completed?
☐No formal schooling
☐Year 10 or below
☐Year 11 or year 12
☐TAFE diploma, trade certificate, apprenticeship
☐University, (undergraduate)
☐University, (post graduate)
☐Other (*write*) ____________________

8. Which of the following best describes your current situation in relation to paid work?
☐Retired
☐Unemployed
☐Unable to work
☐Engaged in home duties
☐Part time or casual paid work (30 hours or less per week or seasonal work)
☐Full time paid work (more than 30 hours per week)
☐Other (*write*) ____________________

9. What is your annual household income from all sources, before taxes?
☐Nil
☐$1- $7799
☐$7800- $12,999
☐$13,000 - $20,799
☐$20,800 - $31,199
☐$32,000 - $41,599
☐$41,000 - $51,999
☐$52,000- $67,599
☐$67,600 - $83,199
☐$83,200 - $103,999
☐$104,000 or more

10. Are you an Australian citizen?
☐Yes
☐No

11. In which country were you born?
☐Australia
☐Other (*write*) ____________________

12. Which language do you mostly speak at home?
☐English
☐Other (*write*) ____________________

13. Do you practice a religion?
☐Yes
☐No

If yes: 13a. What religion do you practice? (*write*)____________________

14. In your opinion, please estimate your knowledge of dogs relative to other members of your community

☐Very unknowledgeable
☐Somewhat unknowledgeable
☐Neither knowledgeable nor unknowledgeable
☐Somewhat knowledgeable
☐Very knowledgeable

15. Have you ever owned or lived with a dog?

☐Yes
☐ No

16. Do you currently own or live with a dog?

☐ Yes
☐ No

17. How many dogs do you currently own or live with?

☐ 1
☐ 2
☐ 3
☐ 4
☐ 5 or more

18. What breed of dog do you own or live with? If not a purebred, please list the breed combination, if known. If you own more than one dog, please list the breed of the dog you have lived with the longest (*write*) _________________

19. How long have you owned or lived with your dog? If you own more than one dog, please answer in relation to the dog you have owned or lived with the longest (*write*) _________

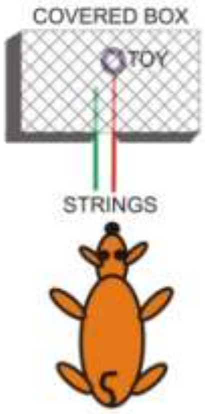
Section B.

This section will ask you how you think dogs will respond in particular situations. Please indicate the extent to which you agree or disagree with the following statements about DOGS IN GENERAL. INSTINCTIVE means an ability that dogs are born with.

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
1. Dogs instinctively recognize themselves in a mirror	☐	☐	☐	☐	☐
2. Dogs can learn to recognize themselves in a mirror	☐	☐	☐	☐	☐
3. Dogs can instinctively use a mirror to find their owner, a treat, or a toy	☐	☐	☐	☐	☐
4. Dogs can learn to use a mirror to find their owner, a treat, or a toy	☐	☐	☐	☐	☐
5. Dogs instinctively understand human gestures like pointing at food or toys	☐	☐	☐	☐	☐
6. Dogs can learn to understand human gestures like pointing at food or toys	☐	☐	☐	☐	☐

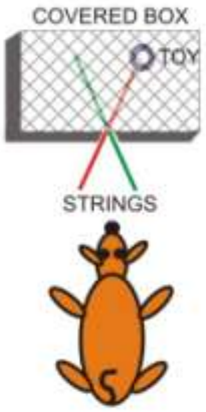
	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
7. When faced with a problem that they can’t solve on their own, such as getting a toy ball from under the sofa, dogs instinctively look at humans for assistance.	☐	☐	☐	☐	☐
8. When faced with a problem that they can’t solve on their own, such as getting a toy ball from under the sofa, dogs can learn to look at humans for assistance.	☐	☐	☐	☐	☐
9. When dogs look at their owner, they instinctively understand when their owner is paying attention to them.	☐	☐	☐	☐	☐
10. Dogs can learn to look at their owner to understand when their owner is paying attention to them.	☐	☐	☐	☐	☐
11. Dogs are instinctively more likely to beg for food from their owner if their owner is looking at them rather than at something else.	☐	☐	☐	☐	☐
12. Dogs can learn to beg for food from their owner when their owner is looking at them rather than at something else.	☐	☐	☐	☐	☐
13. Dogs instinctively know they can steal food more easily when their owner isn’t paying attention to them.	☐	☐	☐	☐	☐
14. Dogs can learn that it is easier to steal food when their owner isn’t paying attention to them.	☐	☐	☐	☐	☐

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
15. Dogs can instinctively solve problems like opening a container lid to get a treat.	☐	☐	☐	☐	☐
16. Dogs can learn to solve problems, like opening a container lid to get a treat, by watching humans do it first.	☐	☐	☐	☐	☐
17. Dogs can learn to solve problems, like opening a container lid to get a treat, by watching other dogs do it first.	☐	☐	☐	☐	☐
18. If you put a toy or treat behind a wire barrier like a fence, dogs instinctively understand that they can go around the barrier to obtain the object.	☐	☐	☐	☐	☐
19. If you put a toy or treat behind a wire barrier like a fence, dogs can learn to go around the barrier to obtain the object by watching humans do it first.	☐	☐	☐	☐	☐
20. If you put a toy or treat behind a wire barrier like a fence, dogs can learn to go around the barrier to obtain the object by watching other dogs do it first.	☐	☐	☐	☐	☐



Please answer the following 3 questions in relation to this figure.

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
21. Dogs instinctively understand that pulling the string will allow them to access the treat or toy at the end.	☐	☐	☐	☐	☐
22. Dogs can learn that pulling the string will allow them to access the treat or toy at the end by watching humans do it first.	☐	☐	☐	☐	☐
23. Dogs can learn that pulling the string will allow them to access the treat or toy at the end by watching other dogs do it first.	☐	☐	☐	☐	☐



Please answer the following 3 questions in relation to this figure.

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
24. Dogs instinctively understand that pulling the string will allow them to access the treat or toy at the end	☐	☐	☐	☐	☐
25. Dogs can learn that pulling the string will allow them to access the treat or toy at the end by watching humans do it first.	☐	☐	☐	☐	☐
26. Dogs can learn that pulling the string will allow them to access the treat or toy at the end by watching other dogs do it first.	☐	☐	☐	☐	☐

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
27. Dogs are capable of understanding when their owner is sad.	☐	☐	☐	☐	☐
28. Dogs are capable of understanding when their owner is happy.	☐	☐	☐	☐	☐
29. Dogs are capable of understanding when their owner is angry.	☐	☐	☐	☐	☐
30. Dogs are capable of understanding when their owner is afraid.	☐	☐	☐	☐	☐
31. Dogs are capable of understanding when a stranger is sad.	☐	☐	☐	☐	☐
32. Dogs are capable of understanding when a stranger is happy.	☐	☐	☐	☐	☐
33. Dogs are capable of understanding when a stranger is angry.	☐	☐	☐	☐	☐
34. Dogs are capable of understanding when a stranger is afraid.	☐	☐	☐	☐	☐
35. Dogs are capable of trying to trick their owner into doing something like moving from their seat so the dog can sit there.	☐	☐	☐	☐	☐
36. Dogs are capable of trying to trick other dogs into doing something like moving from their seat so the dog can sit there.	☐	☐	☐	☐	☐

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
37. Dogs are capable of trying to trick strangers into doing something like moving from their seat so the dog can sit there.	☐	☐	☐	☐	☐
38. Dogs are smarter than most people.	☐	☐	☐	☐	☐
39. Dogs can solve logic problems better than most humans.	☐	☐	☐	☐	☐
40. Dogs can solve social problems better than most humans.	☐	☐	☐	☐	☐
41. Dogs learn the 'sit' command quickly when they are being trained.	☐	☐	☐	☐	☐
42. Once a dog has learned the 'sit' command in one area (like the kitchen), it will respond to the command if it is given in another area (like the backyard) or by another person.	☐	☐	☐	☐	☐
43. Dogs quickly learn to associate actions like picking up the car keys with consequences like going for a ride in the car.	☐	☐	☐	☐	☐
44. The quickest way to house train a dog is to punish it whenever you find a 'mishap' in the house.	☐	☐	☐	☐	☐
45. Dogs learn mostly by trial and error.	☐	☐	☐	☐	☐

	Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree
46. Dogs learn mostly by thinking about the likely consequences of their behaviour.	☐	☐	☐	☐	☐
47. When a dog owner feels sad, their dog feels sad too.	☐	☐	☐	☐	☐
48. When a dog owner feels happy, their dog feels happy too.	☐	☐	☐	☐	☐
49. When a dog owner feels afraid, their dog feels afraid too.	☐	☐	☐	☐	☐
50. When a dog owner feels angry, their dog feels angry, too.	☐	☐	☐	☐	☐
	Newborn to 1 year	1 to 2 years	3 to 5 years	6 to 10 years	11 to 15 years
51. A dog's mental ability is equal to:	☐	☐	☐	☐	☐

Section C: Monash Dog Owner Relationship Scale (MDORS)

(Dog owners only)
Please indicate the extent to which you agree or disagree with the following statements about **your dog**. If you have more than one dog, think about the dog you have lived with the longest.

1. How hard is it to look after your dog?

☐	☐	☐	☐	☐
Very hard	Hard	Neither hard nor easy	Easy	Very easy

2. My dog gives me a reason to get up in the morning.

☐	☐	☐	☐	☐
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

3. There are major aspects of owning a dog I don’t like.

☐	☐	☐	☐	☐
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

4. How often do you kiss your dog?

☐	☐	☐	☐	☐
At least once a day	Once every few days	Once a week	Once a month	Never

5. I wish my dog and I never had to be apart.

☐	☐	☐	☐	☐
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

6. My dog makes too much mess.

☐	☐	☐	☐	☐
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

7. How often do you play games with your dog?

☐	☐	☐	☐	☐
At least once a day	Once every few days	Once a week	Once a month	Never

8. It bothers me that my dog stops me doing things I enjoyed doing before I owned it.

☐	☐	☐	☐	☐
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

9. How often do you take your dog to visit people?

☐	☐	☐	☐	☐
Once a week	Once a fortnight	Once a month	A couple of times a year	Never

10. It is annoying that I sometimes have to change my plans because of my dog.

☐	☐	☐	☐	☐
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

11. My dog costs too much money.

☐	☐	☐	☐	☐
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

12. How often do you buy your dog presents?

☐	☐	☐	☐	☐
Once a week	Once a fortnight	Once a month	A couple of times a year	Never

13. My dog is constantly attentive to me.

☐	☐	☐	☐	☐
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

14. How often do you give your dog food treats?

☐	☐	☐	☐	☐
At least once a day	Once every few days	Once a week	Once a month	Never

15. How often do you tell your dog things you don’t tell anyone else?

☐	☐	☐	☐	☐
Once a day	Once a week	Once a month	Once a year	Never

16. How often do you feel that looking after your dog is a chore?

☐	☐	☐	☐	☐
Once a day	Once a week	Once a month	Once a year	Never

17. How often do you take your dog in the car?

☐	☐	☐	☐	☐
At least once a day	Once every few days	Once a week	Once a month	Never

18. How often does your dog stop you doing things you want to?

☐	☐	☐	☐	☐
Once a day	Once a week	Once a month	Once a year	Never

19. I would like to have my dog near me all the time.

☐	☐	☐	☐	☐
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

20. How often do you groom your dog?

☐	☐	☐	☐	☐
At least once a day	Once every few days	Once a week	Once a month	Never

21. If everyone else left me my dog would still be there for me.

☐	☐	☐	☐	☐
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

22. How often do you feel that having a dog is more trouble than it’s worth?

☐	☐	☐	☐	☐
Once a day	Once a week	Once a month	Once a year	Never

23. My dog helps me get through tough times.

☐	☐	☐	☐	☐
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

24. How often do you hug your dog?

☐	☐	☐	☐	☐
At least once a day	Once every few days	Once a week	Once a month	Never

25. My dog provides me with constant companionship.

☐	☐	☐	☐	☐
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

26. How often do you have your dog with you while relaxing, i.e. watching TV?

☐	☐	☐	☐	☐
At least once a day	Once every few days	Once a week	Once a month	Never

27. My dog is there whenever I need to be comforted.

☐	☐	☐	☐	☐
Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree

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28. How traumatic do you think it will be for you when your dog dies?

☐	☐	☐	☐	☐
Very traumatic	Traumatic	Neither traumatic nor untraumatic	Untraumatic	Very untraumatic