Department of Production Animal Medicine
University of Helsinki
Dissertationes Universitatis Helsingiensis 3/2026

Dog-related factors associated with canine cognitive test performance

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DOCTORAL DISSERTATION
To be presented, with the permission of the Faculty of Veterinary Medicine of the University of Helsinki, for public examination in lecture room 107, Athena, on 16 January 2026, at 12 noon.

Helsinki 2026

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Publisher: Helsingin yliopiston
Sarja (Series): Dissertationes Universitatis Helsingiensis 3/2026
ISBN 978-952-84-1638-8 (print)
ISBN 978-952-84-1637-1 (online)
ISSN 2954-2898 (print)
ISSN 2954-2952 (online)
PunaMusta, Joensuu 2026

Abstract

The domestic dog (*Canis familiaris*) has the longest shared history with humans out of any other species. Traits such as social cognition and inhibitory control may have been especially valuable for dogs to adjust to life with people, and they are likely to have a significant influence on the daily lives of dogs and their owners. Although factors affecting individual differences in cognition have been studied extensively in recent years, research is still lacking in several areas. For example, little is known about the reliability and validity of the various cognitive tests which are utilized in canine cognitive research. In addition, sample sizes in many canine cognitive studies are small, and the factors influencing individual differences in cognitive traits are still poorly understood.

Using one of the largest canine cognitive datasets in the world, the focus of this thesis was on four cognitive tests extensively used in animal research to measure social cognition (gesture test and unsolvable task) and inhibitory control (cylinder test and V-detour). The main aims were to 1) investigate the tests' temporal reliability and validity, i.e., how cognitive traits are reflected in different contexts, especially in everyday life, and 2) identify possible dog-related factors associated with cognitive performance.

The dataset consisted of dogs which had taken part in a commercial test battery called smartDOG™. An owner-completed online survey was used to collect data on everyday behaviour, personality, and background of dogs which had taken part in the smartDOG™ test battery. Two previously validated questionnaires were included: the Dog Impulsivity Assessment Scale (DIAS) and the Canine Behavior Assessment and Research Questionnaire (C-BARQ).

Study I investigated associations between cognitive test performance and everyday behaviour (questionnaire-derived variables) in adult dogs (N = 987), whereas Study II explored whether puppy cognitive test performance could predict everyday behaviour (questionnaire-derived variables) in adult dogs (N = 227). Test-retest reliability of cognitive test performance in adult dogs was examined in Study I (N = 49), whereas Study II investigated the stability and developmental changes of performance from puppy- to adulthood (N = 99). Study III focused on the influence of age, sex, and breed on cognitive performance in adult dogs of 13 different breeds (N = 1,002).

This thesis provides valuable insight into the reliability and validity of cognitive tests as well as how test results are associated with behaviour in everyday contexts. Our findings shed light on the development and stability of cognitive traits and the underlying factors influencing these traits, such as age, sex, and breed. Some of our results replicate those of previous studies, but we also reveal novel associations which future studies can hopefully build on. These studies highlight the importance of social cognition and inhibitory control for the everyday lives of dogs, a deeper understanding of which can benefit both dogs and their owners.

Tiivistelmä

Koiralla (*Canis familiaris*) on pidempi yhteinen historia ihmisten kanssa kuin millään muulla lajilla. Sosiaalinen kognitio ja itsehillintä ovat saattaneet olla erityisen arvokkaita piirteitä, kun koirat ovat sopeutuneet elämään ihmisten kanssa, ja niillä on todennäköisesti valtava merkitys koirien ja omistajien jokapäiväiseen elämään. Vaikka kognition yksilöllisiin eroihin vaikuttavia tekijöitä on tutkittu laajasti viime vuosina, tutkimustiedossa on yhä puutteita usealla alueella. Tiedämme esimerkiksi hyvin vähän tutkimuksissa käytettävien kognitiotestien reliabiliteetista ja validiteetista. Lisäksi useissa kognitiotutkimuksissa käytettävät otoskoot ovat pieniä ja kognitiivisten piirteiden yksilöllisiin eroihin vaikuttavat tekijät edelleen huonosti tunnettuja.

Hyödyntäen yhtä maailman suurimmista koirien kognitiotutkimusaineistoista maailmassa, tämä väitöskirja keskittyi neljään kognitiotestiin, joita on käytetty laajalti eläintutkimuksissa mittaamaan sosiaalista kognitiota (eletesti ja mahdoton tehtävä) ja itsehillintää (sylinteritesti ja V-aita). Väitöskirjan pääasialliset tavoitteet olivat 1) tutkia testien ajallista reliabiliteettia ja validiteettia, eli miten kognitiiviset piirteet ilmenevät eri konteksteissa, erityisesti arkielämässä, ja 2) selvittää koiraan liittyviä muuttujia, joilla on mahdollisesti yhteys kognitiiviseen suoriutumiseen.

Aineisto koostui koirista, jotka olivat osallistuneet kaupalliseen kognitiotestipakettiin nimeltä smartDOG™. Omistajien täyttämää verkkokyselyä käytettiin keräämään tietoa testiin osallistuneiden koirien arkikäyttäytymisestä, persoonallisuudesta ja taustasta. Mukana oli kaksi aiemmissa tutkimuksissa validoitua kyselyä: Dog Impulsivity Assessment Scale (DIAS) ja Canine Behavior Assessment and Research Questionnaire (C-BARQ).

Tutkimus I tarkasteli yhteyksiä kognitiotestien tulosten ja koirien arjessa ilmenevän käyttäytymisen (kyselyvastaukset) välillä aikuisilla koirilla (N = 987), kun taas Tutkimus II selvitti, voivatko pentujen kognitiotestitulokset ennustaa koirien käyttäytymistä arjessa (kyselyvastaukset) aikuisiällä (N = 227). Testien ajallista toistettavuutta aikuisilla koirilla tutkittiin Tutkimuksessa I (N = 49), kun taas Tutkimus II selvitti testitulosten pysyvyyttä ja muutoksia pentuiästä aikuisuuteen (N = 99). Tutkimus III keskittyi iän, sukupuolen ja rodun vaikutukseen aikuisissa koirissa, jotka kuuluivat 13 eri rotuun (N = 1,002).

Tämä väitöskirja tarjoaa arvokasta tietoa kognitiotestien reliabiliteetista ja validiteetista sekä siitä, miten testitulokset liittyvät koirien käyttäytymiseen jokapäiväisessä elämässä. Tutkimustulokset lisäävät ymmärrystä kognitiivisten piirteiden kehittymisestä ja pysyvyydestä sekä näiden piirteiden taustalla vaikuttavista tekijöistä, kuten ikä, sukupuoli ja rotu. Osa tuloksista vahvistaa aiempia tutkimustuloksia, mutta löysimme myös uusia yhteyksiä, joiden varaan tulevat tutkimukset voivat toivon mukaan rakentaa. Nämä tutkimukset korostavat sosiaalisen kognition ja itsehillinnän merkitystä koirien arjessa, ja näiden syvempi ymmärrys voi hyödyttää sekä koiria että omistajia.

List of abbreviations

ADHD	Attention-deficit hyperactivity disorder
AKC	American Kennel Club
C-BARQ	Canine Behavioral Assessment & Research Questionnaire
DIAS	Dog Impulsivity Assessment Scale
FCI	Fédération Cynologique Internationale
ICC	Intraclass Correlation Coefficient
IQ	Intelligence Quotient
PCA	Principal Component Analysis

Index

List of original publications

This thesis is based on the following publications:

I Junttila, S., Valros, A., Mäki, K., & Tiira, K. (2024). Do cognitive traits associate with everyday behaviour in the domestic dog, *Canis familiaris*? *Animal Behaviour, 213*, 71-84.

II Junttila, S., Valros, A., Mäki, K., & Tiira, K. (2025). Puppy (3–7-month-old) cognitive tests as predictors of adult dog cognition and behaviour. *Applied Animal Behaviour Science, 286*, 106599.

III Junttila, S., Valros, A., Mäki, K., Väätäjä, H., Reunanen, E., & Tiira, K. (2022). Breed differences in social cognition, inhibitory control, and spatial problem-solving ability in the domestic dog (*Canis familiaris*). *Scientific Reports, 12*(1), 22529.

The publications are referred to in the text by their roman numerals.

Author's contribution

I **Do cognitive traits associate with everyday behaviour in the domestic dog, *Canis familiaris*?**

&

II **Puppy (3–7-month-old) cognitive tests as predictors of adult dog cognition and behaviour.**

The author participated in the study design and development, translation, piloting, and editing of the questionnaire, as well as questionnaire data collection and processing. The author also conducted the statistical analyses, created the figures and tables, and wrote the manuscript with help from coauthors.

III **Breed differences in social cognition, inhibitory control, and spatial problem-solving ability in the domestic dog (*Canis familiaris*).**

The author participated in the study design and processing of data. The author also conducted the statistical analyses, created the figures and tables, and wrote the manuscript with help from coauthors.

1 Introduction

Dogs are one of the most popular pets worldwide; in Finland, approximately 18 % of households own a dog (SVT, 2020), whereas in the UK, USA, and Australia, the percentage is 30–40 % (AMA, 2022; AVMA, 2024; Murray et al., 2015). Dogs are present in almost every human culture across the world. Throughout their approximately 11,000–32,000-year-old shared history with humans (Tancredi & Cardinali, 2023), dogs have become important members of society. They perform valuable, sometimes even lifesaving, roles as working dogs and as family members. As a result, humans and dogs have developed a unique bond, with many dog owners reporting greater satisfaction with their dogs than with any human relationship apart from their child (Turcsán et al., 2025).

Throughout their domestication, dogs have likely been artificially selected for cognitive traits which make them more suitable for their various roles in human society. Compared to their closest living relative, the grey wolf, dogs have developed more advanced socio-cognitive abilities when interacting with humans (Marshall-Pescini et al., 2015). Social cognition refers to "all cognitive processes relating to interactions with conspecifics or heterospecifics" (Ferreira et al., 2023). It is required for forming and maintaining social relationships, and it includes skills such as cooperation, communication, recognition of emotional states, understanding another individual's point of view, and learning socially from others (Ferreira et al., 2023).

Dogs have also been found to outperform wolves in inhibitory control tests, but only if a human is present (Kaminski & Nitzschner, 2013; Range et al., 2020). Inhibitory control is an executive function which is defined as the animal's "ability to control impulsive or pre-learned behaviours in order to reach a more rewarding goal" (Loyant et al., 2025). It is likely that social cognition and inhibitory control have been important skills throughout dogs' domestication history. Dogs have performed roles which require a willingness to cooperate with humans, an interest in observing and learning from people, and the ability to control their impulses. However, the various roles of dogs each require different cognitive skills. Guide dogs are expected to have high self-control and the ability to problem-solve independently, herding breeds need to cooperate seamlessly with their handler and respond to subtle visual signals, and police dogs are required to learn quickly and respond rapidly to changing situations.

Today, the most common role of the dog is that of companion and family member. For this important role, a wide range of behavioural requirements exists, many of which are influenced by underlying cognitive traits. Pet dogs are required to be well-behaved, calm, respond promptly to commands, and inhibit their unwanted behaviours, such as pulling on the lead, jumping on tables, stealing food, and chasing animals (Power et al., 2024). All of these behaviours require cognitive traits, such as learning ability, memory, social cognition, and inhibitory control (Hare et al., 2002; Olsen, 2018). If a dog is lacking in any of these skills, their owner may have difficulties managing their unwanted behaviour and teaching them appropriate responses and habits. This can strain the bond between the owner and the dog and negatively impact the wellbeing of both (Barcelos et al., 2024; Van Herwijnen et al., 2018). Social cognition is likely an important aspect for forming a positive bond with the owner, and dogs with higher social cognitive abilities may also be more likely to obey commands.

Despite cognitive traits – especially social cognition and inhibitory control – being potentially very important for dogs' suitability for their various roles in society, there is still a lot we do not know about the factors influencing these cognitive traits. Surprisingly little research exists on the reliability and validity of cognitive tests in animal research (Cauchoix et al., 2018; Griffin et al., 2015). It is not fully known whether test results are reliable across time or whether the traits measured by cognitive tests can be seen in other contexts, such as in dogs' everyday life with their owners. In addition, there is still widespread disagreement on which traits canine cognitive tests are in fact measuring (e.g., Cavalli et al., 2018; Kabadayi et al., 2018; Kaminski & Nitzschner, 2013; Mendes et al., 2021b; Miklósi & Soproni, 2005; Prato-Previde et al., 2014).

This thesis intends to investigate the reliability and validity of four cognitive tests extensively utilized in canine cognitive research: the cylinder test, the gesture test, the V-detour, and the unsolvable task. In addition, the aim is to shed light on dog-related factors associated with dogs' cognitive test performance, such as breed, age, sex, and personality, and most importantly, how test performance is reflected in everyday life. For example, could dogs with higher socio-cognitive abilities and inhibitory control be easier to train and manage, and less likely to develop behaviour problems? Hopefully, the results of this thesis will help us to deepen our understanding of the underlying cognitive traits behind dog behaviour, which can ultimately enhance the welfare of both dogs and their owners.

2 Review of the literature

2.1 Animal cognition

Cognition can be defined as the way animals take in, process, retain, and act on information about the world (Shettleworth, 2001). In humans and other animals, cognition is divided into clusters or 'domains'. These include perception, memory, attention, social cognition, language skills, and executive functions, such as working memory, reasoning, problem-solving, and self-control (Harvey, 2022; Vallortigara et al., 2010). There is evidence that IQ (intelligence quotient) and other cognitive measures in humans correlate with real-life outcomes such as socioeconomic success (Strenze, 2007), physical and mental illness (Fries et al., 2025), and even mortality (Batty et al., 2007).

In non-human animals, cognitive traits are important in almost all aspects of an animal's life (Shettleworth, 2001). In order for an individual to flexibly change their behaviour in constantly changing situations and environments, information processing is required (Olsen, 2018). Skills such as learning, memory, inhibitory control, decision making, and problem-solving ability are needed for food acquisition, mate choice, reproduction, parental care, maintenance of social bonds, and predator avoidance (Cauchoix & Chaine, 2016). Therefore, the survival and reproductive fitness of an individual can depend partly on cognitive ability (Boogert et al., 2011; Madden et al., 2025; Thornton et al., 2014).

However, cognitive abilities can incur fitness costs, partly because of the energy costs of developing and maintaining a larger brain (e.g., Burger et al., 2008; Keagy et al., 2011; Kotrschal et al., 2013; Madden et al. 2018; Mery & Kawecki, 2003). Therefore, the evolution of specific cognitive abilities depends largely on the skills that are needed for a particular species' specific environment (Bräuer et al., 2020). For example, social cognition is important for group-living species, but less beneficial for solitary animals (Seyfarth & Cheney, 2015), and inhibitory control and patience may benefit a species living in one type of environment whereas fast reactions and immediate rewards may be more valuable for another species in a different environment (Dunbar & Schultz, 2025; Stephens, 2008).

2.2 The domestic dog

The dog (*Canis familiaris*) was the first species to be domesticated (Freedman & Wayne, 2017). The ancestor of the dog split from wolves approximately 11,000–32,000 years ago (Tancredi & Cardinali, 2023) and formed a mutually beneficial relationship with humans. As a result of both natural and artificial selection, dogs underwent several physical and behavioural changes to make them more suitable for life with humans.

Through domestication, dogs have developed a predisposition to become attached to another species, the human. Compared to their closest living relative, the grey wolf (*Canis lupus*), dogs are more sociable and cooperative with humans, more willing to make eye contact with people, and as puppies they even seem to prefer humans over conspecifics (Gácsi et al., 2005).

In many cases, dogs seem to form an even stronger bond with their owners than with conspecifics in the same household, and for some individuals, the presence of a human can reduce stress more effectively than the presence of a familiar dog (Cimarelli et al., 2019). The dog as a species has undergone genetic changes which are linked to hypersocial behaviour (VonHoldt et al., 2017) and oxytocin production (Kis et al., 2014; Oliva et al., 2016). Oxytocin is a hormone related to social affiliation, attachment, and pair bonding, and could therefore have been an important basis for dogs to form close relationships with humans (Herbeck et al., 2022).

Throughout domestication, dogs have developed cognitive skills which help them communicate, cooperate, and coexist better with humans. Dogs outperform wolves in tasks measuring social cognition and inhibitory control involving a human (Kaminski & Nitzschner, 2013; Marshall-Pescini et al., 2015; Range et al., 2020), which would suggest that both have been important traits during domestication. However, some authors argue that there is little to no evidence for dogs' advanced socio-cognitive abilities compared to wolves (Lea & Osthaus, 2018; Range & Marshall-Pescini, 2022).

Dogs have held various valuable roles across their mutual history with humans. Humans began artificially selecting individual dogs for breeding based on their suitability for a specific role. This resulted in different dog 'types' bred for roles such as hunting, herding, guarding, or pulling sleds (Parker, 2012; Parker et al., 2017). Eventually, approximately 200 years ago, dog breeds became genetically more distinct from each other with closed breeding populations (Lindblad-Toh et al., 2005; Parker, 2012). As a result, over 400 different dog breeds exist today, encompassing a morphological variety not seen within any other mammalian species.

Dog breeds do not differ from each other only physically, but also behaviourally. Various studies have found significant behavioural differences between dog breeds (Mehrkam & Wynne, 2014; Pongrácz & Dobos, 2025). However, since there are

many other factors influencing behaviour, breed explains only a small percentage of variation between individuals (Morrill et al., 2022).

The different roles dogs occupy in our society today is vast. They are used as police dogs, guide dogs, detection dogs, search and rescue dogs, and assistance dogs, among many others. Dogs can be trained to detect cancer and changes in an owner's health state, such as epileptic fits, pain episodes, or hypoglycaemia. They provide emotional and stress-reducing support to people in hospitals, care homes, schools, and libraries.

Of course, the most important job for the large majority of dogs is to provide companionship to their owners. Studies have found that the attachment dogs form with their owners has similarities with the attachment human children form with their mothers (Prato-Previde et al., 2003; Topál et al., 2005; Udell et al., 2021). In addition, dogs provide emotional support to their owners. In a recent study, owners stated that they received more support from their dogs compared to any human partner apart from their child (Turcsán et al., 2025). Both dogs and their owners have been shown to increase their oxytocin production following certain positive social interactions with each other, but this effect seems to be dependent on various dog- and human-related factors, as well as the level of attachment and the type of interaction between dog and owner (Powell et al., 2019; 2020).

Dog ownership – and even the mere presence of a dog – can have various health benefits to humans, such as reducing stress, depression, loneliness, obesity, blood pressure, and mortality, and improving physical and mental health (Kramer et al., 2019; Martins et al., 2023; Matchock, 2015; Wells, 2019). However, several studies have found the opposite effect, with pet ownership impacting negatively on owner health (Herzog, 2011; Scoresby et al., 2021).

One reason dog ownership can have a negative influence on an owner's wellbeing is if the dog is displaying behaviour problems such as aggression, fearfulness, destructiveness, or hyperactivity (Barcelos et al., 2024; Enders-Slegers & Hediger, 2019; Love, 2021). Unwanted behaviours displayed by the dog can lead to feelings of stress, frustration, anger, sadness, anxiety, tiredness, and depression in the owner (Barcelos et al., 2020; Buller & Ballantyne, 2020) and negatively impact the owner's relationship with their dog as well as with other people (Buller & Ballantyne, 2020).

The prevalence of behaviour problems in dogs ranges from study to study between 34 and 99 % (Beaver, 2024; Didehban et al., 2020; Dinwoodie et al., 2019; Meyer et al., 2023; Salonen et al., 2020). Many unwanted behaviours, such as impulsive, hyperactive, or aggressive behaviour, can result from stress or anxiety experienced by the dog. Chronic stress can not only impair a dog's mental wellbeing but can predispose them to various health issues and reduce their lifespan (Dreschel, 2010). Even behaviours which are a normal part of dog behaviour, such as barking or chewing objects, can significantly impair the dog-owner relationship

(Serpell, 1996). At worst, behavioural issues can lead to the dog's relinquishment (New et al., 2000; Salman et al., 2000) or euthanasia (Boyd et al., 2018; Fatjó et al., 2006; O'Neill et al., 2013). An improved understanding of dog behaviour is crucial for the prevention and treatment of behaviour problems and for the welfare of dogs and their owners.

2.3 Dog cognition

Just as in other animal species, cognitive traits influence almost all aspects of a dog's life. In order to be successful in their various roles, whether as working dogs or as family members, dogs need to possess certain cognitive skills. Inhibitory control is required in a wide range of daily situations, such as walking calmly on the leash, waiting to go outside, greeting people calmly, and refraining from unwanted behaviours (Barela et al., 2024; Olsen, 2018). Memory and learning ability are necessary for learning everyday tasks and understanding household rules, whereas social cognition is important for forming a positive relationship with humans and coexisting peacefully with owners. For example, in order to obey commands and refrain from unwanted behaviours, dogs may need to be able to understand human communicative intentions, recognize changes in emotional state, and pay attention to what humans are doing. Especially in many working roles, cooperation and social learning are important socio-cognitive abilities.

Despite cognition having a potentially significant influence on the daily life of pet dogs, very few studies have investigated whether dogs' performance in cognitive tests correlates with their behaviour in everyday life. Impulsivity and inhibitory control have received more research attention, but findings seem to be inconclusive. Some studies have found a correlation between dogs' success in inhibitory control tests and lower impulsivity in daily life, whereas others have found no association (Barela et al., 2024). The contrasting results could be partly due to differing methodologies, small sample sizes, or breeds included in the studies.

Working dogs, such as guide dogs and police dogs, have received more research attention than pet dogs in this aspect. Certain cognitive skills, such as problem-solving ability, inhibitory control, and social cognition, have been found to be associated with working dog success (Hare & Ferrans, 2021; Troisi et al., 2019). Some cognitive tests can even predict working dog success from a young age (e.g., Foraita et al., 2024; Lazarowski, Krichbaum et al., 2020).

Dogs have been selected for behavioural and cognitive traits which make them more suitable for their various roles in human society, whether as working dogs or as family members. Therefore, a deeper understanding of dogs' cognitive traits, especially social cognition and inhibitory control, can have important implications for the welfare of dogs and humans.

2.4 Factors influencing cognition

Behavioural and cognitive traits are influenced by a large number of environmental, physiological, and genetic factors, each having usually only a small effect as well as complex interactions with each other. See Figure 1 for an overview of some of the factors which are associated with canine cognitive test performance.

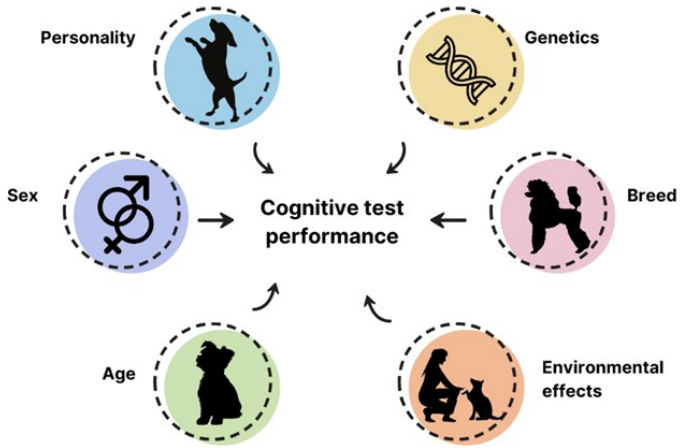


Figure 1 Some of the factors which are associated with dogs' performance in cognitive tests.

2.4.1 Genetic influences

In humans, IQ is highly heritable (Dickens & Flynn, 2001), and cognitive traits in non-human animals have been found to be heritable to varying degrees, although this is still a largely unknown topic (Croston et al., 2015).

The genetically closed populations within dog breeds allow the investigation of the possible existence of genetic influences by studying differences between breeds. However, findings on breed differences on cognition have often been inconsistent (Mehrkam & Wynne, 2014), which could be explained by several factors, such as the pervasive use of small sample sizes (Arden et al., 2016), varying methodologies, and the different breed compositions of studies. Additionally, previous studies have mostly used breed group comparisons, where breeds which are genetically related to each other or share a similar original function are grouped together, which can lead to different findings based on the grouping method and result in the loss of potential differences between individual breeds within breed groups.

Most breed differences have been found for socio-cognitive abilities (Mehrkam & Wynne, 2014), which also seem to be highly heritable (Bray, Gnanadesikan, et al.,

2021; Gnanadesikan et al., 2020; Persson et al., 2015). Non-social cognitive abilities have received less attention, but one study found that inhibitory control had high heritability when using breed-averaged genetic data (Gnanadesikan et al., 2020). This would suggest that breed differences in at least some aspects of inhibitory control exist. Further research with larger sample sizes and a wider range of breeds may be required to improve our understanding of how breeds differ from each other in different tasks, which can also provide insight into the possible genetic basis of various cognitive traits.

In addition, the physical characteristics of breeds influence their performance in some tasks. Larger dogs seem to outperform smaller dogs in gesture following tasks (Helton & Helton, 2010; Horschler et al., 2019), short-term memory, and inhibitory control (Horschler et al., 2019), whereas smaller dogs have been found to be more impulsive according to questionnaire studies (Sulkama et al., 2021; Vas et al., 2007; Wright et al., 2011). One explanation for this effect could be the size of the brain; brain volume seems to be associated with inhibitory control across a wide range of species (MacLean et al., 2014).

Brachycephalic breeds with shorter skulls have been found to outperform breeds with longer skulls in understanding human gestural communication (Gácsi, McGreevy, et al., 2009), which has been attributed to higher visual perception in these breeds. One study found that brachycephalic breeds did not differ from dolichocephalic breeds in their understanding of human gestures, but they performed more poorly in a test of self-control (Horschler et al., 2019). This result could be complicated by the fact that dogs with high cephalic index were also likely to be smaller in size (Horschler et al., 2019).

2.4.2 Environmental effects

In addition to genetics, environmental effects play a large role in the cognitive performance of individual animals. The early experiences of the young individual are especially important, since the brain is still developing. Some examples of factors which can influence cognitive performance in dogs include the amount of socialisation and quality of maternal care they received as young puppies (Foraita et al., 2021).

The rearing environment which dogs experience can greatly influence their cognitive abilities. Shelter dogs and free-ranging dogs have been found to differ from pet dogs in some cognitive tests (e.g., Duranton & Gaunet, 2016; Fagnani et al., 2016; Lazzaroni et al., 2019; O'Riordan & Roth, 2023). This may be related to the extent of human experience they have been subjected to across their lifetime. However, other studies have found different rearing or living environments to have no effect on cognition (Gácsi, Kara, et al., 2009; Lyn et al., 2024; Marshall-Pescini et al., 2017; Pongrácz & Lugosi, 2024). The effect may depend on the cognitive task

and specific methodology used, as well as the specific extent of human experience and environmental enrichment received by each population.

The amount and type of training dogs have experienced can influence cognitive traits in some tests (Barrera et al., 2018; Cavalli et al., 2018; Foraita et al., 2021; Marshall-Pescini et al., 2009, 2016; Mellor et al., 2024). Working dogs have also been found to differ from pet dogs in some cognitive tests (Carballo et al., 2020; Lazarowski, Thompkins, et al., 2020; MacLean & Hare, 2018; Marshall-Pescini et al., 2009; Scandurra et al., 2015; Tiira et al., 2020). The differences in cognitive performance between pet dogs and trained dogs may be a result of the training itself, or because people may be more likely to choose individuals with certain cognitive traits for a specific dog sport or working role. Therefore, it is possible that training experience influences cognitive traits and vice versa.

In addition, dog cognition can be influenced by the owner's personality (Kujala et al., 2023) and the type of relationship between the owner and the dog (Brubaker & Udell, 2023; Hall et al., 2016; Imponen & Pelliccioni, 2021; Thielke & Udell, 2019). Again, this effect could be bidirectional, with the dog's cognitive skills influencing the relationship and vice versa.

2.4.3 Age-related changes

In humans, cognitive performance in relation to peers remains relatively stable across the individual's lifetime, although stability is higher in adulthood than during early development (Briley & Tucker-Drob, 2017). The same effect is seen in dogs (Bray, Gruen, et al., 2021; Lazarowski et al., 2019).

Many cognitive traits show a curve-like development with an inverted U-shape (See Figure 1) across the dog's lifetime (Watowich et al., 2020), with performance increasing as the individual develops into an adult (Bray, Gruen, et al., 2021; Lazarowski et al., 2019; Lazarowski, Krichbaum, et al., 2020) and then declining as the dog ages (Chapagain et al., 2018). There is, however, variation across cognitive traits, with different traits developing at different ages. In addition, some abilities show no signs of cognitive decline, while others continue to increase across the animal's lifetime (Hori et al., 2013; Lazarowski, Thompkins, et al., 2020; Persson et al., 2015).

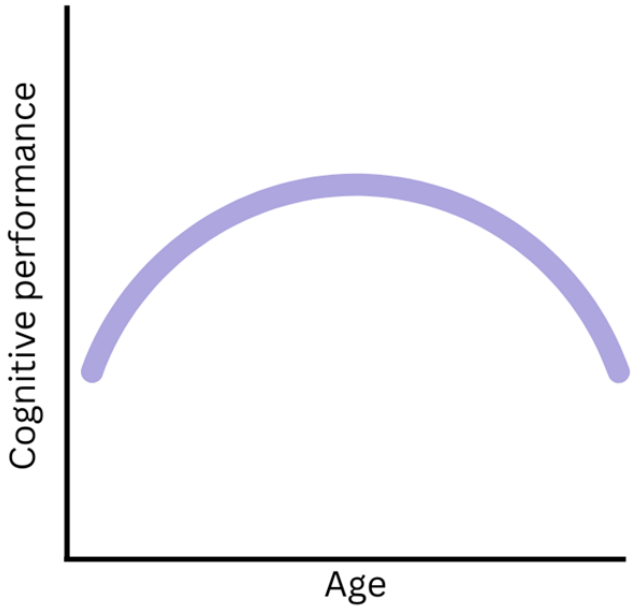


Figure 2 Schematic of how an individual's performance in many cognitive tests changes with increasing age.

2.4.4 Sex and hormonal effects

Some cognitive traits seem to be influenced by reproductive hormones and sex. For example, in some species, a certain type of impulsivity is higher in males than females (Weafer & de Wit, 2014), and a similar effect has been found in dogs (Foraita et al., 2022; Junttila et al., 2021; Krichbaum & Lazarowski, 2022; Salonen et al., 2020, 2022; Silver et al., 2025; Sulkama et al., 2021). However, the result seems to depend largely on the test used to measure impulsivity, since several studies have found no effects of sex (Bray et al., 2013; Brucks, Soliani, et al., 2017; Fadel et al., 2016; Lit et al., 2010; Mellor et al., 2024; Watowich et al., 2020; Wright et al., 2011)

Females seem to generally have higher performance in tests measuring social cognition (Fugazza et al., 2017; Hori et al., 2013). Many studies have found that female dogs spend more time gazing at humans during an unsolvable task compared to males (Hori et al., 2013; Junttila et al., 2021; Kovács et al., 2016; Persson et al., 2015), but others have found no sex differences (Konno et al., 2016; Lazarowski, Thompkins, et al., 2020; Pongrácz & Lugosi, 2024; Van Poucke et al., 2022).

One explanation for the varying findings on sex differences in some cognitive tests could lie in a potential interaction with breed. For example, a master's thesis found that male cocker spaniels had lower inhibitory control in the cylinder test, and they were more likely to give up on the unsolvable task compared to females, but these effects were not seen in Labrador retrievers (Tuikkanen, 2024). Therefore, different breed compositions within studies could influence whether sex differences arise or not.

Reproductive hormones may play an important part in these effects, since gonadectomy can in some cases influence cognitive performance (Fadel et al., 2016; Mongillo et al., 2017), such as gesture following ability (Scandurra et al., 2019; Watowich et al., 2020).

2.4.5 Personality

There has been increasing interest in the possible link between cognition and personality both in humans and other animals (Carere & Locurto, 2011; Griffin et al., 2015). Personality refers to stable, consistent individual differences in behaviour across time and contexts. Cognition and personality are often investigated separately, but some authors suggest that they may be strongly connected (Ackerman & Heggestad, 1997; Dougherty & Guillette, 2018; Rammstedt et al., 2016; Sih & Del Giudice, 2012; Soubelet & Salthouse, 2011). Some even argue that they should not be investigated as separate constructs since they are strongly intertwined (Bray et al., 2017).

For example, personality traits such as boldness, exploration, activity level, sociability, and neophilia can all potentially influence an individual's performance in a cognitive test (Carere & Locurto, 2011; Dougherty & Guillette, 2018). Alternatively, a correlation between cognition and personality might arise because they are both influenced by some common process such as stress (Carere & Locurto, 2011; Griffin et al., 2015). Various studies show associations between personality and cognitive traits, but the direction of these associations may vary across species as well as within them (Dougherty & Guillette, 2018).

Some canine studies suggest a complex relationship between personality and cognition (Bray et al., 2017; Cox et al., 2020; Turcsán et al., 2018). Especially anxiety and fear seem to influence a variety of cognitive traits in dogs and other animals (Beuzen & Belzung, 1995; Henriksson et al., 2019; Kalueff & Murphy, 2007; Passalacqua et al., 2013; Piotti et al., 2021; Pirrone et al., 2024), possibly as a result of chronic stress, which can negatively influence cognitive performance (Sandi, 2013). In dogs, impulsivity shows associations with various behavioural and personality traits (Gobbo & Šemrov, 2022; Piotti et al., 2018; Salonen et al., 2022; Sulkama et al., 2021; Wright et al., 2011), but these results are mainly based on

questionnaire studies rather than behavioural tests. Regarding other cognitive traits, there is little to no research on their possible associations with personality.

2.5 Measuring cognition

Animal cognition research has frequently taken either a comparative approach, where the average cognitive abilities of a species are compared to another species, or the limits of a species' cognitive abilities are explored (Boogert et al., 2018). Until fairly recently, individual differences in cognition have been largely ignored (Boogert et al., 2018; Thornton & Lukas, 2012). Questions about the evolution, development, and mechanisms of cognitive traits are difficult to answer without measuring individual differences and their causes and effects.

In canine research, the main focus has similarly been on the cognitive abilities dogs as a species are capable of, as well as comparing dogs' cognition to that of wolves in order to understand possible changes during domestication (Arden et al., 2016). In recent years, however, the focus has shifted more toward individual variation, which has allowed the investigation of the factors which influence and are influenced by cognitive traits, but more research on this topic is still needed (Arden et al., 2016; Bensky et al., 2013).

Behavioural and cognitive traits of dogs can be measured in several ways, all of which have their benefits, disadvantages, and challenges. Two of the most common methods are to measure behaviour directly using behavioural tests or indirectly using questionnaire surveys.

2.5.1 Surveys

Despite being potentially subjective, questionnaire surveys allow the possibility for large sample sizes, which can reduce their subjective bias (Jones & Gosling, 2005). Questionnaires are filled in by the dog's primary carer, and they provide an indication of the dog's behaviour from a longer time range and in a much wider range of contexts than a direct observation of behaviour taken in one moment in time. Some behaviours may even be impossible to measure in a standardized behaviour test. Previous research shows that questionnaires, when properly validated, correlate well with more direct behavioural measures and show good interrater reliability and test-retest reliability (Wiener & Haskell, 2016).

However, questionnaire studies still depend on the owners' ability to recognize and describe their dogs' behaviour accurately. More importantly, cognitive traits are difficult – if not impossible – to measure using questionnaires, since owners might not be aware of their dog's cognitive traits in relation to other individuals. Regardless, some studies have attempted this, for example by asking owners questions about their dogs' executive functions or memory (Foraita et al., 2022;

Pongrácz et al., 2012). In addition, questionnaires are often used to measure impulsivity (Barela et al., 2024) and cognitive aging (Chapagain et al., 2018) of dogs.

2.5.2 Behavioural tests

A more objective method for measuring behaviour is using behavioural coding by an experimenter. A common approach in cognitive research is to use standardised behavioural tests, in which each individual is provided with the same test situation. One disadvantage of behavioural testing is that it measures only one small moment in time, and therefore factors such as motivational and emotional state, stress level (Belanoff et al., 2001), satiety (Miller & Bender, 2012), environmental conditions, and time of day can potentially influence results (Serpell & Hsu, 2001).

One possible solution to reduce the influence of non-cognitive factors on test results is to assess consistency of results through repeated testing. Unfortunately, few cognitive studies on animals have investigated this (Griffin et al., 2015), and the few studies that exist on the topic have found low to moderate levels of temporal repeatability (Cauchoix et al., 2018). Results from these studies can sometimes be problematic to interpret, especially in cognitive research, since previous test occasions may induce learning effects and therefore influence the results of the second test occasion. However, one study which combined dogs´ cognitive test results using factor analysis found high temporal reliability for factor scores (Bognár et al., 2024).

When measuring cognitive performance, it is important to determine what a particular test is measuring; this may be different from what was initially assumed. Various cognitive and personality traits may influence how an animal performs in a cognitive test, and these may be difficult to tease apart. It is possible that no task is "process pure" (Olsen, 2018), meaning that a single cognitive test might measure more than one cognitive ability as well as potentially being influenced by non-cognitive traits. This should be taken into account when interpreting results from cognitive tests.

One way to ensure a test is measuring the assumed cognitive trait is to investigate the trait across different contexts which are assumed to require similar cognitive processes. This has been attempted regarding some cognitive traits with mixed results (Bray et al., 2014; Brucks, Marshall-Pescini, et al., 2017; Brucks et al., 2019; Müller et al., 2016), but in many cases no such validation is attempted (Griffin et al., 2015). Whether a cognitive trait is observable in 'real' life situations would be valuable information regarding the validity of a particular cognitive test, but this is rarely investigated.

Another problem with behavioural testing lies in the difficulty of attaining large sample sizes due to time and space requirements. As a result, sample sizes in

cognitive research are often small (Arden et al., 2016; Shaw & Schmelz, 2017). One way to avoid this problem is by utilizing citizen science, i.e., allowing owners to test their dogs at home according to specific guidelines (Hecht & Rice, 2015; Horowitz & Hecht, 2014; Pelgrim et al., 2024; Stewart et al., 2015; Willgohs et al., 2023). This allows for a much larger dataset when properly validated, but there is still a risk for systematic bias and inconsistencies in the way owners conduct the tests (Griffin et al., 2024).

This thesis focuses on behavioural testing of two aspects of cognition which are potentially important for domestic dogs: social cognition and inhibitory control. These are described in greater detail in the following chapters.

2.6 Social cognition

Social cognition involves skills which are required for forming and maintaining social ties, usually in a social group. Social cognition is defined as the cognitive processes which are used to understand and store information derived from, or relevant to, social companions (Heyes, 1994; Van Overwalle, 2009). This includes, for example, the ability to distinguish between individuals, recognize emotions, understand communicative cues, learn socially from other individuals, and cooperate with others.

It is widely believed that domestication has produced advanced social skills in dogs, especially in relation to cooperation with humans and responsiveness to human social cues (Cooper et al., 2003; Hare & Tomasello, 2005; Miklósi et al., 2004; Reid, 2009; Topál et al., 2009). It has been hypothesized that during their co-evolution with humans, dogs have improved their socio-cognitive skills either as a result of selection for these types of cognitive abilities or as a by-product of selecting for tameness or sociability (Hare, 2007; Hare et al., 2002; Kaminski & Nitzschner, 2013; Miklósi et al., 2000, 2004). However, recent reviews suggest that when confounding factors are taken into account, the evidence for socio-cognitive differences between dogs and wolves is lacking (Lea & Osthaus, 2018; Range & Marshall Pescini, 2022; Wynne, 2016).

Domesticated species in general seem to have advanced socio-cognitive skills compared to their wild counterparts (Hernádi et al., 2012; Kaminski et al., 2005; Maros et al., 2008; McKinley & Sambrook, 2000; Miklósi et al., 2005). Domestication experiments in foxes have shown that their social cognition with humans is more advanced if they have been selected for tameness over just a small number of generations (Hare et al., 2005).

When intensively socialized, wolves (*Canis lupus*) can reach similar levels as dogs for understanding human gestural communication, such as pointing (Gácsi, Gyoöri, et al., 2009; Hansen Wheat et al., 2022; Udell et al., 2008; Udell et al., 2012; Virányi et al., 2008), but dogs seem to develop this ability at an earlier age and with

less socialisation than wolves (Hare & Tomasello, 1999; Salomons et al., 2021; Soproni et al., 2002; Virányi et al., 2008). Dogs also have a stronger tendency to use eye contact to communicate with humans compared to wolves (Kubinyi et al., 2007; Miklósi et al., 2003; Salomons et al., 2021; Virányi et al., 2008). When provided with a problem-solving task, wolves are more persistent and independent, whereas dogs tend to give up sooner and direct their attention to a human (Frank & Frank, 1985; Marshall-Pescini et al., 2017; Salomons et al., 2021), which is often considered a communicative behaviour (Miklósi et al., 2003).

The studies included in this thesis focus on two aspects of social cognition which have been extensively studied: dogs' understanding of human gestural communication and their human-directed behaviour in a problem-solving situation. There is still a lack of information and disagreements among researchers regarding what these tests are measuring, and their validity and reliability has received little research attention. However, they also show great potential for producing interesting information about dogs' socio-cognitive traits which might also be reflected in everyday life.

2.6.1 Use of human communicative gestures

In humans, pointing with the arm and index finger seems to be an almost universal gesture. The ability to understand pointing gestures develops between 6 and 12 months of age (Senju & Csibra, 2008; Tang et al., 2023). This ability is considered an example of infants' increasing responsiveness to social cues and knowledge of the attentional states of others and may even be a prerequisite for the development of language (Bertenthal et al., 2014; Sodian & Thoermer, 2004). Similarly, dogs seem to have an almost innate ability to understand human gestural communication, such as pointing or gazing toward a location with a hidden reward (Hare & Tomasello, 2005). However, this ability does not seem to apply to all communicative cues in all situations (e.g., Alberghina et al., 2023).

2.6.1.1 Methodology

The dog's ability to follow human communicative cues is often measured using an object-choice task. In this task, dogs are provided with two choices of containers, one of which has food hidden inside. In some variations of the task, the dog is provided with a choice between two toys (Kirchhofer et al., 2012; Tauzin et al., 2015). Control trials have shown that dogs do not choose the correct location based on scent or other environmental cues (Kaminski & Nitzschner, 2013). In fact, some dogs will even prefer a location gestured at by a human despite seeing or smelling the food reward in a different location (Szetei et al., 2003).

The performance of dogs in tests measuring gesture-following ability depends largely on the specific cue which is used. The most commonly researched gesture is pointing with a hand, where the experimenter points with their arm and index finger toward the baited location. There are many variations of this gesture, with dogs showing differing success with different pointing topographies (Hauser et al., 2011; Lakatos et al., 2009, 2011; Lyn et al., 2024; Soproni et al., 2002; Udell et al., 2013).

Proximal pointing (where the hand is close to the baited location) seems to be easier for dogs to understand than distal pointing (where the hand is further away from the baited location) (Lyn et al., 2021; Miklósi et al., 2005; Soproni et al., 2001; Udell et al., 2013). How far apart the objects are from each other is also influential; the task is easier for dogs if the objects are further apart rather than close together (Lyn et al., 2021). Dogs are also more successful when the gesture is dynamic (the gesture is continued while the dog makes their choice) rather than momentary (the dog is shown the gesture after which they are allowed to make their choice) (Bräuer et al., 2006; Udell et al., 2013).

In addition to pointing with a hand, dogs can also understand other communicative cues, such as pointing with a foot (Hauser et al., 2011; Lakatos et al., 2009; Soproni et al., 2002). Head turns and gaze seem to be the most difficult communicative cues for dogs (Ittyerah & Gaunet, 2009; Soproni et al., 2001), although some individual dogs are successful at this task (Agnetta et al., 2000; Lazarowski, Thompkins, et al., 2020).

Dogs' performance in all gesture tasks is improved if an expression of communicative intent is included, such as eye contact or speaking to the dog to attract their attention (Byosiere et al., 2022; Kaminski et al., 2012; Pettersson et al., 2011; Téglás et al., 2012). The same has been found for infants' ability to follow an adult's gaze (Senju & Csibra, 2008). In conclusion, the specific style of pointing as well as additional communicative cues seem to strongly influence dogs' ability to understand human pointing gestures.

The mechanisms enabling dogs to interpret human gestural communication remain heavily debated (Elgier et al., 2012; Kaminski & Nitzschner, 2013; Miklósi & Soproni, 2005; Scheider et al., 2013). Some researchers suggest that dogs have an almost innate ability to understand human gestural communication, with only some experience of humans required. Others have suggested that dogs view human gestures as orders or imperative directives (Kaminski & Nitzschner, 2013; Topál et al., 2009), whereas some argue that this ability is mainly a learned skill and that human hands have simply become associated with food (Espinosa et al., 2023).

With sufficient socialisation to humans, other animal species in addition to dogs seem capable of using human pointing cues to locate hidden food, such as cats (Miklósi et al., 2005), horses (Maros et al., 2008; McKinley & Sambrook, 2000), domestic goats (Kaminski et al., 2005), and even non-domesticated species such as

African elephants (Smet & Byrne, 2013), bats (Hall et al., 2011), and sea lions (Malassis & Delfour, 2015). Dogs, however, seem to be more skilled at understanding more difficult gestural cues, such as momentary distal pointing and following gaze to a location, whereas other species seem to understand only the more salient cues (Kaminski & Nitzschner, 2013; Kaminski et al., 2005; Maros et al., 2008). Dogs also learn to follow human gestural communication from a young age, and many individuals are successful starting from the first trial (Kaminski & Nitzschner, 2013).

2.6.1.2 Factors influencing gesture test performance

Dogs are able to understand dynamic pointing from as young as 6–8 weeks of age (Bray, Gnanadesikan et al., 2021; Bray, Gruen, et al., 2021; Riedel et al., 2008; Zaine et al., 2015). When it comes to momentary pointing gestures, studies have found that young (under 21-week-old) puppies perform at chance levels (Dorey et al., 2010; Salomons et al., 2024), whereas performance seems to increase with age and is above chance level after about 21 weeks of age (Dorey et al., 2010).

Some studies suggest that dogs' ability to respond to communicative gestures does not show age-related improvement, unlike many other cognitive traits (Agnetta et al., 2000; Espinosa et al., 2023; Gácsi, Kara, et al., 2009; Lazarowski, Krichbaum, et al., 2020; Lyn et al., 2021; Riedel et al., 2008). However, other studies have found that dogs' performance improves across development and throughout adulthood (Bray, Gnanadesikan, et al., 2021; Bray, Gruen, et al., 2021; Byosiere et al., 2022; Dorey et al., 2010; Watowich et al., 2020; Wynne et al., 2008). The result may depend on the methodology used as well as the extent and quality of experience with humans for the tested population.

It seems that sufficient exposure to humans is necessary for this skill to develop (Jarvis & Hall, 2020), since pet dogs living in homes often outperform shelter and kennel-raised dogs as well as free-ranging dogs (Bhattacharjee et al., 2017; D'Aniello et al., 2017; Duranton & Gaunet, 2016; Lazarowski & Dorman, 2015; Udell et al., 2008; Udell et al., 2010; Zaine et al., 2015). However, some studies have found no differences between dogs with different living conditions or backgrounds (Cunningham & Ramos, 2014; Gácsi, Kara, et al., 2009; Hare et al., 2002; Lyn et al., 2024). These differing results may be due to detailed differences in the extent of positive human experiences in the different populations. For example, free-ranging dogs which received brief social petting from the experimenter were more likely to follow pointing cues (Bhattacharjee & Bhadra, 2022).

The influence of previous training experience has not been investigated greatly, but agility training was not associated with success in these tasks (Gácsi, Kara, et al., 2009), and guide dogs and detection dogs do not perform differently to pet dogs (Ittyerah & Gaunet, 2009; Lazarowski, Thompkins, et al., 2020).

Even though dogs as a species perform above chance levels at gesture following tasks (at least when using the easier pointing styles), there is a wide range of variation between individual dogs. A relatively large percentage of this variation can be explained by genetic factors (Bray, Gnanadesikan, et al., 2021; Gnanadesikan et al., 2020). Most studies report differences between groups of breeds. Breeds which have been selected for cooperation with humans (e.g., herding dogs) outperform those selected for independent work (e.g., ancient breeds) (Gácsi, McGreevy, et al., 2009; Kujala et al., 2023; Lazarowski, Thompkins, et al., 2020; Wobber et al., 2009), and "working breeds" outperform those which have not been selected for working roles (McCartney & Leavens, 2024).

However, when dog breeds were grouped according to genetic relatedness or original function in a meta-analysis, no differences between breed groups could be identified (Dorey et al., 2009). Similarly, no differences between hunting and herding breeds have been found (Riedel et al., 2008), or between border collies and Labrador retrievers (Szabó et al., 2017).

It seems likely that dogs' success in the object-choice task is possibly more based on heritable traits compared to other cognitive traits, but it is additionally influenced by lifelong learning and experiences with humans. More research is still required to provide a clearer picture of how age, sex, and breed influence dogs' performance in this task and how it might relate to real-life situations.

2.6.2 Unsolvable task

In addition to having an understanding of human communication, dogs attempt to direct communication toward humans in various ways. As an example, when dogs know the location of a reward which they cannot reach, they attempt to 'show' where the reward is hidden to the human who is not aware of the location (Hare et al., 1998; Miklósi et al., 2000). The dog might use movement, vocalization, or gaze alternations between the human and the location. This kind of 'showing' behaviour has been suggested to be similar to the pointing infants engage in to direct an adult's attention towards something (Butterworth & Jarrett, 1991; Tomasello et al., 2007). Dogs will engage in similar behaviours when they cannot reach a visible reward or when they are faced with a difficult problem-solving task.

2.6.2.1 Methodology

One commonly used method to investigate human-directed communication in dogs is the unsolvable task (Cavalli et al., 2018; Mendes et al., 2021b). There are many variations of this task, but in most cases the dog is presented with an apparatus with a reward inside. In most studies, the dog is first presented with solvable trials,

during which they learn to access the reward inside. After this, the task becomes unsolvable: the dog can see and smell the reward but cannot access it.

Dogs will usually first attempt to solve the task independently, as they did during the solvable trials, but eventually most dogs will engage in attention-seeking behaviour toward the human, such as gazing. Some may give up on the task altogether and engage in other behaviours, such as exploring the environment. Dogs spend significantly more time on human-directed behaviour during this task than intensively socialised wolves (Marshall-Pescini et al., 2017; Miklósi et al., 2003; Virányi et al., 2008). Therefore, it has been suggested that this behaviour is a result of domestication (Miklósi et al., 2003; Prato-Previde et al., 2014).

There are many hypotheses for why dogs gaze at humans in this situation (Mendes et al., 2021b; Prato-Previde et al., 2014). One common hypothesis is that dogs are engaging in communicative, 'help-seeking' behaviour (Hirschi et al., 2022; Miklósi et al., 2003; Riemer et al., 2024). Others have theorized that this behaviour is something dogs engage in when they have given up on the task. This is supported by the fact that dogs seem to be less persistent than wolves in problem-solving tasks, spending less time attempting to solve the task even when no human is present (Lazzaroni et al., 2019, 2020; Marshall-Pescini et al., 2017; Rao et al., 2018; Udell, 2015).

There have also been suggestions that this kind of human-directed action is mainly a learned behaviour (Barrera et al., 2011; D'Aniello & Scandurra, 2016), or simply a result of dogs' tendency to gaze at human faces in different contexts (Miklósi et al., 2003). Indeed, dogs have been found to gaze at humans in various situations, such as when facing an anxiety-inducing situation (Merola et al., 2012), and they are more likely to engage in eye contact with humans than wolves are (Bentosela et al., 2016).

2.6.2.2 Factors influencing unsolvable task performance

Just as is the case with gesture-following ability, dogs show a wide range of individual variation in their response to the unsolvable task; some will attempt to independently solve the task for the entire test duration, some will quickly abandon the task and explore the test room, and others will spend a large proportion of their time gazing at the human or engaging in other human-directed behaviours.

The tendency for this behaviour seems to be heritable (Persson et al., 2015), and breeds differ from each other in their response to this test. For example, ancient breeds (e.g., Alaskan Malamutes and basenjis) spend less time gazing at a human during the unsolvable task (Konno et al., 2016; Passalacqua et al., 2011), whereas herding and hunting breeds spend more time engaging in human-directed gazing (Passalacqua et al., 2011). However, one study found no differences between herding and ancient breeds (Kujala et al., 2023). Cooperative breeds also spend

more time gazing at humans compared to independent breeds (Pongrácz & Lugosi, 2024), although another study found no difference between these two breed groups (Lazarowski, Thompkins, et al., 2020). These different results could be explained partly by the specific breed compositions included in the different studies.

Dogs' behaviour in the unsolvable task is greatly influenced by ontogeny. Young, 2-month-old-puppies spend very little time in human-directed behaviour when faced with the unsolvable task, but their tendency for this behaviour increases with age (Bray, Gnanadesikan et al., 2021; Bray, Gruen, et al., 2021; Passalacqua et al., 2011; Salomons et al., 2024), and continues to increase in adulthood (Hori et al., 2013; Lazarowski, Thompkins, et al., 2020; Persson et al., 2015). However, some studies have found no effect of age (Konno et al., 2016; Van Poucke et al., 2022).

The results may depend on the specific methodology used but could also be influenced by the breed. In Labrador retrievers, age was not found to influence behaviour in the unsolvable task, but in German shepherds there was an increase in experimenter contact and decrease in owner contact with age (Sundman et al., 2018). Therefore, it is possible that age may have different effects in different breeds.

The age-related increases in human-directed gazing may be a result of experience with humans, since pet dogs living inside the house engage in more human-directed behaviour compared to shelter dogs, free-ranging dogs, and dogs living in kennels or outside the house (D'Aniello & Scandurra, 2016; Gould et al., 2022; Lazzaroni et al., 2020; Mendes et al., 2021a; O'Riordan & Roth, 2023). However, when faced with a solvable task or when no human is present, pet dogs seem to be more persistent than free-ranging dogs (Barrera et al., 2015; Lazzaroni et al., 2019; Rao et al., 2018).

When it comes to the influence of training, the direction of the effect seems to depend on the specific type of training. For example, dogs trained to perform as guide dogs, assistance dogs, or in scent work are more independent during the unsolvable task compared to pet dogs (Carballo et al., 2020; Lazarowski, Thompkins, et al., 2020; Marshall-Pescini et al., 2009; Pallonen, 2024; Scandurra et al., 2015). These are all roles which require dogs to make independent decisions without too much influence from humans.

In contrast, dogs trained for water rescue, agility, or animal-assisted interventions spend more time engaging with humans during the task (Cavalli et al., 2018; D'Aniello et al., 2015; Marshall-Pescini et al., 2009; Piotti et al., 2021). These are roles in which dogs may be required to be cooperative with people and to rely on the assistance of humans.

It should be noted that even if training for a particular role can influence dogs' behaviour in the unsolvable task, an individual's success in their role may be determined by different traits. For example, human-directed gazing was associated with success as a detection dog (Lazarowski et al., 2019) and assistant dog

(MacLean & Hare, 2018), even though dogs in both roles are more independent during the unsolvable task compared to pet dogs (Carballo et al., 2020; Lazarowski, Thompkins et al., 2020).

In conclusion, dogs' human-directed behaviour in the unsolvable task develops as the individual matures and is reliant on the extent of their exposure to humans and influenced by training. There seem to be significant heritable influences on this behaviour, but more research is still needed on the effects of breed, sex, and age, as well as how dogs' test performance might manifest in everyday life. For example, could more independent or persistent dogs be more challenging to train?

2.7 Inhibitory control and impulsivity

Inhibitory control is an executive function which allows individuals to suppress impulsive behaviour, thoughts, or emotions that would otherwise be performed almost automatically (Diamond, 2013). The opposite of inhibitory control is impulsivity, which is often defined as the tendency to act without foresight (Dougherty et al., 2003; Riemer et al., 2014). In humans, impulsivity is a stable behavioural trait which has been found to be associated with ADHD, mental health problems, reduced quality of life, substance abuse, poor financial habits, obesity, risky behaviour, aggression, and poorer academic success (de Ridder et al., 2012).

In dogs, impulsivity is associated with various behaviour problems (Piotti et al., 2018; Salonen et al., 2022; Sulkama et al., 2021; Vas et al., 2007; Wright et al., 2011), such as aggression (Amat et al., 2009; Brady, Hewison, et al., 2018; Gobbo & Šemrov, 2022; Peremans et al., 2003; Piotti et al., 2018; Pongrácz et al., 2021; Reisner et al., 1996; Salonen et al., 2022; Sulkama et al., 2021; Wright et al., 2011, 2012). Impulsive dogs may have difficulties calming down, relaxing, or concentrating for long periods of time, and they may become easily frustrated or distracted (Vas et al., 2007). As a result, impulsive dogs and their owners may struggle with everyday life, which may impact the dog-human relationship (Imponen & Pelliccioni, 2021) and the quality of life of both.

However, impulsivity is not always maladaptive; it can be advantageous in some working roles and dog sports which benefit from higher arousal, enhanced alertness and vigilance, higher responsiveness and motivation, and rapid reactions to commands and external stimuli (Brady, Cracknell, et al., 2018; Rooney et al., 2004). One example of this is the fact that in some breeds, working lines can be more responsive/impulsive than show lines (Fadel et al., 2016).

2.7.1 Measuring impulsivity/inhibitory control

Impulsivity is usually divided into at least two different types: impulsive choice and impulsive action (Dougherty et al., 2003; Winstanley et al., 2006). Impulsive choice

– sometimes referred to as cognitive impulsivity – is defined as a reduced tolerance to delayed reinforcement/gratification, i.e., how likely an animal is to choose a smaller, immediate reward in favour of a larger, delayed reward. Impulsive action – sometimes referred to as motor impulsivity – is defined as a difficulty in inhibiting a prepotent motor response in favour of a more advantageous behaviour.

Impulsive choice has most often been measured utilizing delay-discounting tasks (e.g., Brucks, Soliani, et al., 2017; Gobbo & Šemrov, 2022; Range et al., 2020; Riemer et al., 2014; Wright et al., 2012), which measure the maximum delay animals are willing to accept before switching to an instant, smaller reward. Various methodologies exist to test this, many of which require extensive training prior to testing. Other studies have used spatial delay discounting instead (Brady, Hewison, et al., 2018; Mongillo et al., 2019); the distance to the reward becomes gradually longer, until the maximum distance is reached for the individual.

Impulsive action is most often measured using the A-not-B task (e.g., Bray et al. 2014; Cook et al. 2016; Fagnani et al. 2016; MacLean et al. 2014; Topál et al., 2009) or some variation of a detour task. In the A-not-B task, the animal observes the experimenter placing a reward under cup A over a number of trials. During test trials, the experimenter shows how the reward is removed from under cup A and placed under cup B. The subject then has to inhibit their prepotent response of looking for the reward in the previously rewarded location.

In detour tasks, the animal is provided with a transparent barrier with a reward on the other side, and they are required to inhibit their prepotent response of attempting to reach the reward through the barrier, instead detouring around it to reach the reward. There are many variations of this task (Kabadayi et al., 2018), all of which may measure slightly different traits. The shape of the barrier can be, for example, a straight or a V-shaped fence (Albuquerque et al., 2021; Pongrácz & Veres, 2025; Pongrácz et al., 2001), or a transparent cylinder (Bray et al. 2014; Fagnani et al. 2016; MacLean et al. 2014; Marshall-Pescini et al. 2015).

Dogs' success on detour tasks depends largely on the shape of the barrier (Kabadayi et al., 2018; Pongrácz & Veres, 2025) and on the distance they are required to detour. Dogs as a species are more successful at the cylinder test, which requires reaching a short distance for the reward, than at the V-detour, which requires a longer detour (Kabadayi et al., 2018; Olsen, 2018). During the V-detour task, many dogs will, similarly to the unsolvable task, engage in human-directed gazing (e.g., Dobos & Pongrácz, 2023; Pongrácz et al., 2001; Shajid Pyari, 2022), which might reflect the difficulty of the task.

Some detour tasks variations include initial training trials during which the barrier is opaque. This is often the case with the cylinder test. After the dog learns to detour around to the open side, the cylinder becomes transparent. This makes the task more difficult, because the dog can see the reward through the barrier. In most studies, the dog is provided with multiple test trials, whereas in other detour

task variations, only one trial is provided. This is often the case with the V-detour task, where the dog's initial performance when faced with the problem is measured.

Other types of tests have also been used to measure inhibitory control in dogs, and these usually require the dog to obey a human in one way or another, such as waiting for permission before consuming a treat (e.g., Gnanadesikan et al., 2020; Horschler et al., 2019; Müller et al, 2016; Watowich et al., 2020). The problem with these kinds of tests is, however, that they may be heavily influenced by the dog's training history and environment.

Even though some tests of impulsivity have been found to be correlated (Mellor et al., 2024; Müller et al., 2016), most studies have found no correlations between tests, even when they are supposedly measuring the same subtype of impulsivity (Barela et al., 2024). The same finding has been made in studies of humans and other animals (Dick et al., 2010). The conclusion made by most researchers is that impulsivity is highly context specific (Barela et al., 2024; Dick et al., 2010); an individual may be impulsive in one context but show excellent self-control in a different context.

Another reason for the lack of correlation between tests of inhibitory control might be that many of these tests may require other cognitive abilities in addition to inhibitory control (Bray et al., 2014). For example, the A-not-B task might require working memory, object permanence, and reversal learning ability (Vernouillet et al., 2018). Tests which include several trials may measure learning speed, whereas others, such as the V-detour, might require spatial awareness and problem-solving skills (Marshall-Pescini et al., 2016; Pongrácz et al., 2005; Smith & Litchfield, 2010). Therefore, more research is needed to determine which cognitive and behavioural traits these tests are measuring.

2.7.2 Factors influencing impulsivity and inhibitory control

Similarly to social cognition, inhibitory control seems to be highly heritable (Gnanadesikan et al., 2020), and significant breed differences have been found for owner-assessed impulsivity (Fadel et al., 2016; Lit et al., 2010; Salonen et al., 2020; Sulkama et al., 2021; Wright et al., 2011).

However, most studies utilizing cognitive tests have found no differences between breeds or breed groups for the cylinder test (Silver et al., 2025), V-detour (Clarke et al., 2019; Marshall-Pescini et al., 2016), or other tests of inhibitory control (Horschler et al., 2019; Mellor et al., 2024). One study found a significant breed difference between German shepherds and giant schnauzers (Pongrácz et al., 2005), and another found high among-breed heritability values for a social self-control task (Gnanadesikan et al., 2020). It is possible that there are differences between individual breeds, but when breeds are divided into groups, these differences disappear.

Inhibitory control develops during ontogeny, with puppies usually being more impulsive than adults (Bray, Gnanadesikan et al., 2021; Bray, Gruen, et al., 2021; Foraita et al., 2023; Lazarowski, Krichbaum, et al., 2020; Salomons et al., 2024). Some aspects of inhibitory control show an inverted U-shape across aging, with performance increasing in puppyhood and reducing in adulthood (Watowich et al., 2020). For example, cylinder test performance has been found to improve during the puppy's first year of life (Bray, Gruen, et al., 2021; Lazarowski, Krichbaum, et al., 2020) and decrease in adulthood (Bray et al., 2014).

Questionnaire studies, in contrast, have found that hyperactivity/impulsivity decreases with age (Lit et al., 2010; Salonen et al., 2020; Sulkama et al., 2021; Wright et al., 2011), but this may be more related to activity levels decreasing with age rather than with inhibitory control improving. For the V-detour, contrasting results have emerged, with one study finding no age effects (Marshall-Pescini et al., 2016) and another finding that performance decreased with age (Mellor et al., 2024). Other tests of inhibitory control, such as the A-not-B-task, do not seem to be influenced by age (Bray et al., 2014; Brucks, Soliani, et al., 2017; Mellor et al., 2024; Mongillo et al., 2019; Vas et al., 2007).

In addition, the animal's experiences and environmental conditions can influence their ability to control their impulses. For example, high hyperactivity/impulsivity was more common in dogs that got less daily exercise and spent more time alone at home (Sulkama et al., 2021). Dogs which receive more training are generally more successful in tests of inhibitory control (Barrera et al., 2019; Horschler et al., 2019; Marshall-Pescini et al., 2016; Mellor et al., 2024) and score lower on owner-assessed impulsivity (Foraita et al., 2023; Lit et al., 2010). However, some studies have found no effect of training on impulsivity or inhibitory control (Silver et al., 2025; Vas et al., 2007).

The results may depend on the specific type of training received by dogs. Dogs trained for scent work exhibited higher overall inhibitory control compared to agility dogs (Mellor et al., 2024), and dogs which competed in barn hunting performed significantly worse on the cylinder test compared to untrained dogs (Silver et al., 2025). These differences may be due to inhibitory control being of more value in some roles (such as scent work), whereas impulsive reactions could even be advantageous in others (such as barn hunting).

Inhibitory control is a behavioural trait which seems to have many different subtypes, and an individual's ability to control their impulses can depend greatly on the context. Research on the factors associated with inhibitory control in dogs is still scarce, and different methodologies seem to produce different results. Since this is a potentially important trait for pet dogs as well as working dogs, more information is required on the factors which might influence different aspects of inhibitory control.

3 Aims of the study

Individual differences in canine cognition exist as a result of genetic, ontogenetic, and environmental factors. Especially social cognition and inhibitory control can greatly influence the daily lives of dogs and their owners, and therefore it is important to enhance our understanding of the causes and consequences of these traits.

Therefore, the aim of this thesis was to take a closer look at cognitive tests which are designed to measure social cognition (unsolvable task and gesture test) and inhibitory control (cylinder test and V-detour). The first aim was to determine the reliability and validity of these tests, i.e., whether results are stable across time and whether test performance correlates with individual's behaviour in other contexts outside of the test situation. The second aim was to investigate how and why individual differences in test performance occur, i.e., how does performance change across ontogeny, and what are the possible influences of dog-related factors such as sex, age, and breed.

The detailed research questions were:

1. Are there associations between cognitive test results and other contexts, such as everyday life? Do the same associations emerge when comparing test performance of puppies to owner-reported behaviour in adulthood?
2. Is there temporal stability in dogs' performance in these cognitive tests, either in adulthood or from puppy- to adulthood? Does repeated testing influence results, i.e., is there a possible learning effect?
3. How does age influence cognitive test results? Does performance change from puppy- to adulthood, and in what direction? Are there age-related changes during adulthood (between 1–8 years of age)?
4. How do breed and sex influence test results?

4 Materials and methods

4.1 Ethical statement

The study was conducted according to the guidelines of the Declaration of Helsinki and declared as ethically approved by the University of Helsinki Viikki Campus Research Ethics Committee (Statement 12/2021, accepted on 18/05/2021). Informed consent was obtained from all respondents.

4.2 smartDOG™ test battery

The cognitive test battery used in these studies was developed by adjunct professor Katriina Tiira in 2016 based on previous scientific publications (e.g., Bray et al., 2014; Marshall-Pescini et al., 2015, 2017; Miklósi & Soproni, 2005; Miklósi et al., 2003). SmartDOG™ Ltd is a company providing behavioural testing for dog owners, and therefore owners who wish to have their dogs tested pay a fee for participation. In return, they receive a report on how their dog performed in the test battery and what this might mean based on current research. In order to participate, dogs are required to have no overt aggression towards unfamiliar people.

SmartDOG™ offers different test batteries based on the owners' preferences. These are outlined in Table 1. Other variations are available to owners but outlined are the most common test batteries. Each of these test batteries includes the cylinder test, gesture test, and unsolvable task, with additional tests (such as the V-detour) included in the COGNITION and PUPPY test batteries. The most popular test battery is the smartDOG™ COGNITION test battery, which is available only for adults (>7 months old). The second most popular is the smartDOG™ PUPPY test battery, which includes many of the same cognitive tests but is only available for 3–7-month-old puppies (Study II).

Table 1 The types of test batteries offered by smartDOG™.

Test battery	Age of dogs	Length	Cognitive tests	Personality/behaviour tests
COGNITION	>7 mo	~1.5 h	8	3
PUPPY	≤7 mo	~1 h	5	5
SMALL PERSONALITY ASSESSMENT	>7 mo	~1 h	3	6

SmartDOG™ test batteries were provided by 14 trained female license testers at different test locations across Finland, most commonly a dog training hall/room with a minimum size of 30m². The testers had undergone intensive training in order to ensure consistency when administering the tests. Fresh drinking water was available throughout the test battery, the dog was off the lead, and the owner was always present during testing. The PUPPY and COGNITION test batteries included a short break of a maximum of 2 minutes between the gesture test and the V-detour task, during which the owner was asked to walk the dog outside briefly.

Each test included in the test batteries involved solving various problems for food or toy rewards. The owners were advised to bring the dog's favourite treats and/or toys to use as rewards. Participant dogs were required to be food motivated to some extent, since some tests (e.g., the gesture test) always included a food reward. In some cases, if the dog was more motivated by toys than food, a toy reward was used. In the majority of cases, however, food rewards were used. Owners were advised not to feed their dogs for a few hours prior to the test battery to ensure food motivation.

Tests included in the COGNITION test battery are outlined in Table 2, and more details on methodology can be found in Study II for the PUPPY test battery and Study III for the COGNITION test battery. Tests were performed in the same order for all dogs in all test batteries to ensure consistency across subjects. In the studies included in this thesis, we focused on four cognitive tests: the cylinder test, gesture test, V-detour, and unsolvable task. These tests were chosen because they are assumed to measure social cognition and inhibitory control, traits which have potentially important implications for the everyday life of dogs and their owners. In addition, these particular tests have been the focus of a wide range of research on the cognition of dogs as well as other species.

Table 2 Tests included in the COGNITION test battery, in the same order they were presented to the dog. Table reprinted and modified from Junttila, S., Valros, A., Mäki, K., & Tiira, K. (2024). Do cognitive traits associate with everyday behaviour in the domestic dog, *Canis familiaris*? *Animal Behaviour*, 213, 71-84 under CC BY 4.0 license.

Test	Trait(s) measured	No. of test trials	Description	Measure
Greeting	Sociability, greeting behaviour towards an unfamiliar person	1	The dog's behaviour upon first greeting the tester was rated.	Scale of 1–7: 1=aggressive/fearful 7=overexcitedly friendly
Activity level	Average activity level during the test battery	N/A	The dog was supplied with a FitBark (Colpoys & deCock, 2021) activity monitor for the duration of the test battery, providing an average activity level for the dog.	Bark Points (www.fitbark.com)
Exploration	Explorative behaviour	1	The dog's explorative behaviour during its first few minutes in the testing environment was rated while the owner was sitting down to fill an information sheet.	Scale of 1–5: 1=no exploration, staying next to owner 5=very active exploration, running
Cylinder test	Inhibitory control, impulsivity	10	The dog had to first pass a minimum of 4 successful trials where they had to detour to the side of an opaque cylinder to reach a reward inside. The cylinder then became transparent, and the dog had to inhibit their response to reach directly for the reward and instead go around the barrier (See Figure 3).	% of correct responses (reaching the reward without touching the front of the cylinder with muzzle or paw)
Gesture test	Social cognition, ability to understand human communicative signals	30 for adults, 18 for puppies	A food reward was placed in one of two bowls. The human provided a gesture towards the baited bowl while standing (adult dogs) or kneeling (puppies) in front of the dog (See Figure 4). Each gesture was provided over 6 trials. Gestures included: dynamic distal pointing, momentary distal pointing, dynamic foot pointing, dynamic cross-forward pointing, and gaze. Momentary distal pointing and foot pointing were not included in the PUPPY test.	% of correct responses out of all trials
V-detour	Inhibitory control, spatial problem-solving ability	1 trial of 180 s	The dog was required to reach a reward by detouring around a V-shaped fence (See Figure 5).	Latency (s) to reach the reward
Unsolvable task	Social cognition, communicative / help-seeking behaviour, persistence, problem-	1 trial of 120 s	The dog first learned to open a puzzle box over a minimum of 4 trials to reach a reward inside (See Figure 6). The problem then became unsolvable, and the reward was visible but out of reach. For puppies and small dogs, the size of the apparatus was smaller.	Time (s) spent on each of the three possible behaviours: a) human-directed behaviour such as gazing

	solving strategy			b) independent behaviour, attempting to solve the task c) abandoning the task, i.e., engaging in behaviours not directed at a human or the apparatus
Logical reasoning (not included in PUPPY test)	Logical reasoning, ability to make inferences based on exclusion	6	The dog was shown that one of two bowls was empty, and they had to infer that the treat was hidden under the other bowl.	% of correct responses
Memory vs gesture (not included in PUPPY test)	Dog's tendency to choose based on human gesture vs visual information, social cognition	2	The dog could see a human placing a treat in one bowl, and the human gestured towards the other (unbaited) bowl. The dog's choice was then observed.	Number of trials where the dog chose based on the human's gesture
Memory (not included in PUPPY test)	Spatial short-term memory	4	The dog was required to remember the location of a food treat which was hidden under one of three bowls for an increasing duration of time, from 1 to 2.5 minutes.	Number of correct trials
Social learning	Social learning from a human demonstrator, social cognition	1	The dog watched as the tester pressed the button on a treat-dispensing apparatus, after which the dog was allowed to eat the treats. This was repeated 5 times, after which the dog was allowed to attempt accessing the treats independently.	Whether or not the dog shows evidence of social learning (binary variable)

Figure 3 Cylinder test: Test phase with a transparent cylinder. Imagine by Mainossatama Oy. Figure reprinted from Junttila, S., Valros, A., Mäki, K., Väätäjä, H., Reunanen, E., & Tiira, K. (2022). Breed differences in social cognition, inhibitory control, and spatial problem-solving ability in the domestic dog (*Canis familiaris*). *Scientific Reports*, 12(1), 22529 under CC BY 4.0 license.

Figure 4 Gesture Test for adult dogs: Dynamic distal pointing. Image by Mainossatama Oy. Figure reprinted from Junttila, S., Valros, A., Mäki, K., Väätäjä, H., Reunanen, E., & Tiira, K. (2022). Breed differences in social cognition, inhibitory control, and spatial problem-solving ability in the domestic dog (*Canis familiaris*). *Scientific Reports*, 12(1), 22529 under CC BY 4.0 license.

Figure 5 V-detour. Image by Minna Sirviö. Figure reprinted from Junttila, S., Valros, A., Mäki, K., Väätäjä, H., Reunanen, E., & Tiira, K. (2022). Breed differences in social cognition, inhibitory control, and spatial problem-solving ability in the domestic dog (*Canis familiaris*). *Scientific Reports*, 12(1), 22529 under CC BY 4.0 license.

Figure 6 Unsolvable Task: Test phase, during which the puzzle box is sealed shut. The dog is engaging in independent problem-solving behaviour. Image by Mainossatama Oy. Figure reprinted from Junttila, S., Valros, A., Mäki, K., Väätäjä, H., Reunanen, E., & Tiira, K. (2022). Breed differences in social cognition, inhibitory control, and spatial problem-solving ability in the domestic dog (*Canis familiaris*). *Scientific Reports*, 12(1), 22529 under CC BY 4.0 license.

4.3 Questionnaire (Studies I and II)

In order to investigate everyday behaviour of dogs in their home environment, a questionnaire was sent to dog owners who had participated in the smartDOG™ test battery between 2016 and 2022.

In addition to questions regarding demographic and background information, the questionnaire included the Dog Impulsivity Assessment Scale (DIAS) and the Canine Behavior Assessment and Research Questionnaire (C-BARQ). Both questionnaires have been extensively validated in previous studies (Duffy & Serpell, 2012; Hsu & Serpell, 2003; Wright et al., 2011). We translated the questionnaires into Finnish, after which they were back translated and adjusted when necessary. A pilot version of the questionnaire was then sent to a small number of dog owners. The wording of questions was changed accordingly if necessary.

We ran a factor analysis and principal component analysis (PCA) for the C-BARQ and DIAS, respectively, in order to ensure that the emerging factors were similar to the original English-language questionnaires. For C-BARQ, this resulted in 11 factors which accounted for 51.9 % of the variation. For DIAS, the final structure included two factors which accounted for 40.2 % of the variation. The processes and emerging factor structure are described in more detail in the supplementary materials of Study I.

We decided to investigate behavioural variables which, based on current theoretical knowledge, could be most likely to be associated with cognitive measures. As a result, we included 4 factors from the C-BARQ questionnaire and 2 from the DIAS questionnaire. In addition, we calculated an overall questionnaire score for DIAS, using the same methodology as the original DIAS study (Wright et al., 2011). We included two additional variables calculated from the C-BARQ questionnaire: 'Stereotypies' and 'Management Problems', as well as an individual question "Is your dog slow to learn new tricks or tasks?". For Study II, we included only the questionnaire variables which had significant associations with cognitive test results in Study I. An outline of the factors and additional variables we included in Studies I and II is provided in Table 3.

Table 3 Variables included from the C-BARQ and DIAS questionnaires in Studies I and II.

Variable	Type of variable	Study
C-BARQ		
Stranger-directed Fear	Factor	I & II
Trainability	Factor	I & II
Energy Level	Factor	I & II
Excitability	Factor	I & II
Stereotypies	Additional variable (highest score from questions regarding stereotypical behaviour, e.g., tail chasing)	I
Management Problems	Additional variable (sum of scores for questions regarding excessive pulling on the lead, stealing food, escaping, and chewing on inappropriate objects)	I & II
Slowness to Learn	Individual question "Is your dog slow to learn new tricks or tasks?"	I & II
DIAS		
Behavioural Regulation	Factor	I & II
Impulsive Aggression	Factor	I
Overall DIAS score	Calculated score from all 18 DIAS questions	I & II

Study data were collected and managed using REDCap (Harris et al., 2009, 2019) electronic data capture tools hosted at the University of Helsinki. Access to the online questionnaire opened at the beginning of 2022, and access was available until the end of 2022. We sent a link via email to all dog owners who had taken part in any smartDOG™ test battery since 2016 and had given written permission to participate in research (N = 4,383). Out of the total number of tested dogs, we received valid questionnaire replies for 1,420 dogs, out of which 1,407 could be matched with smartDOG™ test battery results.

4.4 Subjects

A total of 4,383 dogs took part in a smartDOG™ test battery between 2016 and 2022. Out of these, 1,456 were puppies (7 months or younger).

Study I included three different datasets of dogs:

1. Adult dogs which had taken part in the test battery two times (N = 49), to analyse test-retest reliability of the cognitive tests.
2. Adult dogs which had taken part in the cognitive tests and had valid questionnaire answers filled in by owners (N = 987), to investigate associations between cognitive test scores and questionnaire variables.

3. Adult dogs which had taken part in the cognitive tests (N = 2,874), to investigate associations between cognitive test scores and personality/behavioural test scores (greeting, exploration, and activity level).

Study II included three different datasets of puppies and adult dogs:

1. Dogs which had taken part in the test battery once as a puppy and once as an adult (N = 99), to investigate the stability of traits from puppy- to adulthood, as well as the direction of any age-related changes.
2. Naïve adult dogs which had not taken part in a test battery previously (N = 2,946). This dataset was compared to the adults in dataset 1, which had been tested once as a puppy and once as an adult, in order to determine whether any age-related changes might be due to possible learning effects from repeated testing.
3. Dogs which had taken part in the test battery as a puppy and their owners had filled in the questionnaire when the dogs were adults (N = 227), in order to investigate associations between puppy cognitive test results and adult questionnaire variables.

Study III included adult dogs from 13 breeds in order to investigate breed differences of cognitive test scores (N = 1,002). Only breeds with a minimum of 40 adult dogs tested per breed were included.

See Table 4 for sample sizes and demographic details for each study. Most participants were pet dogs and lived in the house with their owners, although some working dogs (7 % of dogs in Study I) also took part, most of which lived in the house with their owners. We limited the age range for each study, since cognitive traits take time to develop in puppies (Bray, Gruen, et al., 2021; Lazarowski, Krichbaum, et al., 2020; Passalacqua et al., 2011) and can decline with age (Chapagain et al., 2018).

Table 4 Sample sizes and demographic details of dogs in each study.

Age 1 refers to the age of the dogs at the first testing occasion, whether as puppies or as adults. Age 2 refers to the age when the questionnaire was filled in or at the time of the second test occasion. Background information in Study II Dataset 3 was collected from adult dogs.

Study	Dataset	Sample size N	No. of breeds	% males	Age 1 range (median)	Age 2 range (median)	Range of time between age 1 and age 2 (median)
Study I	**Dataset 1** (test-retest reliability)	49	23	28.6	11mo–6.3y (1.8y)	12mo–8.9y (3.8y)	0mo–5y (1.3y)
	Dataset 2 (cognition and questionnaire)	987	157	46.7	8mo–13.5y (2.8y)	11mo–15.3y (5.2y)	0 days–6.6y (1.8y)
	Dataset 3 (cognition and behaviour tests)	2,874	223	45.9	8mo–7.1y (2.7y)	–	–
Study II	**Dataset 1** (stability from puppy- to adulthood)	99	47	48.5	3–7mo (5mo)	1–6.6y (2.1y)	6mo–6.1 y (1.7y)
	Dataset 2 (naïve adults)	2,946	230	45.8	1–7.1y (2.7y)	–	–
	Dataset 3 (cognition and questionnaire)	227	80	43.2	3–7mo (5mo)	1–7.1y (2.2y)	6mo–6.6y (1.7y)
Study III	(breed differences)	1,002	13	43.8	1–8y (2.9y)	–	–

Most participants were experienced dog owners who had owned a minimum of 2 dogs previously, including the current dog (90 % of owners in Study I), and many had owned 6 or more dogs (35 % of owners in Study I). The large majority of participant dogs had taken part in dog sports or some other training activity (90 % of dogs in Study I). Most dogs were acquired from a breeder or similar, and only 7.5 % of dogs in Study I were rescue dogs or rehomed dogs.

4.5 Data handling and analysis

All statistical analyses were performed using IBM SPSS, using version 28 for Study III and version 29 for Studies I and II. An alpha level of 0.05 was used for all statistical tests. All p-values were corrected for multiple testing using false discovery rate (FDR) with the Benjamini-Hochberg procedure in Studies I and II, and Bonferroni-correction for Study III. For Studies I and II, p-values before and after FDR-correction are reported. See Table 5 for an overview of statistical analyses used for each study.

Table 5 Methods used in Studies I, II and III for each dataset.

Variables are continuous unless stated otherwise. Explanations of datasets: Study I dataset 1: Test-retest reliability. Study I dataset 2: Associations between cognitive test scores and questionnaire scores in adults. Study I dataset 3: Associations between cognitive test scores and behavioural test scores in adults. Study II dataset 1: Stability of cognitive test scores from puppy- to adulthood. Study II dataset 2: Comparison of naïve adult dogs and adult dogs with previous experience of the cognitive tests. Study II dataset 3: Associations between puppy cognitive test scores and adult questionnaire scores. Study III: Breed differences of cognitive test scores.

	Study I			Study II			Study III
Dataset	**1**	**2**	**3**	**1**	**2**	**3**	
Sample collection							
Test battery	■	■	■	■	■	■	■
Questionnaire		■				■	
Data analysis							
Linear mixed models		■				■	
Generalized linear mixed models		■				■	
Spearman's rank correlation			■	■			
Mann-Whitney U-test					■		
Wilcoxon signed rank test				■			
Multiple logistic regression							■
Ordinal logistic regression							■
Fisher's exact test							■

	Study I			Study II			Study III
Dataset	**1**	**2**	**3**	**1**	**2**	**3**	
Intraclass correlation coefficient	■						
Weighted kappa	■						
Questionnaire variables							
DIAS overall score		■				■	
DIAS Behavioural Regulation		■				■	
DIAS aggression (ordinal)		■					
Stranger-directed fear							
Continuous (log-transformed)		■					
Ordinal						■	
Trainability		■				■	
Management problems		■				■	
Stereotypies (ordinal)		■					
Test battery variables							
Cylinder Test (% correct)	■	■	■	■	■	■	■
Gesture Test (% correct)	■	■	■	■	■	■	■
V-detour							
Latency for solving (s)	■	■	■	■	■	■	■
Success in V-detour (binary)							■
Unsolvable Task							
Human-directed behaviour (s)	■	■	■	■	■	■	■
Independent problem-solving (s)			■	■	■		
100 % independent (binary)							■
Abandoning task (s)			■	■	■		
Task abandoned (binary)							■
Greeting (ordinal)			■				
Exploration (ordinal)			■				
Activity level			■				
Independent variables							
Test battery variables	■	■	■	■	■	■	
Breed (categorical)							■
Dependent variables							
Questionnaire variables		■				■	
Test battery variables	■		■	■	■		■
Control variables							
Age		■				■	■

	Study I			Study II			Study III
Dataset	**1**	**2**	**3**	**1**	**2**	**3**	
Sex		■				■	■
Presence of illness (binary)		■				■	
Food motivation (ordinal)		■				■	
Previously owned dogs (ordinal)		■				■	
Origin of dog (rescue/breeder)		■					
Training level (ordinal)		■				■	

4.5.1 Studies I and II

In Studies I and II, breed and tester identity were included as random variables (random intercept) where possible. In some models, however, one or both variables were redundant and resulted in uncertain model fit and were therefore excluded (See Studies I and II for details).

4.5.2 Study III

Breed was used as the independent variable in all models. The Labrador retriever was used as the reference breed, since this was the breed with the largest sample size out of the included pedigree breeds.

The cylinder test variable was reflected, and a square-root transformation was applied due to negative skew. As a result, the variable was inverted. The original values for all transformed variables are reported in the figures, whereas the transformed variables are reported in the text.

Due to a skewed distribution of the continuous V-detour variable, unsuccessful dogs were removed. In addition, the variable was log-transformed due to non-normality. We created an additional binary variable, 'Success in V-detour', which divided dogs into successful and unsuccessful groups.

For the same reason, dogs which spent 100 % of their time attempting to independently solve the unsolvable task had to be removed from the continuous variable 'Human-directed behaviour'. An additional binary variable was created, called '100 % independent', which divided dogs into those which spent 100 % of their time on independent problem-solving and those which spent a minimum of 1 second on human-directed behaviour. In addition, instead of investigating time spent on abandoning the task, which was not normally distributed, we divided dogs into two groups: those which spent a minimum of 1 second abandoning the task and those which never abandoned the task. See Table 1 for the full list of independent and dependent variables.

A two-tailed paired samples t-test showed that there was no significant change in dogs' performance in the gesture test between the first 6 trials and the last 6 trials (mean decrease of 0.84 %, 95 % CI [-2.65, 0.96], $t(831) = -0.92$, $p = 0.36$, $d = -0.03$). Therefore, it is unlikely that there was a learning effect during the test.

5 Results

5.1 Associations between cognition and everyday behaviour (Studies I and II)

See Table 6 for detailed results of all significant associations. For Study II the puppy-adult associations described below were statistically significant only prior to FDR-correction.

Table 6 Results from linear mixed models from Studies I and II.

The table includes all associations between cognitive test results and questionnaire variables which were significant prior to FDR-correction. Significant p-values are in bold. Table reprinted and modified from Junttila, S., Valros, A., Mäki, K., & Tiira, K. (2024). Do cognitive traits associate with everyday behaviour in the domestic dog, *Canis familiaris*? *Animal Behaviour*, 213, 71-84, and Junttila, S., Valros, A., Mäki, K., & Tiira, K. (2025) Puppy (3–7-month-old) cognitive tests as predictors of adult dog cognition and behaviour. *Applied Animal Behaviour Science*, 286, 106599 under CC BY 4.0 license.

Independent variable	Dependent variable	*N*	B	SE	95 % CI	*P*	FDR-corrected *p*-value
Cylinder test (Study I: adult)	**Trainability**	937	0.07	0.03	0.02–0.12	**0.007**	**0.04**
	Slowness to Learn	924	-0.16	0.06	-0.28–-0.03	**0.02**	0.07
	Excitability	937	-0.07	0.03	-0.12–-0.01	**0.02**	0.07
	Energy Level	937	-0.06	0.03	-0.12–-0.007	**0.03**	0.09
	Overall DIAS	922	-0.02	0.003	-0.03–-0.01	**<0.001**	**<0.001**
	Behavioural Regulation (DIAS)	896	-0.04	0.005	-0.05–-0.03	**<0.001**	**<0.001**
Cylinder test (Study II: puppy)	**Energy Level**	221	-0.114	0.051	-0.215–-0.013	**0.03**	0.38
	Overall DIAS	221	-0.014	0.006	-0.026–-0.01	**0.03**	0.38
	Behavioural Regulation (DIAS)	220	-0.02	0.01	-0.04–0	**0.045**	0.45
Gesture test (Study II: puppy)	**Trainability**	185	0.115	0.038	0.041–0.189	**0.003**	0.15
V-detour (Study I: adult)	**Management Problems**	867	-0.26	0.083	-0.42–-0.09	**0.002**	**0.01**
	Slowness to Learn	933	0.15	0.06	0.03–0.27	**0.02**	0.07
	Overall DIAS	931	-0.008	0.003	-0.01–-0.001	**0.02**	0.08

Independent variable	Dependent variable	*N*	B	SE	95 % CI	*P*	FDR-corrected *p*-value
Unsolvable task: Human-directed behaviour (Study I: adult)	**Trainability**	926	0.07	0.03	0.02–0.12	**0.006**	**0.03**
	Stranger-directed Fear	926	0.02	0.005	0.006–0.03	**0.002**	**0.01**
	Management Problems	847	-0.28	0.09	-0.45–-0.11	**0.001**	**0.01**
	Overall DIAS	911	-0.01	0.003	-0.02–-0.004	**0.001**	**0.01**
	Behavioural Regulation (DIAS)	885	-0.02	0.005	-0.03–-0.006	**0.002**	**0.01**
Unsolvable task: Human-directed behaviour (Study II: puppy)	**Stranger-directed Fear**	218	0.341	0.141	0.064–0.619	**0.02**	0.38

5.1.1 Cylinder test

Adult dogs (Study I) which had lower inhibitory control in the cylinder test were evaluated as significantly less trainable, and they had significantly higher impulsivity scores, both in the overall DIAS score and the factor 'Behavioural Regulation'. These dogs were also more excitable, slower at learning, and had higher energy levels, but these associations became marginally nonsignificant after FDR-correction.

Puppies (Study II) which had lower inhibitory control in the Cylinder Test were significantly more likely to have higher energy levels and impulsivity (overall DIAS and Behavioural Regulation) as adults.

5.1.2 Gesture test

Puppies which were more successful at following human gestures were significantly more trainable as adults (Study II).

5.1.3 V-detour

Adult dogs (Study I) which were faster at solving the V-detour task had significantly more management problems (such as excessive pulling on the lead, stealing food, escaping, and chewing on inappropriate objects). They were also more impulsive (overall DIAS) and faster at learning new tasks, but these associations became marginally nonsignificant after FDR-correction.

5.1.4 Unsolvable task

Adult dogs (Study I) which spent more time on human-directed behaviour were significantly more trainable. They also had significantly lower impulsivity (overall DIAS and Behavioural Regulation), less management problems, and higher stranger-directed fearfulness.

Puppies (Study II) which spent more time on human-directed behaviour were more likely to be fearful of strangers as adults.

5.2 Associations between cognitive test and behavioural test results

We found significant correlations between several cognitive test results and behavioural test scores. See Table 7 for detailed results.

Table 7 Correlations between personality/behavioural measures and cognitive test scores.

High greeting scores refer to higher friendliness, whereas lower scores refer to higher fearfulness. Significant correlations are in bold. **p < 0.001; *p < 0.05. Table reprinted and modified from Junttila, S., Valros, A., Mäki, K., & Tiira, K. (2024). Do cognitive traits associate with everyday behaviour in the domestic dog, *Canis familiaris*? *Animal Behaviour*, 213, 71-84 under CC BY 4.0 license.

Variable		Greeting	Exploration	Activity Level
Cylinder Test	r	**-0.12****	**-0.11****	**-0.1****
	(*N*)	(2 676)	(2 364)	(2 354)
Gesture Test	r	0.02	**0.09****	**0.06***
	(*N*)	(1 683)	(1 481)	(1 652)
V-detour (latency)	r	**-0.06***	**-0.17****	**-0.15****
	(*N*)	(2 704)	(2 391)	(2 379)
Unsolvable task				
Human-directed behaviour	r	-0.03	**-0.06***	**-0.09****
	(*N*)	(2 654)	(2 371)	(2 332)
Independent problem-solving	r	**0.1****	**0.11****	**0.09****
	(*N*)	(2 655)	(2 372)	(2 332)
Abandoning task	r	**-0.1****	**-0.1****	0.008
	(*N*)	(2 656)	(2 373)	(2 329)

5.3 Test-retest repeatability

All cognitive tests showed fair to moderate agreement (Koo & Li, 2016; Landis & Koch, 1977). See Table 8 for detailed results.

Table 8 Test-retest reliability of cognitive tests.

Table reprinted and modified from Junttila, S., Valros, A., Mäki, K., & Tiira, K. (2024). Do cognitive traits associate with everyday behaviour in the domestic dog, *Canis familiaris*? *Animal Behaviour*, 213, 71-84 under CC BY 4.0 license.

Test	Result	Analysis	Strength of Agreement
Cylinder test	0.35	Weighted kappa	Fair
Gesture test	0.53	ICC	Moderate
V-detour	0.48	Weighted kappa	Moderate
Human-directed behaviour (unsolvable task)	0.46	Weighted kappa	Moderate

5.4 Development and stability of cognitive traits

Most cognitive test results correlated significantly between puppies and adults, apart from cylinder test performance and time spent on abandoning the unsolvable task. See Table 9 for detailed results for the correlations between puppy and adult scores.

Table 9 Results from Spearman's rank correlation analyses comparing puppy and adult test scores, and median scores for puppies and adults.

Significant p-values are in bold. Table reprinted and modified from Junttila, S., Valros, A., Mäki, K., & Tiira, K. (2025). Puppy (3–7-month-old) cognitive tests as predictors of adult dog cognition and behaviour. *Applied Animal Behaviour Science*, 286, 106599 under CC BY 4.0 license.

Test variable	r_s	*p*	FDR-corrected *p*	*N*	Puppy median (min–max)	Experienced adult median (min–max)	Naïve adult median (min–max)
Cylinder Test	0.15	0.07	0.11	98	80 (0–100)	90 (0–100)	80 (0–100)
Gesture Test	0.41	**<0.001**	**<0.001**	98	83 (42–100)	80 (43–100)	77 (17–100)
V-detour (s)	0.43	**<0.001**	**<0.001**	99	23 (3–180)	11 (3–180)	17 (2–180)

Test variable	r_s	*p*	FDR-corrected *p*	*N*	Puppy median (min–max)	Experienced adult median (min–max)	Naïve adult median (min–max)
Unsolvable task							
Independent problem-solving (s)	0.32	**<0.001**	**0.009**	96	90 (10–120)	51 (5–120)	47 (0–120)
Human-directed behaviour (s)	0.22	**0.02**	0.05	96	11.5 (0–110)	50 (0–115)	57.5 (0–120)
Abandon task (s)	0.1	0.17	0.23	96	2.5 (0–94)	0 (0–96)	0 (0–120)

5.4.1 Cylinder test

There was a weak correlation between puppy and adult test scores in the cylinder test. Dogs' performance in the test increased significantly from puppy- to adulthood ($z = 5.33$, $p < 0.001$, FDR-corrected $p < 0.001$, $N = 98$). Adult dogs showed improved performance if they had previously taken part in a puppy test, compared to naïve adult dogs with no experience of cognitive testing ($U = 84{,}105.5$, $z = -6.93$, $p < 0.001$, FDR-corrected $p < 0.001$, $N = 2{,}985$).

5.4.2 Gesture test

There was a moderate correlation between puppy and adult test scores in the gesture test. Puppies and adults did not significantly differ from each other in their median scores ($U = 114{,}257.5$, $z = -1.41$, $p = 0.16$, FDR-corrected $p = 0.24$, $N = 2{,}643$). There was no significant difference between median scores of naïve and experienced adult dogs ($U = 114{,}257.5$, $z = -1.41$, $p = 0.16$, FDR-corrected $p = 0.24$, $N = 2{,}643$).

5.4.3 V-detour

There was a moderate correlation between puppy and adult scores in the V-detour task. Dogs' performance in the test increased significantly from puppy- to adulthood ($z = -3.1$, $p = 0.002$, FDR-corrected $p = 0.004$, $N = 99$), with adults solving the task faster. Adult dogs showed improved performance if they had previously taken part in a puppy test, compared to naïve adult dogs with no experience of cognitive testing ($U = 123{,}088.5$, $z = -2.53$, $p = 0.01$, FDR-corrected $p = 0.03$, $N = 3{,}021$).

5.4.4 Unsolvable task

There was a weak correlation between puppy and adult test scores for time spent on independent problem-solving and human-directed behaviour. Adult dogs spent significantly more time on human-directed behaviour ($z = 5.86$, $p < 0.001$, FDR-corrected $p = 0.001$, $N = 96$) and less time on independent problem-solving ($z = -5.47$, $p < 0.001$, FDR-corrected $p < 0.001$, $N = 96$) compared to when they were puppies.

There was no significant correlation between puppy and adult test scores for abandoning the task. The median time spent on abandoning the task did not differ significantly between puppies and adults ($z = -1.53$, $p = 0.13$, FDR-corrected $p = 0.16$, $N = 96$). However, in a larger dataset of puppies ($N = 1,486$) and naïve adults ($N = 3,154$), puppies spent significantly more time abandoning the task than adults (puppy median = 7 s, adult median = 0 s, $U = 1,768,472.5$, $z = -14.44$, $p < 0.001$). It must be noted, though, that this was a cross-sectional rather than a longitudinal analysis.

None of the test variables differed significantly between naïve and experienced dogs ($p > 0.1$).

5.5 Breed differences (Study III)

5.5.1 Cylinder test

The multiple regression model significantly predicted the percentage of incorrect trials ($F(14, 961) = 6.96$, $p < 0.001$, adj. $R^2 = 0.08$). Increasing age was associated with an increased percentage of incorrect trials in dogs aged 1–8 years ($\beta = 0.13$, $p < 0.001$). Females made significantly fewer mistakes than males ($\beta = -0.09$, $p = 0.004$). Breed was a significant predictor of test performance. See Figure 7 for significant results and the mean percentages of correct trials for each breed.

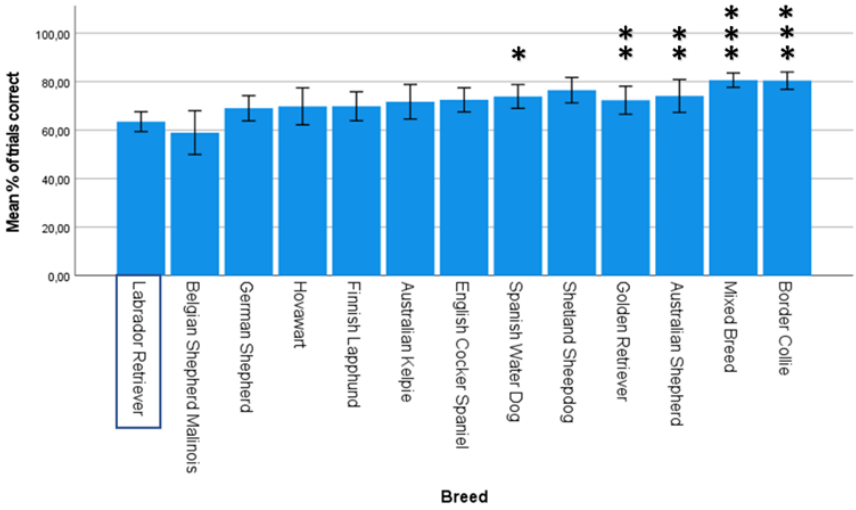


Figure 7 Raw data with the mean percentage of correct trials for each breed in the cylinder test are presented, using the untransformed, original data (n = 992). Error bars represent 95 % confidence intervals. Breeds are ordered based on B-values, with lowest success (low inhibitory control) on the left and highest success (high inhibitory control) on the right. The breeds which differ significantly from the reference breed (the Labrador retriever) are indicated with asterisks: ***p ≤ 0.001, **p ≤ 0.01, *p ≤ 0.05 (Bonferroni-corrected). Figure reprinted from Junttila, S., Valros, A., Mäki, K., Väätäjä, H., Reunanen, E., & Tiira, K. (2022). Breed differences in social cognition, inhibitory control, and spatial problem-solving ability in the domestic dog (*Canis familiaris*). *Scientific Reports*, 12(1), 22529 under CC BY 4.0 license.

5.5.2 Gesture test

The multiple regression model significantly predicted the percentage of correct trials ($F(14, 804) = 3.41$, $p < 0.001$, adj. $R^2 = 0.04$). Sex and age (in dogs aged 1–8 years) did not significantly predict performance in the Gesture Test. Breed was a significant predictor of test performance. See Figure 8 for significant results and the mean percentages of correct trials for each breed.

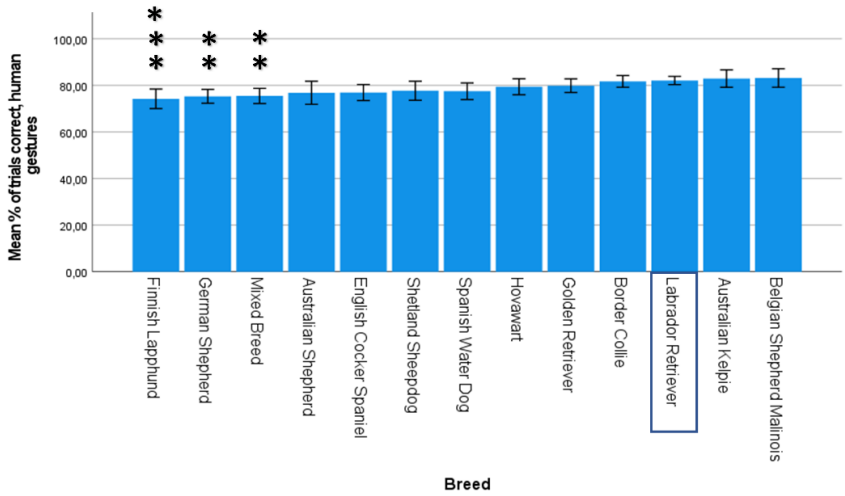


Figure 8 Raw data with the mean percentage of correct trials for each breed in the gesture test are presented (n = 831). Error bars represent 95 % confidence intervals. Breeds are ordered based on B-values, with lowest success rates on the left and highest success rates on the right. The breeds which differ significantly from the reference breed (the Labrador retriever) are indicated with asterisks: ***p ≤ 0.001, **p ≤ 0.01, *p ≤ 0.05 (Bonferroni-corrected). Figure reprinted from Junttila, S., Valros, A., Mäki, K., Väätäjä, H., Reunanen, E., & Tiira, K. (2022). Breed differences in social cognition, inhibitory control, and spatial problem-solving ability in the domestic dog (*Canis familiaris*). *Scientific Reports*, 12(1), 22529 under CC BY 4.0 license.

5.5.3 V-detour

Breeds did not significantly differ from each other in the proportion of dogs succeeding versus failing (p = 0.13, 99 % CI [0.12, 0.14]).

When including only individuals which were successful, the multiple regression model significantly predicted latency to solve the task (n = 863, F (14, 848) = 2.52, p = 0.002, adj. R^2 = 0.02). Sex and age (in dogs aged 1–8 years) did not significantly predict latency to solve the V-detour. Breed was a significant predictor of test performance. See Figure 9 for significant results and the mean latency (s) for each breed.

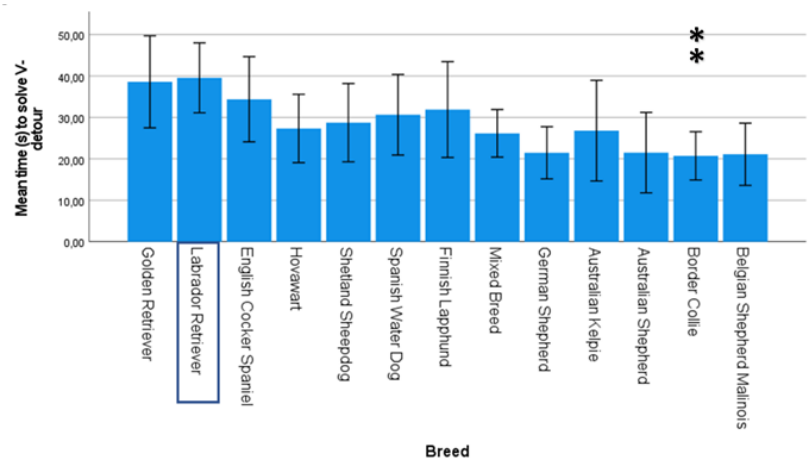
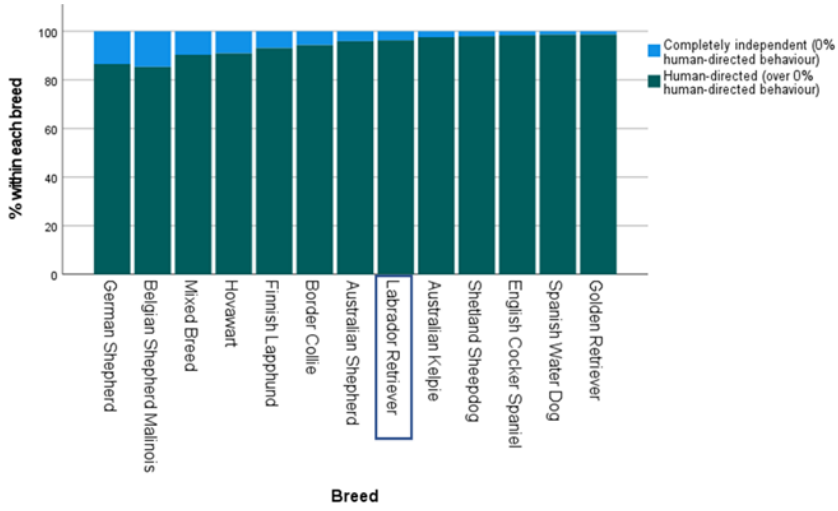


Figure 9 Raw data with mean latencies (s) for solving the V-detour for each breed using the untransformed, original data (n = 863). Breeds are ordered based on B-values, with slowest breeds (long latency to solve) on the left and fastest breeds (short latency) on the right. Error bars represent 95 % confidence intervals. The breeds which differ significantly from the reference breed (the Labrador Retriever) are indicated with asterisks: ***p ≤ 0.001, **p ≤ 0.01, *p ≤ 0.05 (Bonferroni-corrected). Figure reprinted and modified from Junttila, S., Valros, A., Mäki, K., Väätäjä, H., Reunanen, E., & Tiira, K. (2022). Breed differences in social cognition, inhibitory control, and spatial problem-solving ability in the domestic dog (Canis familiaris). Scientific Reports, 12(1), 22529 under CC BY 4.0 license.

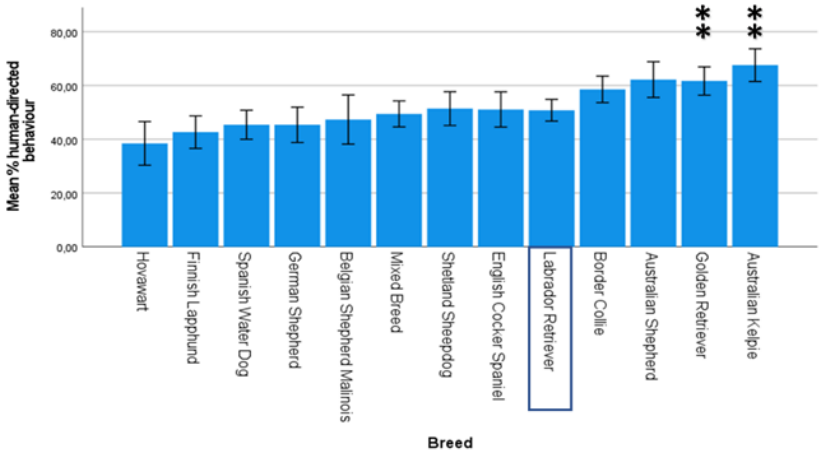
5.5.4 Unsolvable task

When comparing completely independent dogs (5.7 % of all dogs) to dogs which spent a minimum of 1 s on human-directed behaviour during the unsolvable task, the binomial logistic regression model was statistically significant ($\chi2(14) = 34.28$, $p = 0.002$) and explained 9.7 % (Nagelkerke R^2) of the variance. Female dogs had lower odds of being 100 % independent compared to males ($\chi2(1) = 5.22$, $p = 0.02$). Age was not a significant predictor in dogs aged 1-8 years ($\chi2(1) = 0.59$, $p = 0.44$). Breed was a significant predictor of independence ($\chi2(12) = 23.13$, $p = 0.03$), although no breed differed significantly from the Labrador retriever. See Figure 10a for the proportions of individuals within each breed which were 100 % independent.

a


% within each breed
100
80
60
40
20
0
Completely independent (0% human-directed behaviour)
Human-directed (over 0% human-directed behaviour)
German Shepherd
Belgian Shepherd Malinois
Mixed Breed
Hovawart
Finnish Lapphund
Border Collie
Australian Shepherd
Labrador Retriever
Australian Kelpie
Shetland Sheepdog
English Cocker Spaniel
Spanish Water Dog
Golden Retriever
Breed

b


Mean % human-directed behaviour
80,00
60,00
40,00
20,00
0,00
**
**
Hovawart
Finnish Lapphund
Spanish Water Dog
German Shepherd
Belgian Shepherd Malinois
Mixed Breed
Shetland Sheepdog
English Cocker Spaniel
Labrador Retriever
Border Collie
Australian Shepherd
Golden Retriever
Australian Kelpie
Breed

c

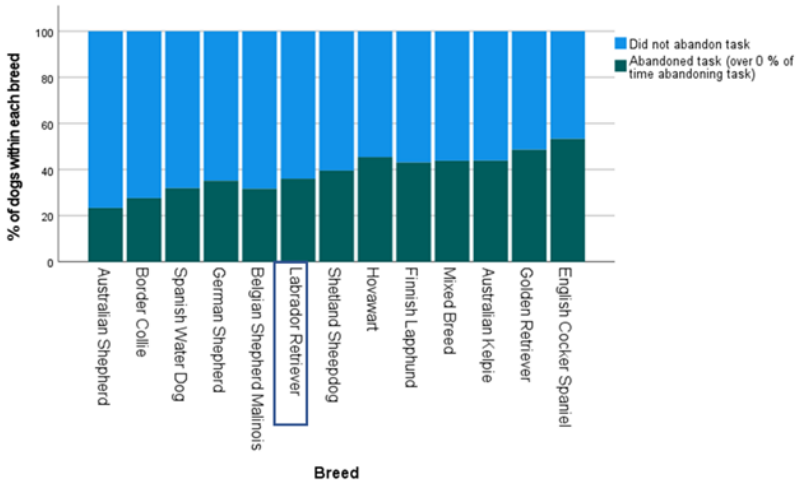

% of dogs within each breed
100
80
60
40
20
0
Did not abandon task
Abandoned task (over 0 % of time abandoning task)
Australian Shepherd
Border Collie
Spanish Water Dog
German Shepherd
Belgian Shepherd Malinois
Labrador Retriever
Shetland Sheepdog
Hovawart
Finnish Lapphund
Mixed Breed
Australian Kelpie
Golden Retriever
English Cocker Spaniel
Breed

Figure 10 Raw data with the performance of breeds in the unsolvable task (n = 969). Error bars represent 95 % confidence intervals. The breeds which differ significantly from the reference breed (the Labrador retriever) are indicated with asterisks: ***p ≤ 0.001, **p ≤ 0.01, *p ≤ 0.05 (Bonferroni-corrected). **a)** Percentage of dogs within each breed which were 100 % independent (0 % of time spent on human-directed behaviour). Breeds are ordered based on odds-ratios, with least independent breeds on the right and most independent breeds on the left. **b)** Mean percentage of time spent on human-directed behaviour for each breed. Breeds have been ordered based on B-values, with the least human-directed behaviour on the left and the most human-directed behaviour on the right. **c)** Percentage of dogs within each breed which abandoned the task. Breeds are ordered based on odds ratios, with the least persistent breeds on the right and the most persistent breeds on the left. Figure reprinted from Junttila, S., Valros, A., Mäki, K., Väätäjä, H., Reunanen, E., & Tiira, K. (2022). Breed differences in social cognition, inhibitory control, and spatial problem-solving ability in the domestic dog (*Canis familiaris*). *Scientific Reports*, 12(1), 22529 under CC BY 4.0 license.

After removing completely independent dogs from the analysis, the multiple regression model significantly predicted the percentage of time spent on human-directed behaviour ($n = 912$, $F(14, 885) = 5.7$, $p < 0.001$, adj. $R^2 = 0.07$). Sex was not a significant predictor, but increasing age (in dogs aged 1–8 years) was associated with an increased proportion of time spent on human-directed behaviour ($\beta = 0.09$, $p = 0.009$). Breed was a significant predictor of performance. See Table 10b for significant results and the mean percentage of time spent on human-directed behaviour for each breed.

When comparing dogs which spent a minimum of 1 s on abandoning the task (37.2 % of dogs) to dogs which did not abandon the task, the binomial logistic regression model was statistically significant ($\chi2(14) = 40.89$, $p < 0.001$) and explained 5.7 % (Nagelkerke R^2) of the variance. Sex was not a significant predictor, but older dogs were less likely to abandon the task (in dogs aged 1–8 years old) ($\chi2(1) = 16.34$, $p < 0.001$). Breed was a significant predictor ($\chi2(12) = 24.16$, $p = 0.02$), although no breed differed significantly from the Labrador retriever. See Figure 10c for the proportion of dogs abandoning the task within each breed.

6 Discussion

This thesis provides a deeper understanding of individual differences in dog performance in tests measuring social cognition, problem-solving ability, and inhibitory control. Using one of the largest canine cognition datasets in the world, the studies included in this thesis focused on examining the reliability and validity of these cognitive tests as well as dog-related factors associated with test performance. The results indicate that specific cognitive tests measure relatively stable traits which can be observed in the everyday lives of dogs. In addition, we found that breed, sex, age, and previous experience of the test are significant factors influencing cognitive test performance, but this depends largely on the specific cognitive test.

6.1 Cylinder test

6.1.1 Associations with behavioural/personality traits

The results of Study I are what would be expected if the cylinder test does indeed measure an aspect of inhibitory control, since we found that higher performance in the cylinder test was associated with lower impulsivity (DIAS). This result is in line with one previous study (Krichbaum & Lazarowski, 2022), although another study with a smaller sample size found no correlation between DIAS and the cylinder test (Olsen, 2022).

Cylinder test performance was associated with lower excitability and energy level scores, as well as higher trainability and faster learning based on owners' assessment. Higher cylinder test performance also correlated with lower greeting, exploration, and activity level scores during the test battery (Study I), which could be explained by lower impulsivity or be an indication of a bold personality trait. These results seem to be in line with human research, since impulsivity is a symptom of ADHD, which is associated with hyperactivity, inattention, and reduced cognitive performance both in childhood and adulthood (Davidson, 2007; Drechsler et al., 2020; Kooij et al., 2019; Sonuga-Barke et al., 2023). Similar associations between ADHD-like traits have been found in dogs (González-Martínez et al., 2024).

Previous canine studies have additionally found that high owner-reported impulsivity is associated with lower trainability and increased behaviour problems (Piotti et al., 2018; Salonen et al., 2022; Sulkama et al., 2021; Wright et al., 2012), and higher inhibitory control in the cylinder test was associated with higher success at explosive detection (Tiira et al., 2020). Therefore, inhibitory control, activity level, learning ability, and trainability all seem to be interconnected.

Interestingly, we found no association between aggressive behaviour and lack of inhibitory control in the cylinder test, even though previous studies have found a connection between impulsivity and aggression (Dinwoodie et al., 2019; Gobbo & Šemrov, 2022; Peremans et al., 2003; Piotti et al., 2018; Reisner et al., 1996; Salonen et al., 2022; Sulkama et al., 2021). The reason for this could be that our dataset had a low occurrence of aggressive behaviour, partly because one requirement for taking part in the test battery is that the dog should not be overly aggressive to strangers. Another possibility is that the type of impulsivity measured by the cylinder test is not correlated with aggression. Indeed, a previous study similarly to us found no association between the 'Aggression' subscale of DIAS and the cylinder test (Krichbaum & Lazarowski, 2022).

When comparing puppies' performance in the cylinder test to their everyday behaviour in adulthood, high-performing puppies were more likely to have lower impulsivity (DIAS) and lower energy levels (C-BARQ) in adulthood (Study II). One previous study found that puppy performance in the cylinder test was not predictive of detection dog performance (Lazarowski, Krichbaum et al., 2020), whereas A-not-B task performance as a puppy predicted successful selection as a guide dog (Foraita et al., 2024) and detection dog (Lazarowski, Krichbaum, et al., 2020). Based on our results, however, it seems that cylinder test performance of puppies may help to predict some types of adult behaviour in pet dogs.

6.1.2 Repeatability and age

In Study I we found that cylinder test results of dogs were the least reliable across test-retest occasions out of the four cognitive tests, although reliability was still fair (weighted kappa 0.35). One other study found excellent test-retest reliability for the cylinder test (ICC = 0.78) when test sessions were only two weeks apart (Olsen, 2022). Therefore, it is possible that a longer duration between test occasions reduced the reliability of the cylinder test in our study.

There was no significant association between puppy and adult performance in the cylinder test, and individuals improved their performance from puppy- to adulthood (Study II). Similarly, other studies have found no correlation between puppy and adult scores in the cylinder test, with performance increasing from puppy- to adulthood (Bray, Gruen, et al., 2021; Lazarowski, Krichbaum, et al.,

2020). Another study found that test-retest reliability of another measure of inhibitory control was poor in young dogs (Brady, Hewison, et al., 2018).

It is possible that previous experience of the same test may produce learning effects in dogs. This was apparent when comparing adult dogs which had experience of the cylinder test to naïve adult dogs which had no prior experience of the test (Study II); experienced dogs were significantly more successful. The fact that we found an association between cylinder test performance and owner-reported learning speed in Study I seems to align with this.

Some previous studies suggest that learning does not occur within 10 trials (Bray et al., 2014; Marshall-Pescini et al., 2015), although others have shown evidence of learning (Fagnani et al., 2016; Vernouillet et al., 2018). When more than 10 trials are provided, dogs' performance improves (Krichbaum & Lazarowski, 2022; Salomons et al., 2024), which is in line with our results. Cauchoix et al. (2018) found that repeatability was lower if animals received a high number of repetitions of the same cognitive task. Therefore, based on our results, the cylinder test should not be administered to dogs on more than one occasion of 10 trials.

The improvement across development could be partly due to the previously mentioned learning effect, since longitudinal studies require repeated testing. However, it is also possible that dogs become more skilled at inhibiting their responses throughout their development, since most studies report improvements in inhibitory control in dogs across the first year of age (Bray, Gnanadesikan, et al., 2021; Bray, Gruen, et al., 2021; Foraita et al., 2023; Lazarowski, Krichbaum, et al., 2020; Salomons et al., 2024; Watowich et al., 2020).

It should be noted, though, that even though there was no significant association between puppy and adult scores, puppy performance in the cylinder test still predicted questionnaire-derived impulsivity in adulthood (Study II).

We found in Study III that dogs' inhibitory control in the cylinder test decreased between the ages of 1 and 8 years, which is in line with a previous study (Bray et al., 2014). Therefore, it seems that dogs improve their performance from puppy- to adulthood and performance decreases as they age, which has also been found for another measure of self-control in dogs (Watowich et al., 2020). The same effect can be seen in humans as well (Christ et al., 2001; Craik & Bialystok 2006; Harada et al. 2013).

6.1.3 Sex and breed

Inhibitory control seems to be influenced by the sex of the dog. Study III found that female dogs had higher inhibitory control than males, which confirmed the results of our previous study (Junttila et al., 2021). Similar results have been found in other studies (Krichbaum & Lazarowski, 2022; Silver et al., 2025), although one study found no sex effects in the cylinder test (Bray et al., 2014).

We found that breed is another factor which influences dogs' performance in the cylinder test (Study III). Our results support questionnaire studies where significant differences have been found between breeds and breed groups for owner-reported impulsivity and hyperactivity (Fadel et al., 2016; Lit et al., 2010; Salonen et al., 2020; Sulkama et al., 2021; Wright et al., 2011). However, no breed group differences have been found by most studies investigating behavioural tests of inhibitory control (Horschler et al., 2019; Mellor et al., 2024), such as the cylinder test (Silver et al., 2025). These results could have emerged due to the grouping of breeds into breed groups, which may hide some of the differences between individual breeds.

Our results suggest that breed differences exist when investigating individual breeds rather than breed groups. Based on this finding, inhibitory control might be a heritable trait, which is supported by heritability studies in dogs (Gnanadesikan et al., 2020) and other animals (Langley et al., 2020).

Some of our results are in line with previous studies. For example, the Labrador retriever was one of the most impulsive breeds based on their cylinder test results, and they were also found in a previous study to be among the more impulsive breeds according to DIAS results (Wright et al., 2011). However, in a different questionnaire study, they had some of the lowest scores for hyperactivity/impulsivity (Salonen et al., 2020).

One explanation for this could be that Labrador retrievers are impulsive in some contexts but have high self-control in other contexts. Labrador retrievers are still used actively in their original role as hunting dogs, which could explain why they differed significantly from golden retrievers, which have recently been used increasingly in the role of pet dog. There may also be differences between show and working lines, although a master's thesis found no difference between lines for cylinder test performance in Labrador retrievers or cocker spaniels (Tuikkanen, 2024). However, in a questionnaire study, working line Labrador retrievers and border collies differed from show line dogs in one aspect of impulsivity in the DIAS questionnaire, 'responsiveness' (Fadel et al., 2016).

German shepherds also had relatively low success rates in the cylinder test, and previous studies have similarly found that the breed has high impulsivity/hyperactivity (Salonen et al., 2020; Sulkama et al., 2021). The German shepherd is a breed which is utilized in various working roles, including as police dogs and detection dogs. High impulsivity may be a useful trait in roles where the dog is required to be active, energetic, and highly motivated.

Some of our results contradict the findings of previous studies. For example, we found that Border collies were the least impulsive breed in the cylinder test (Study III), whereas questionnaire studies have found that Border collies and other herding breeds have high scores in impulsivity and hyperactivity (Fadel et al., 2016; Lit et al., 2010; Sulkama et al., 2021). Of course, when questionnaires include

additional traits such as hyperactivity, it is not surprising that results will differ from the cylinder test, which measures a very specific aspect of inhibitory control. It is possible that Border collies are impulsive when measured in some aspects of impulsivity, since they are bred to be active, persistent, and to have quick responses. They nevertheless seem to have high motor inhibitory control, which might have been an important trait in herding work.

Our results suggest that the cylinder test is a relatively reliable and valid measure of inhibitory control, the effects of which can be seen in everyday life. However, in order to provide reliable results, this test should not be repeated to the same dog over time, since there seems to be a learning effect. In addition, we found that the age, breed, and sex of the dog affect the results. Therefore, this is a test which is influenced by a wide range of factors, but which can tell us interesting details about dogs' behavioural traits and even predict adult behaviour based on puppy test results.

6.2 Gesture test

6.2.1 Associations with behavioural/personality traits

In Study I, we found no associations between adult dogs' gesture test performance and their everyday behaviour, but there was a weak correlation between gesture test results and two behavioural measures during the test battery. Dogs which were better at understanding human gestures were more explorative in a novel environment and had a higher average activity level throughout the test battery (Study I). There might therefore be some association between gesture test performance and dogs' boldness or interest in their environment.

We found that puppies which performed well in the gesture test were more trainable in adulthood (Study II). Puppies which are proficient at understanding human gestures might be better able to focus on lengthy tasks or to form associations, they may be more attentive to humans, more willing to cooperate, or they might have higher socio-cognitive abilities.

The emotional reactivity hypothesis (Hare & Tomasello, 2005; Hare et al., 2005) states that dogs' ability to follow pointing gestures is based partly on their interest toward social interactions with humans, which developed during domestication. Foxes which have been selected for human sociability perform better at pointing tasks than foxes with no such selection (Hare et al., 2005), and dog breeds which have been selectively bred for cooperation with humans are more successful in these tests than independent breeds (Gácsi, McGreevy, et al., 2009; Kujala et al., 2023; Lazarowski, Thompkins, et al., 2020; Udell et al., 2014; Wobber et al., 2009). Oxytocin administration has been found to improve dogs' performance in communicative gesture tests (Oliva et al., 2015; Macchitella et al., 2017). These

results suggest that dogs' understanding of human communicative cues may be based on their tendency to cooperate, communicate and socialize with humans – which may additionally improve their trainability.

A previous study found a similar result to ours, although in adult dogs rather than puppies. Dogs' performance at a point-following task was associated with how well they followed commands according to their owners (McCartney & Leavens, 2024). However, another study found no correlation between owner-assessed trainability (C-BARQ) and adult dogs' success at a pointing task (Espinosa et al., 2023). In another study, adult dogs' ability to understand human gestural communication was predictive of their success as a detection dog (MacLean & Hare, 2018). Even though we found no link between trainability and performance in the gesture test in adulthood, it is possible that dogs' ability to understand human gestures may be linked to other everyday behaviours in adulthood, which might be of interest for future studies.

There is, however, still disagreement on whether dogs' understanding of human gestures is based on an awareness that these gestures are communicative cues, or simply because they have associated human hands with food using simple associative learning mechanisms (Espinosa et al., 2023). One possibility is that puppies which succeed at gesture tests do so because they are more proficient at learning associations, which also makes them easier to train in adulthood.

It has additionally been suggested that dogs are interpreting human gestural cues as commands (Kaminski & Nitzschner, 2013; Kaminski et al., 2012; Kirchhofer et al., 2012; Topál et al., 2009), although this seems an unlikely explanation (Espinosa et al., 2023; Scheider et al., 2013). This would, however, explain the association with trainability, as puppies which follow the gesture might be more likely to obey other commands as well.

6.2.2 Repeatability and age

We found that the gesture test had the highest test-retest reliability out of the four cognitive tests (ICC = 0.53) (Study I). There was also a moderate correlation between puppy and adult performance (r = 0.4), and scores did not significantly change across development (Study II). In adult dogs aged 1–8 years, we found no effect of age either (Study III), and there were no significant differences between naïve and experienced dogs (Study II). There did not seem to be any learning effect across the 30 trials dogs took part in during the test battery (Study III).

These findings suggest that dogs' results in this test are not greatly influenced by learning across trials or repeated test sessions, a similar finding which has been reported in previous studies (Bray, Gnanadesikan, et al., 2021; Bray, Gruen, et al., 2021; Dorey et al., 2010; Gácsi, Kara, et al., 2009; Lyn et al., 2024; Wobber et al., 2009). With intensive experience of gesture following tasks dogs can, however,

improve their performance. This seems to be especially the case for dogs which initially fail to perform above chance levels (Jarvis & Hall, 2020; Lyn et al., 2024; Udell et al., 2010, 2014). One reason we found no learning effects could be because dogs' success in our study was not dependent on only one type of communicative cue, and each gesture was repeated only over 6 trials. However, it seems that dogs can also learn more difficult communicative cues if first provided with experience of easier cues (Elgier et al., 2012; Udell et al., 2013).

Previous studies have, similarly to ours, found that puppies' ability to follow human gestures seems to be a relatively stable trait from puppy- to adulthood (Bray, Gruen, et al., 2021; Gácsi, Kara, et al., 2009) with little change across age (Agnetta et al., 2000; Bray, Gnanadesikan, et al., 2021; Bray, Gruen, et al., 2021; Espinosa et al., 2023; Gácsi, Kara, et al., 2009; Lazarowski, Krichbaum, et al., 2020; Lyn et al., 2021; Riedel et al., 2008;). However, other studies have found contrasting findings with puppies' performance improving with age (Bray, Gnanadesikan, et al., 2021; Bray, Gruen, et al., 2021; Dorey et al., 2010; Watowich et al., 2020; Wynne et al., 2008). This may be partly due to differing methodologies.

In addition, in the studies included in this thesis, slightly different methodologies were used for puppies and adult dogs. This may have partly reduced possible learning effects and allowed for a slightly easier testing situation for the puppies, which are not yet as advanced in their understanding of human gestures. If puppies were provided with tests which are more difficult, there might not have been a correlation with adult performance.

6.2.3 Breed

In Study III we found that breed was a significant predictor of performance in the gesture test, which is in line with many previous studies (Gácsi, McGreevy, et al., 2009; Kujala et al., 2023; Lazarowski, Thompkins, et al., 2020; McCartney & Leavens, 2024; Sundman et al., 2018; Udell et al., 2014; Wobber et al., 2009). Dogs' ability to understand a pointing task seems to be highly heritable (Bray, Gnanadesikan, et al., 2021; Gnanadesikan et al., 2020). In contrast, three previous studies have found no differences between breed groups when using AKC, FCI, or genetic groupings (Dorey et al., 2009; Horschler et al., 2019; Riedel et al., 2008). It is possible that whether differences are found or not depends on the specific compositions of the breed groups.

In our study, the Border collie and Labrador retriever were among the best-performing breeds and did not significantly differ from one another. This could explain why one previous study similarly found no differences between these two breeds (Szabó et al., 2017). Our findings support those of Udell and colleagues (2014), in which Border collies were the best-performing breed. In addition, our results showed that German shepherds performed significantly worse than

Labrador retrievers, which is in line with results from a previous study (Sundman et al., 2018). However, in another study, Wobber et al. (2009) found that German shepherds, together with Siberian huskies, outperformed toy poodles and basenjis. Therefore, even though German shepherds were the poorest performers in our study, they are likely more skilled at this task than many other breeds.

It seems, based on our results, that dogs' ability to follow human-given communicative cues is a rather innate and stable trait, which is not influenced greatly by factors such as age, sex, or learning. Instead, there seems to be a genetic basis for this trait, since breeds differed significantly from each other. Since the ability is already present from a young age, puppies' performance in this test can provide useful information about their future behavioural traits.

6.3 V-detour

6.3.1 Associations with behavioural/personality traits

The V-detour is a popular detour test which has often been utilized to measure inhibitory control of animals (Albuquerque et al., 2021; Pongrácz & Veres, 2025; Pongrácz et al., 2001). Our results suggest, however, that latency to solve the task is unlikely to be an indication of dogs' degree of inhibitory control. If this test did measure inhibitory control, we would assume to see an association between impulsivity and lower success in the test, as we saw with the cylinder test. Instead, we found the opposite association; dogs which were faster at solving the task showed a tendency to be more impulsive (DIAS).

These dogs were also slower at learning new tasks, they had more management problems, and they had higher greeting, exploration, and activity level scores in the test battery (Study I). Not surprisingly, there was no association between cylinder test and V-detour performance, consistent with previous studies (Bray et al., 2014; Marshall-Pescini et al., 2015; Vernouillet et al., 2018).

What could be the reason that more successful dogs have traits and behaviours which are often considered undesirable by owners, such as impulsivity and management problems? One possible explanation is that these dogs are, in a way, 'too smart'. Higher problem-solving ability or faster learning speed does not necessarily mean that the dog is easier to train; dogs may also learn problematic and unwanted behaviours. For easier trainability and management in daily life, one important aspect is the dog's willingness and ability to cooperate with the owner. Dogs which perform well in the V-detour might be more likely to solve problems they are faced with independently, rather than work together with a human.

We found that some dogs behaved in this test similarly to how many dogs behave in the unsolvable task; instead of attempting to solve the task, they were engaging in human-directed behaviour. Indeed, dogs which turned towards a human during

the V-detour spent significantly more time on human-directed behaviour during the unsolvable task (Study I). It is possible that the reason some dogs struggle with this task is not necessarily because they lack problem-solving skills, but because they are more focused on the human, compared to the more independent dogs which may be more persistent at attempting to solve the task.

Dogs which solve the V-detour quickly might be more independent, active, and persistent, and as a result more difficult to manage in daily life, despite being good problem-solvers and fast learners. Instead, they may be more suitable for some working roles or dog sports which require persistence and independent problem-solving skills.

6.3.2 Repeatability and age

Study I found moderate test-retest repeatability for the V-detour (ICC = 0.48), and in Study II we found a moderate correlation between puppy and adult performance (r = 0.43). However, adult performance significantly improved from puppy performance (Study II). This may have been partly due to a learning effect, since experienced adults were significantly faster at solving the task than naïve adults (Study II), and dogs which performed well in the V-detour were rated as faster at learning new tasks in daily life (Study I).

However, naïve adults were still faster at solving the task than puppies (Study II), suggesting that performance may also be dependent on the development of certain cognitive skills, such as spatial problem-solving ability (Lazarowski, Krichbaum, et al., 2020). In adulthood (1–8 years of age) age did not have an influence on dogs' performance in this test. Therefore, it seems that the cognitive traits required in the V-detour have a developmental during the dog's first year, after which performance remains relatively stable.

6.3.3 Breed

Study III found that breed influenced the latency to solve the V-detour task. Herding breeds, such as the Belgian Malinois, Border collie, and Australian shepherd, were fastest at solving the task, whereas retrievers, such as the golden retriever and Labrador retriever, were the slowest. However, not all herding breeds were as successful, which could explain why two previous studies have failed to find differences between breed groups (Marshall-Pescini et al., 2016; Pongrácz et al., 2005). One study did find differences between individual breeds, with German shepherds solving the task significantly faster than giant schnauzers (Pongrácz et al., 2005). This is similar to our finding, as the German shepherd was one of the fastest breeds at solving the task. It is possible that some herding and working

breeds have been purposefully selected for high spatial cognition and persistence, whereas for retrievers this ability may not have been as important.

In conclusion, we found that dogs' performance in the V-detour task is relatively consistent across time but is also influenced by previous experience of the test and should therefore not be administered on more than one occasion. There seems to be a developmental period during which dogs' cognitive abilities related to this task develop, after which age has little influence. Based on our results, it seems unlikely that latency for solving the V-detour is related to inhibitory control. Instead, individual differences in dogs' performance could be related to the type of problem-solving strategy dogs engage in when faced with a difficult problem, their persistence, activity level, or spatial problem-solving ability. It seems that there may be a genetic basis for these traits, since breeds differed significantly from each other.

6.4 Unsolvable task

6.4.1 Associations with behavioural/personality traits

In Study I we found that human-directed behaviour in the unsolvable task was associated with several behavioural traits in dogs' everyday life.

We found that more human-directed behaviour was associated with higher trainability and lower management problems, which could be partly related to the finding that these dogs were less impulsive. It is also possible that dogs which are very human-focused during the unsolvable task are more attentive to human faces and more willing to communicate and cooperate with people in general. These dogs may also have higher socio-cognitive abilities. In contrast, more independent dogs which focus on the task instead of the person may be more difficult to manage and train in daily life. A previous study found that dogs which succeeded in a social learning task were more trainable according to their owners (Marshall-Pescini et al., 2008).

Additionally, human-directed dogs may find human attention and interaction more rewarding than more independent dogs, which could be related to oxytocin levels. It has been found that oxytocin administration can increase human-directed behaviour in the unsolvable task in some dogs (Kovács et al., 2016; Persson et al., 2017), and in cows, a correlation was found between serum oxytocin levels and human-directed behaviour in the unsolvable task (D'Aniello et al., 2022).

Dogs which spent more time on human-directed behaviour were less impulsive in daily life, and they had higher inhibitory control in the cylinder test. To our knowledge, this is the first study which has investigated a possible link between impulsivity and unsolvable task performance. Dogs which spent more time on human-directed behaviour were additionally less explorative and active during the test battery, which may be related to their reduced impulsivity.

The reason for these findings might be that impulsivity may impair dogs' ability to switch between problem-solving strategies, and instead they get 'stuck' on the unsuccessful strategy, i.e., attempting to open the apparatus. In humans, it has been found that ADHD (which is usually characterized by impulsivity) can be associated with hyperfocus and difficulties switching between tasks (Groen et al., 2020; Halleland et al., 2012; Hupfeld et al., 2019; Rohlf et al., 2012). This task-switching may be even more challenging when in a state of high arousal, which can be induced by the potential frustration of the unsolvable task. One study found, for example, that when high arousal was induced, dogs with higher baseline arousal were less successful in an inhibitory control task than dogs with lower baseline arousal (Bray et al., 2015).

Impulsive humans seem to have lower frustration tolerance (Caprara et al., 1985; Horesh et al., 1997; Scime & Norvilitis, 2006; Seymour & Miller, 2017), and the same has been found in dogs (McPeake et al., 2019). Impulsive dogs may therefore become more frustrated during the unsolvable task than non-impulsive dogs, which can cause them even more difficulties with switching from one strategy to another.

Our finding that dogs which spend more time on human-directed behaviour in the unsolvable task are easier to train seems to be reflected in research on working dogs. Studies have found that greater levels of human-directed gazing are associated with success as an assistance dog and as a detection dog (Lazarowski et al., 2019; MacLean & Hare, 2018) and with a lower likelihood of giving up during an explosive search according to the dogs' handlers (Tiira et al., 2020).

It is possible though, that independence may be a valuable trait in some dog sports and working dog roles. Compared to pet dogs, detection dogs spent more time on independent problem-solving and gazed less at humans (Lazarowski, Thompkins, et al., 2020), and so did dogs trained for scent work (Pallonen, 2024). Therefore, it seems that training for scent work, which requires dogs to perform independently without too much influence from the owner, may make dogs more independent in the unsolvable task and less dependent on humans. Alternatively, more independent individuals and breeds may be chosen for these roles.

Interestingly, human-directed behaviour in the unsolvable task was associated with increased stranger-directed fear (Study I), and this could already be predicted from puppy performance in the task (Study II). Fear and anxiety have been found to impair certain types of cognitive test performance in humans as well as in other animals (Eysenck et al., 2007; Robinson et al., 2013). However, this explanation seems unlikely since we did not find associations between stranger-directed fearfulness and any other cognitive test results. Therefore, another possibility is that human-fearful dogs might be generally lacking in confidence, which may result in reduced persistence on a difficult task. A previous study based on owner-filled questionnaires found that fearful dogs had lower perseverance scores (MacKay et

al., 2023). Therefore, it is possible that anxious/fearful dogs might give up more easily during difficult situations such as the unsolvable task.

Unfortunately, we did not have data on whether dogs directed their behaviour towards the experimenter or the owner, although most dogs in general seemed to interact with the experimenter (personal experience of Katriina Tiira). One possibility is that human-fearful dogs may focus more on the potentially threatening novel person, the experimenter, due to an attentional bias for threat-related stimuli (Bar-Haim et al., 2007). Alternatively, attention directed towards the experimenter may result from appeasement behaviours, which dogs generally engage in during mildly stressful social situations (Barrera et al., 2010; Firnkes et al., 2017; Pedretti et al., 2023). Another possibility is that human-fearful dogs may direct their behaviour towards their owner as a way to gain reassurance or comfort or as a way of gathering information from the owner's behaviour in a novel situation (Merola et al., 2012). Further research may be warranted to determine whether fearful dogs are gazing primarily at their owner, at the experimenter, or both.

Our results contrast with a previous study (Passalacqua et al., 2013) which found that anxious dogs spent less time gazing at the experimenter than control dogs. This could result from the lower severity of anxiety and fear of the dogs in our study; dogs with mild anxiety may respond to the task by gazing at humans, whereas dogs with more extreme forms of anxiety might completely avoid the situation (as happened in Passalacqua and colleagues' study). In addition, during the solvable part of the task, the anxious dogs in their study seemed to behave as if it was unsolvable, gazing more at the people present – similarly to our results – whereas during the unsolvable phase they tended to avoid the apparatus completely. Similarly, we found that dogs which were fearful of strangers during the greeting test were more likely to abandon the task altogether (Study I).

One previous study (Piotti et al., 2021) found that if dogs had a personality type of being cautious, thinking before acting, and inhibiting their responses (Behavioural Inhibition System), they looked at their owner more and had fewer orientations to the puzzle box. Dogs which were more likely to react to fearful stimuli by escaping or freezing (Fight-Flight-Freeze System) interacted more with the container and gazed less at their owner. Therefore, it is possible that the human-fearful dogs in our study were of the cautious personality type, which resulted in more gazing behaviour and less persistence with the task, whereas the anxious dogs in Passalacqua and colleagues' study (2013) had a more active avoidance reaction to fearful stimuli, which resulted in less gazing behaviour.

6.4.2 Repeatability and age

We found in Study I that human-directed behaviour in the unsolvable task was moderately reliable across time (weighted kappa = 0.46). In Study II we also found

a weak correlation between puppy and adult performance for both human-directed behaviour (r = 0.2) and independent problem-solving (r = 0.3). There was no significant difference between naïve and experienced adult dogs for either behaviour (Study II). Previous studies have found that multiple repetitions may influence dogs' performance in the test (Lazarowski et al., 2019; Salomons et al., 2024), but our results suggest that two test occasions might not be sufficient to induce learning effects.

However, even though dogs' behaviour was somewhat stable between puppy- and adulthood, there were significant changes (Study II). Similarly to what has been found in previous studies (Bray, Gruen, et al., 2021; Lazarowski et al., 2019; Passalacqua at al., 2011), dogs' human-directed behaviour increased and independent problem-solving decreased from puppy- to adulthood. What is interesting is that this trajectory of development seems to be similar in all studies regardless of breed and training history. Bray, Gruen, et al. (2021) included candidate assistance dogs, Lazarowski et al. (2019) tested candidate detection dogs, Passalacqua et al. (2011) included pet dogs with no training experience, whereas in our study most dogs participated in some kind of training or dog sports. Our study as well as Passalacqua and colleagues' study included a variety of breeds, whereas Bray, Gruen, et al. and Lazarowski et al. tested mainly retrievers and their crosses.

This would suggest that, even though training experience as well as breed influence dogs' performance in the unsolvable task, the natural development seems to be that puppies living closely with humans increase their human-directed behaviours as they age. This may occur either as a result of a developmental period for this trait, or due to increased exposure to humans across time.

Experience with humans may be one important requirement for this trait to develop, since we found that human-directed behaviour increased with age both in puppy- as well as in adulthood (Study III). Previous studies have found that dogs' behaviour in the unsolvable task continues to increase with age in adulthood (Hori et al., 2013; Lazarowski, Thompkins, et al., 2020; Persson et al., 2015;) and is influenced by an individual's experience of humans (D'Aniello & Scandurra, 2016; Gould et al., 2022; Lazzaroni et al., 2020; Mendes et al., 2021a; O'Riordan & Roth, 2023).

However, there was still a significant correlation between puppy and adult behaviour in the unsolvable task, similarly to what was found in a previous study (Bray, Gruen, et al., 2021). In fact, we even found a moderate correlation (r = 0.25) when comparing only 3–4-month-old puppies and adults (Study II), although the sample size was small (n = 40). This would suggest that dogs' innate problem-solving strategy in this test can to some extent be already measured at a young age.

In contrast, the likelihood of abandoning the task was not stable from puppy- to adulthood. Puppies spent more time abandoning the task than adults, but this difference was not statistically significant. However, when comparing a larger,

cross-sectional dataset of puppies and naïve adults, puppies spent significantly more time abandoning the task. It is possible that this effect was not found in the longitudinal dataset due to the small sample size (N = 99) in combination with the low number of dogs which abandoned the task.

6.4.3 Sex and breed

Another factor which we found was associated with dogs' behaviour during the unsolvable task was the sex of the dog. Female dogs were less likely to be 100 % independent compared to male dogs (Study III). In a previous study, we similarly found that female dogs spent more time on human-directed behaviour compared to males (Junttila et al., 2021). Some studies have found similar findings to ours (Hori et al., 2013; Kovács et al., 2016; Persson et al., 2015), and female dogs seem to in general show more interest in gazing and interacting with people than males do (Duranton & Gaunet, 2016; Lore et al., 1986; Mongillo et al., 2016; Nagasawa et al., 2015). However, several studies have found no sex differences in the unsolvable task (Carballo et al., 2020; Konno et al., 2016; Lazarowski, Thompkins, et al., 2020; Pongrácz & Lugosi, 2024; Van Poucke et al., 2022).

Breeds differed from each other in all three measures of the unsolvable task (Study III), which is in line with previous research (Hirschi et al., 2022; Konno et al., 2016; Kovács et al., 2016; Lazarowski et al., 2019; Maglieri et al., 2019; Passalacqua et al., 2011; Pongrácz & Lugosi, 2024; Sommese et al., 2019; Sundman et al., 2018; Van Poucke et al., 2022). This is consistent with the finding that human-directed behaviour during the unsolvable task is significantly heritable (Persson et al., 2015). Some studies, however, have found no differences between breed groups (Kujala et al., 2023; Lazarowski, Thompkins, et al., 2020), which could be due to the specific breed compositions included in the breed groups.

Two previous studies have looked at differences between Labrador retrievers and German shepherds. Maglieri and colleagues (2019) found that German shepherds spent a larger amount of time manipulating the apparatus than Labrador retrievers, and gazed towards their owner rather than the experimenter, whereas Labrador retrievers gazed at both equally. In Sundman and colleagues' (2018) study, German shepherds scored higher on 'passivity', as well as on human contact, whereas Labrador retrievers scored higher on eye contact.

In contrast, our study found no significant differences between German shepherds and Labrador retrievers in any measure. It is possible that no breed differences arise when all human-directed behaviours and all apparatus-directed behaviours are combined, as was done in our study, but nuanced breed differences might be seen when looking at dogs' behaviours in more detail.

Our study found significant breed differences in persistence, i.e., how likely dogs are to abandon the unsolvable task (Study III). One previous study found that

Belgian and German shepherds continued more persistently with a problem-solving task even when no longer rewarded for it, compared to Labrador and golden retrievers (Shimabukuro et al., 2015). Our findings are somewhat in line with this, since the golden retriever was one of the most likely breeds to abandon the task. However, the Belgian Malinois, German shepherd, and Labrador retriever all performed similarly to each other. The methodology of the unsolvable task is of course different to the study design used by Shimabukuro and colleagues, which might explain the contrasting results.

Another study (MacKay et al., 2023), however, was in line with our finding that Border collies were among the more persistent breeds (less likely to abandon the task). They found that according to owner-filled questionnaire results, Border collies had significantly higher perseverance compared to mixed breed dogs.

In conclusion, dogs' performance in the unsolvable task is relatively stable across time but also shows ontogenetic changes which do not seem to be related to repeated testing. Dogs' behaviour in this task was influenced by a variety of factors, such as age, sex, and breed. It seems that human-directed behaviour in the unsolvable task is influenced by heritable factors, but dogs still require sufficient human experience for this trait to develop fully. Test performance is reflected in the everyday life of dogs and can provide valuable information about dogs' traits related to sociability, cooperation, independence, trainability, and impulsivity. Some adult behavioural traits, such as stranger-directed fear, can even be predicted from puppy performance in the unsolvable task.

6.5 General discussion

This thesis provides valuable findings which future studies can hopefully build on. The results provide further validation for these four cognitive tests, since the traits measured by the tests could be seen in other contexts, such as in the dogs' everyday life. Study I shed light on the types of traits these tests might be measuring, and what kinds of behavioural or personality traits might influence dogs' performance in these tests.

Our results provide further confirmation that the cylinder test is likely to measure inhibitory control and impulsivity, whereas performance in the V-detour is possibly more related to spatial problem-solving ability or general activity level. Our results suggest that high problem-solving ability is not necessarily always a desirable quality for pet dogs. We additionally show that traits such as inhibitory control and social cognition can have an influence on various aspects of daily life. This provides a basis for future research to investigate the implications these traits might have in different contexts.

Study II further discovered that some adult behavioural traits could even be predicted from puppy performance. This would suggest that some cognitive traits

are already relatively stable before 8 months of age, and testing of 3-7-month-old puppies can provide owners important information about these traits. However, none of the associations found in Study II were significant after controlling for multiple testing, which would suggest that these cognitive traits are not as stable from puppy- to adulthood as they are during adulthood. The sample size for Study II was also much smaller, which would inevitably affect p-values. Further research may be warranted to determine whether puppy cognitive tests can have predictive value even in puppies younger than 3 months of age.

What is remarkable is that we found significant associations between cognitive traits and daily behaviours in Studies I and II despite controlling for several variables which might be influencing the dogs' behaviour, such as training experience, food motivation, owner experience, breed, age, sex, source of the dog, and illness. This is the first time that cognitive tests have been found to associate with everyday behaviour to this extent.

Study I investigated the temporal repeatability of cognitive test performance in dogs, something which has received very little attention so far (Griffin et al., 2015). We found moderate test-retest reliability (~0.5) for all cognitive tests apart from the cylinder test which showed only fair reliability (0.35), likely due to a learning effect. We additionally found interrater reliability to be high (Study I).

In previous studies, the average repeatability of animal personality and behavioural traits has been found to be moderately consistent (0.37) (Bell et al., 2009), and the same has been found for dogs specifically (0.43) (Fratkin et al., 2013). Regarding cognitive performance, a meta-analysis found low to moderate (0.15 - 0.28) temporal repeatability in a range of species (Cauchoix et al., 2018). Therefore, the repeatability of all four cognitive tests included in this thesis was the same as or higher than the average repeatability in previous animal behavioural studies.

In cognitive research, measuring temporal repeatability of tests is especially challenging, since previous test occasions are likely to influence performance due to possible memory and learning effects (Cauchoix et al., 2018; Griffin et al., 2015). One option is, of course, to use different contexts or methodologies to measure the same cognitive trait across time (Cauchoix et al., 2018; Griffin et al., 2015), but this poses additional challenges, as it may be difficult to determine whether different tests measure the same trait. Indeed, Cauchoix et al. (2018) found that contextual repeatability was not much higher than temporal repeatability across studies.

Temporal repeatability of canine cognitive tests has been investigated very little, and hopefully there will be more focus on this in cognitive research in the future. It would be useful to investigate further to what extent repeated testing influences results, since we found that previous experience of the same cognitive test improved results in the V-detour and the cylinder test (Study II). Further research focusing on the contextual repeatability of these tests may be warranted, since repetitions of

the same test might influence results in some cases. A valuable finding is that two repetitions was not enough to induce learning effects in the gesture test or the unsolvable task (Study II), both of which also had moderate test-retest reliability scores (Study I).

In Study II, we found weak to moderate correlations between puppy and adult performance in cognitive tests, apart from the cylinder test. Some cognitive tests seemed to be influenced more by previous experience of the task than others. Changes in dogs' performance occurred in all of the cognitive tests across the dog's development, apart from the gesture test, which did not seem to be influenced by the individual's age either in puppy- or adulthood (Studies II and III).

These findings provide a more complete picture of ontogeny- and age-related changes in canine cognitive traits, but more research is still needed to further our understanding of these processes. Future studies could focus on determining how early these cognitive traits begin to develop, and how development changes across the first year of life, month by month. The sample sizes in our longitudinal study were unfortunately not large enough to investigate this further.

Study III found that another factor influencing dogs' performance in two cognitive tests (cylinder test and unsolvable task) was the sex of the dog. Males were more impulsive in the cylinder test, whereas females were more human-focused in the unsolvable task. These results are in line with our previous study (Junttila et al., 2021).

These differences may be partly related to sex hormones. We found in our previous study that neutering had no effect on test results in males or females (Junttila et al., 2021), but previous studies have found neutering to have an effect on impulsivity (Fadel et al., 2016) and dogs' understanding of human gestures (Scandurra et al., 2019; Watowich et al., 2020). The problem is that neutering may be performed selectively on individuals with specific traits, such as impulsivity or aggression, and interpreting causality is challenging. Future studies could investigate how the sex of the dog might influence other cognitive tests related to social cognition and inhibitory control, as this has been studied very little in dogs.

Study III provided a clearer picture of how cognitive traits differ between breeds. Our study had some advantages compared to many previous studies; due to a large dataset, we were able to include several individual breeds with sufficient sample sizes, instead of having to combine breeds into groups, in which case some information might be lost. This resulted in the finding that breeds differed significantly from each other, sometimes even despite belonging to the same breed group. Future studies should take this into account when forming breed groups and keep in mind that breed differences can potentially be lost when grouping breeds together. However, our study was missing breeds from several breed groups, such as terriers, livestock guarding breeds, and sighthounds, and therefore further research is needed to determine how other breeds differ from each other.

What is important to note is that even though significant differences for various cognitive traits emerged between breeds, no breed outperformed the others in all tests. Instead, each breed had their own strengths and weaknesses. Breeds which scored high in one test did not necessarily score high in other tests, even when the tests were measuring similar traits.

It is possible that some of the breed differences we found in the cognitive tests are partly related to personality differences between breeds. An interesting example is the golden retriever. They had the largest percentage of friendly and overexcited greeting scores out of all breeds (Study III), which is consistent with a study by Asp and colleagues (2015). In our study, golden retrievers performed relatively well in the gesture test, and they scored high on human-directed behaviour during the unsolvable task (Study III). They were also more likely to abandon the unsolvable task than other breeds, suggesting that they spent very little time attempting to solve the task independently.

In addition, golden retrievers took the longest amount of time to solve the V-detour task, and they were the breed which most often failed to solve this task within the given time (Study III), which may be due to their likelihood to turn towards humans in a difficult situation. We found that 53 % of Golden retrievers engaged in human-directed gazing during the V-detour, whereas for other breeds this ranged from 12 to 38 % (unpublished result from Study III). Lower success in the V-detour is not necessarily a negative trait, since we found that it was associated with fewer management problems and lower impulsivity (Study I). Therefore, it seems that personality traits such as sociability can explain some of the breed differences seen in cognitive test performance.

The breed differences found by our study suggest that there might be a genetic component to these cognitive traits, although owners' assumptions about breeds as well as keeping practices may influence the behaviour of their dogs. High heritability rates are nevertheless found in previous studies as well as our unpublished results, where we found that dogs' performance in the cylinder test and gesture test was significantly heritable (Junttila et al., unpublished manuscript). It was also found that breeding lines can differ cognitively from each other even within a breed (Tuikkanen, 2024).

The effect sizes for all the associations we found were relatively small, which is not surprising, as behavioural traits are likely to be explained by a large number of factors which all have complex associations with each other. Therefore, our results provide only one piece of the puzzle in understanding the factors which influence individual differences in cognitive performance.

6.6 Limitations

The results of this thesis provide information about a very specific population of dogs and their owners in Finland. Owners and dogs were self-selected, and this should be kept in mind when interpreting the results of this thesis. Participants who replied to the questionnaire (Studies I and II) were even further self-selected from the population of owners who took part in the test battery. Participants were mostly dedicated and knowledgeable dog owners who were active in dog sports, training, or other activities with their dogs, and any behaviour problems were mild and rare compared to previous studies.

Another possible limitation is the use of different rewards for different individuals. Most dogs were rewarded with food, but toys were used for individuals which were more motivated by toys than food. Previous research shows that reward type can have an influence on dogs' behaviour in cognitive tests (Hirschi et al., 2022; Krichbaum & Lazarowski, 2022). However, utilizing different rewards for different dogs may be beneficial, since not all individuals are motivated by food to the same extent (Gerencsér et al., 2018), and choosing only food-motivated individuals for participation may bias results. Therefore, it may be worth investigating in future studies whether adjusting the reward type based on the dog's preferences might actually produce more accurate results.

One limitation of Studies I and II was that since test data was provided retrospectively, the large majority of questionnaire answers were provided after dogs had taken part in the cognitive test battery. Owners who took part in the test battery were always provided with a report of their dogs' behavioural and cognitive traits and what is currently known about these cognitive tests, as well as access to a database comparing their dog's results to average results of their breed. Therefore, the provided test results and reports may have influenced owners' views of their dogs and their assessment of their personality, which might have influenced how they answered the questionnaire.

If requested, owners were additionally provided with brief advice on how to utilize their dogs' strengths and work on their possible challenges. This could have had an effect on how dogs behaved at the time of the questionnaire. In order to confirm our findings, they may need to be replicated in future studies by providing questionnaires to owners before their dogs take part in a cognitive test.

What must be additionally noted is that it is impossible to interpret causality from our results; we do not know whether personality or other behavioural traits affected cognitive abilities or vice versa – or whether cognitive and behavioural traits are so tightly interconnected that it is almost impossible to infer causality.

A limitation of Study III was that we did not have information on the dogs' background, training history, or other demographic factors, and therefore it was not possible to control for these variables. However, our results seem to be mostly in line with previous research, suggesting that breed differences can be detectable

regardless of this. In addition, only a limited number of breeds was included, and therefore, future studies will need to be conducted in order to understand differences between a more variable range of breed types, as well as whether there might be associations with the breeds' original or current function.

6.7 Applications

The benefit of these cognitive tests as opposed to the more commonly used personality tests is that they provide owners and people working with dogs with information which might otherwise be difficult to assess. The usual personality/temperament tests utilized for dogs do not usually include sections about dogs' inhibitory control, impulsivity, problem-solving behaviour, independence, social cognition, or persistence in the same way as the cognitive tests in our studies do (e.g., Svartberg & Forkman, 2002). However, knowledge about these traits could be extremely useful in everyday life. Another benefit of these cognitive tests is that they can be administered even to fearful or anxious dogs, since fear-inducing sections are not included.

The sociability/greeting test included in the COGNITION and PUPPY test batteries is a potentially valuable measure of human-directed fearfulness, and we found that it correlated with several cognitive test scores. The benefit of a short, simple test such as this is that it does not require any fear-eliciting stimuli or threatening behaviour from the human, as is often the case in personality assessment tests (e.g., Svartberg & Forkman, 2002); instead, the experimenter simply talks to the dog and allows them to approach in their own time. The test is not continued further if the dog shows signs of fear or aggression.

We found in Study I that results from the greeting test had high test-retest and interrater reliability. Dogs' fearfulness in the test additionally correlated with owners' assessment of stranger-directed fear ($r = -0.28$, $p < 0.001$) (unpublished result from Study I). Adult fearfulness could also be predicted from puppy greeting scores (Study II). A similar human sociability test was validated in a previous study (Tiira & Lohi, 2014). Therefore, this test has potential value for assessing human-directed fearfulness, even predicting it from a young age.

The results of this thesis show that the traits measured by these tests can be important in various situations in dogs' everyday life, and they can therefore have potentially important implications for dogs, owners, breeders, and the working dog community.

6.7.1 Breeding choices

Dog breeders might be able to utilize the information provided by these studies for choosing suitable individuals for breeding. Our results suggest a potential genetic

component for the traits measured by the included cognitive tests (Study III). Therefore, depending on the purpose of breeding, different cognitive traits may be favoured. For example, if the aim is to produce suitable pet dogs, in that case individuals with high inhibitory control and human-directed behaviour may be valued for breeding. If the aim is to produce dogs for scent detection work, then individuals with high independence may be favoured. More research will be required to determine the more specific traits which are valuable for each role and situation.

6.7.2 Informing adoption decisions of owners

Future dog owners may benefit from the knowledge provided by this thesis when choosing a suitable individual to adopt. Based on our results, female dogs may be easier to manage in everyday life compared to males, and therefore they may be more suitable for the role of a pet dog. In contrast, males may be more suited for some working roles and dog sports, since they seem to be more impulsive and independent. Similarly, understanding breed-typical behaviour is valuable information when choosing a breed for a specific role or for being more informed about potential challenges that may arise.

It might be even more beneficial to combine different cognitive test results to create a 'cognitive profile' for each breed. For example, Labrador retrievers had low inhibitory control in the cylinder test but they were relatively human-dependent in the unsolvable task, suggesting that even though they can be impulsive, they are not extremely independent. This may make training and management easier in everyday life. In contrast, the Belgian Malinois was highly impulsive and relatively independent. This could suggest that they are especially challenging dogs, as the combination of impulsivity and independence may make them difficult to control and train – although these same traits can make them extremely talented working dogs when properly trained.

If we also include personality and activity results from the test battery, the resulting behavioural profiles may be even more useful. Bray et al. (2017) found in a principal factor analysis that combined personality and cognitive measures in the same components produced the best model fit and successfully predicted individuals' success as guide dogs. These kinds of combinations of personality and cognitive profiles can potentially be created for individual dogs to understand an individual's traits on a deeper level.

6.7.3 Predicting future traits of puppies

Puppy owners may find it useful if they can, to some extent, predict their puppy's future traits based on their behaviour in a cognitive/behavioural test. Since only

puppies older than 2 months of age were included in this thesis, it is unfortunately not possible to base puppy adoption choices on our results. However, the tests can nevertheless provide helpful information for dog owners who can then tailor their training and management practises based on their puppy's individual traits. This can potentially prevent problematic behaviours from developing or escalating, which can be extremely valuable regarding the welfare of pet dogs.

In addition, previous studies show that cognitive tests can be potentially useful tools for predicting working dog success (Foraita et al., 2024; Lazarowski, Krichbaum, et al., 2020), and therefore information about the validity of these tests as well as factors associated with test performance can be extremely useful regarding the use of these tests for working dog selection.

6.7.4 Improved understanding of individual traits

Another potential benefit of cognitive testing is the reason most owners take part in the smartDOG test battery: to understand their dogs and their individual traits more thoroughly. This allows for owners to appreciate their dogs' strengths as well as identify potential difficulties their dog may be experiencing.

An understanding of dog behaviour is important for dog welfare, for the development of a positive human-dog relationship, and for the prevention of undesirable dog behaviours (Gazzano et al., 2008; Pfaller-Sadovsky et al., 2020; Philpotts et al., 2019; van Herwijnen, 2021). This is one important step when modifying canine behaviour problems; when the owner understands why their dog is behaving the way they do, this often makes the problem much more bearable, and in some cases can even positively influence the dog's behaviour.

The comments owners have made after taking part in the smartDOG™ test battery show that they often see their dogs in a new light (personal communication by Katriina Tiira). They may realize that their dog is not just 'difficult', 'annoying', or 'stupid', but instead, they might have specific traits that make them unique and strengths which the owners were not previously aware of. Their dog might be difficult to train simply because they are, for example, very independent or impulsive, but they might excel at tasks which require independent problem-solving ability.

Owners' questionnaire answers to the question "Has your dog's behaviour changed after taking part in the smartDOG test?" (unpublished results from Study I) demonstrate the importance of understanding their dog better. Many stated that their dog had remained the same, but their own attitude and understanding of their dog had changed significantly. "I have learned to be a bit calmer and more patient when I understood that the dog is trying his best, he just has difficulties controlling his impulsivity", one owner answered. Another replied: "The test results have helped me to have a better attitude toward my dog. I understand better that she

wants to solve things herself and is very smart. Our relationship is much better, because I know my dog better".

6.7.5 Behaviour management and training

As a result of improved understanding of their dogs' behavioural traits, owners can potentially prevent any additional problems from arising or escalating. Owners can tailor their training based on their individual dog's traits and even understand the potential reasons behind their dog's problem behaviour. The information provided by these cognitive tests can even be beneficial for dog trainers and behaviour consultants attempting to aid with the behaviour modification of an individual dog.

Some owners stated in their questionnaire answers that they utilized the information provided by the cognitive test in their training and daily management, and their dog's behaviour improved as a result. For example, a dog that is very human-dependent in the unsolvable task may benefit from more encouragement for independence: "We have strengthened the dog's initiative and self-confidence in training, and these have improved a lot". In contrast, other owners have focused on increasing cooperation and reducing independence: "We have purposefully trained cooperation in retriever trials, as a result of which the dog's independent behaviour has reduced a little". For others, working on inhibitory control has been more important: "We have attempted to improve self-control, because my dog is very impulsive, and we have improved that with training."

Therefore, these tests have great potential for dog owners to not only understand but also influence their dogs' traits through training and management, which could positively influence the relationship and wellbeing of both dog and owner. This is a topic which could be explored further in future studies; can cognitive and behavioural tests such as these positively influence the relationship between dogs and their owners, and does the act of taking part in this type of test say something about an owner's relationship with their dog?

6.8 Conclusions

In summary, the studies included in this thesis provide valuable information on the reliability and validity of cognitive tests which are widely used in canine research, as well as the factors which are associated with dogs' test performance.

The results of Study I suggest that these tests measure cognitive and behavioural traits which can be seen in other contexts outside the test situation. These are novel findings which provide further insight into the traits measured by these tests and the contexts in which they can be observed.

Study II further found that these cognitive traits can already be measured at 3-7 months of age and that they can predict everyday behavioural traits in adulthood.

These results show that cognitive tests could provide an interesting addition to personality tests and could potentially help owners with identifying and preventing issues from arising in the future.

Studies II and III improve our understanding of the effects of sex, age, and breed on cognitive performance of dogs. Understanding the development and underlying factors behind cognitive traits is valuable information from both a theoretical and applied perspective.

The findings from this thesis highlight the importance of cognitive traits in the everyday life of dogs and their owners. Perhaps the most valuable potential application of these cognitive tests lies in improving owners' understanding of their dogs. The unpublished questionnaire comments emphasize how important it can be for owners to understand their dogs' behavioural traits on a deeper level than what can be achieved by simple personality tests. This improved understanding can influence the relationship between owners and dogs, improve cooperation, and improve owner wellbeing as they can see their dogs' 'problematic' behaviour from a new perspective.

Understanding the causes and effects of dog behaviour is important in order to coexist with the millions of dogs which are our pets, working companions, and family members. This thesis helps us to understand dogs better, which in turn can influence the wellbeing of dogs, their owners, and those around them.

Acknowledgements

This doctoral thesis was conducted at the University of Helsinki, Research Centre for Animal Welfare, Department of Production Animal Medicine, Faculty of Veterinary Medicine. The thesis was carried out as a doctoral student in the Doctoral Programme in Clinical Veterinary Medicine (CVM).

I would like to thank the doctoral school of Clinical Veterinary Medicine for my university-funded doctoral researcher position. I am grateful to Suomen eläinlääketieteen säätiö (Finnish Foundation of Veterinary Research) for receiving a two-month personal grant as well as two travel grants, and to Eläinlääketieteen tutkimuksen tukisäätiö (Finnish Veterinary Foundation), Nestle Purina, the doctoral school of Clinical Veterinary Medicine, and the University of Helsinki Doctoral School for their travel grants which allowed me to take part in many interesting conferences and to share our findings internationally. I would also like to acknowledge Suomen kennelliitto (Finnish Kennel Club) for providing family tree data for an additional study on heritability, which was not included in the thesis.

I express my deepest gratitude to the supervisors of my thesis, docent Katriina Tiira, Professor Anna Valros, and Katariina Mäki for their support, encouragement, and advice. I could not have imagined better supervisors. Thank you, Katriina, for taking me on for this project and trusting me with the data you and the other smartDOG testers have collected over the years. Thank you, Anna, for agreeing five years ago to chat with me about PhD possibilities and giving me the idea and encouragement to contact Katriina. Thank you, Katariina, for providing your knowledge and expertise on the heritability and genetics in dogs.

The pre-examiners of this thesis were Professor Per Jensen and professor Friederike Range, who I would like to thank for their efforts. The comments helped to improve the thesis further. I am very grateful to Professor Per Jensen for agreeing to serve as my opponent.

I would like to express special thanks to Jukka Siren from the Biodata Analytics Unit's helpdesk for his valuable help with statistics. I am grateful to assistant professor Rose Thorogood and Professor Pekka Uimari for being my thesis committee members and providing support and encouragement throughout my PhD journey.

I warmly thank all the dog owners and dogs who participated in the smartDOG test battery, especially those who also provided questionnaire answers, and the smartDOG license testers Katja Kontu, Liisa Tikka, Sanni Somppi, Kati Vierimaa, Elisa Reunanen, Heli Väätäjä, Päivi Kontkanen, Siru Salin, Sari Somersalmi, Mari Kallio, Nina Petäsnoro, Tiina Eskel-Mustonen, and Ulla-Marja Ruistola for collecting the test battery data together with Katriina Tiira. Without all of you this thesis would not have been possible.

I further wish to thank my colleagues and fellow PhD researchers who have made this journey significantly more enjoyable and provided much-needed peer support. Thank you to Emilia, Kristina, Hilkka, Vilja, and Miina for all our 'distance coffees' over Teams. These were not only enjoyable, but we also got to share ideas, advice, opinions, and tips which helped with the whole process of completing this PhD. Thank you to the other student representatives, Tuuli and Rayhan, who have helped me arrange social activities for CVM doctoral students over the years. Thank you also to everyone who took part in these events, especially Petra who joined almost every time. These events were extremely valuable for peer-support, socialization, and generally just having a fun time with other students who are in the same situation.

I am deeply grateful to my friends and family for being there for me throughout my thesis and celebrating each milestone with me. Thank you to my parents for their many ways of support, especially with the development of the questionnaire. Thank you Teemu, for all your support and the discussions which sometimes helped immensely with getting a clearer picture of things. Ville, thank you for your help and valuable discussions about statistics.

Franz, I am so grateful for having you in my life. Thank you for being there for me even in difficult times, supporting me, making me forget about the stresses of work, and being amazing in every way.

Thank you Ghada, Annaïg, Markus, Fletcher, Iraís, Agathe, Jonna, Emily, and everyone else who I haven't mentioned, for providing support as well as a welcome distraction from work.

Thank you also to Mette, Megan, Aida, and the many other four-legged friends who have inspired me over the years and sparked my interest in the field.

Last but not least, thank you, Jessie, for being in my life throughout most of my PhD journey. You were part of the reason why I started on this journey, and you taught me so much. I will always miss you.

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