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ManyDogs Project: A Big Team Science Approach to Investigating Canine Behavior and Cognition

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Dogs have a special place in human history as the first domesticated species and play important roles in many cultures around the world. However, their role in scientific studies has been relatively recent. With a few notable exceptions (e.g., Darwin, Pavlov, Scott, and Fuller), domestic dogs were not commonly the subject of rigorous scientific investigation of behavior until the late 1990s. Although the number of canine science studies has increased dramatically over the last 20 years, most research groups are limited in the inferences they can draw because of the relatively small sample sizes used, along with the exceptional diversity observed in dogs (e.g., breed, geographic location, experience). To this end, we introduce the ManyDogs Project, an international consortium of researchers interested in taking a big team science approach to understanding canine behavioral science. We begin by discussing why studying dogs provides valuable insights into behavior and cognition, evolutionary processes, human health, and applications for animal welfare. We then highlight other big team science projects that have previously been conducted in canine science and emphasize the benefits of our approach. Finally, we introduce the ManyDogs Project and our mission: (a) replicating important findings, (b) investigating moderators that need a large sample size such as breed differences, (c) reaching methodological consensus, (d) investigating cross-cultural differences, and (e) setting a standard for replication studies in general. In doing so, we hope to address previous limitations in individual lab studies and previous big team science frameworks to deepen our understanding of canine behavior and cognition.

Keywords: dogs, ManyDogs, big-team science, canine science, replication

Introduction

When asked to think back to one's last interaction with a dog, each of us would likely describe something different. Some might imagine an intent border collie herding its charges through a pasture, others will recount their friend's lap dog begging for treats, others again recall a feisty dachshund hunting in the forest. A hallmark of domestic dogs (*Canis familiaris*) is the extraordinary range of variation they exhibit, not just in size, shape, and color but particularly in behavior and disposition. And this behavior offers a window into their cognition, how they process information in their environment. From selecting service dogs to training pet dogs, measuring behavior and cognition is vital to understanding dogs and their relationships with people.

From a scientific perspective, the variation observed in dogs makes them an ideal and unique study system for behavior and cognition that provides exciting opportunities as well as frustrating challenges. Centuries of selective breeding have resulted in hundreds of different dog breeds, many of which were selected for particular behavioral traits and their ability to carry out specific tasks (for a review, see Serpell & Duffy, 2014). Despite this selection process, and our intuitive impression that dog breeds differ in their behavioral traits and cognitive abilities, the scientific evidence for such differences is limited, and many questions remain about the connection between breed and behavior (Mehrkam & Wynne, 2014; Morrill et al., 2022; Svartberg, 2005). Moreover, across cultures, massive variation exists both in the human environment in which dogs live and in the ways and the extent to which people interact with dogs (Serpell, 2017). How individuals in different societies perceive the value and role of dogs also shapes dogs' behavior (Wan et al., 2009) and results in additional variation, leading to critical questions about the role of the social environment on dog behavior and cognition.

As a result, dogs are uniquely positioned to help us answer questions about the evolution of behavior and cognition, as well as the influence of the environment on behavior. Yet several practical challenges impede our ability to address these questions appropriately. Most of the challenges stem from the relatively small sample sizes that individual research groups can collect—typically fewer

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than 100 subjects—coupled with the enormous variation observed across dogs (e.g., Bensky et al., 2013). Therefore, sampling variability may result in different outcomes when drawing from relatively small samples, which may lead to mixed results across studies. For instance, Brady et al. (2018) found that owner perceptions of their dogs' impulsivity matched their behavioral measures, which suggests that they are relatively accurate. Using larger sample sizes, however, Mongillo et al. (2019) and Stevens et al. (2022) did not find a relationship between owner perceptions and behavioral measures of impulsivity.

Mixed results found across different studies could also stem from the use of different methods or other moderators such as dogs' training histories (Marshall-Pescini et al., 2008, 2009; Osthaus et al., 2005; Silver et al., 2021), breed (Gnanadesikan et al., 2020; Horschler et al., 2019), or cultural differences across study samples (Stevens et al., 2022; Wan et al., 2009). As a result, even if an individual lab is able to test several hundred dogs in a preregistered study with the video-recordings of all tests publicly available (Lonardo et al., 2021), some of the aforementioned issues remain.

The problem of subsequent studies failing to replicate previous research is not unique to canine science (Camerer et al., 2018; Errington et al., 2014; Open Science Collaboration, 2015). A number of solutions have been proposed, including preregistration of studies, publicly posting data and analyses, and considering alternatives to null-hypothesis significance testing (Asendorpf et al., 2013; Wagenmakers, 2007). In particular, big team science approaches have been initiated to address issues of replicability by bringing together multiple labs across the world to use the same methods and aggregate their data (Forscher et al., 2022). Here we introduce the ManyDogs Project (hereafter ManyDogs), a big team science approach not only to help address replicability problems but also to provide opportunities to answer questions that cannot be easily addressed in single laboratories. ManyDogs is a large-scale multilab collaboration akin to those used with infants (Frank et al., 2017; The ManyBabies Consortium, 2020), nonhuman primates (Many Primates et al., 2019), and avian species (ManyBirds; Lambert et al., 2022).

Assembling experts in canine behavior and cognition allows for the development of methodological best practices, which we extend by formalizing and promoting open science practices to improve replicability. Further, combining data across many labs not only provides the sample sizes large enough to overcome the sampling variability problem but also allows researchers to investigate questions that are unanswerable with smaller samples, notably how variation in breed or cultural differences may impact results. In short, the following big team science approach provides a unique opportunity to use canine expertise and large sample sizes to advance the field of canine behavioral science. The big team science approach is not intended to replace single lab studies but to complement them, as collaboration and creative minds in small groups are needed to advance research. With ManyDogs—an ongoing effort that leverages an international collaborative network of researchers aligning their efforts toward common goals—we can solve problems inherent to single-lab studies and help converge on answers to complex questions.

To be clear, big team approaches cannot solve all the replication issues facing behavioral science. Big team science does not inherently improve statistical, registration, or reporting practices, though individual teams may engage those practices. In fact, there can be drawbacks to this approach. Although larger sample sizes can often help generate stronger inferences, this is not always the case. Very large sample sizes coupled with null-hypothesis testing can result in false positives, whereas small differences across variables (resulting from sampling error) result in "statistically significant differences" at large sample sizes (Armstrong, 2019). Despite this possibility, the sample sizes feasible for our ManyDogs project are likely in the hundreds rather than thousands, reducing the chances of these false positives. Large sample sizes can also result in ethical concerns associated with unnecessary animal testing. Given the voluntary nature of ManyDogs participation, this is less of a concern for our project. Moreover, the benefits of larger sample sizes, such as the ability to include phylogenetic statistical methods to examine breed differences, are incredibly helpful for novel tests of canine behavior and cognition.

To introduce ManyDogs, we first review the question, Why dogs? Namely, we discuss the extent to which dogs, as a study system, can (a) yield insights into the evolutionary origins of various cognitive abilities, (b) advance our understanding of genetic and environmental impacts on human health, (c) inform theories regarding social cognition, and (d) increase canine and human welfare by improving our understanding of the behavioral and cognitive traits that underlie dogs' unique bond with humans and by enhancing our dog training protocols for working roles. We then review recent big team science initiatives in both canine science and other subfields of psychology. Finally, we explore how the big team science framework might best be applied to canine research and how ManyDogs can enhance our understanding of canine cognition and behavior.

Why Dogs?

Studying dogs has practical and applied implications given the many roles that dogs fill in our societies (for an overview of the natural history of dogs, see Miklósi, 2018). The domestic dog is also very interesting from a basic science point of view and, over the past 2 decades, has become an especially important species in the field of comparative psychology (Morell, 2009). Although dog research has a long history, with the studies of Darwin, Lubbock, and Pavlov as famous historical examples, cognitive and behavioral studies with dogs became commonplace only after the 1990s (for a historical review, see Feuerbacher & Wynne, 2011). The canine research that has unfolded since this time has demonstrated that dogs are an ideal study system not only for cognitive and behavioral research but also for evolutionary, health, and applied questions (Horowitz, 2014; Kaminski & Marshall-Pescini, 2014; Miklósi, 2015).

Evolutionary Origins of Cognition and Behavior

Dogs are uniquely positioned to offer insights about evolutionary processes. Evidence from the paleo archaeological record suggests that dogs were the first animals to be domesticated by Pleistocene-era humans (*Homo sapiens*) and were domesticated from an ancestral wolf (also the ancestor of modern wolves) between 14,000 and 40,000 years ago (Clutton-Brock, 2016; Germonpré et al., 2012; Perri et al., 2021; Thalmann et al., 2013).

Several authors hypothesize that, along with numerous changes in size and appearance, domestication has had particularly important effects on dog social behavior and cognition, altering the extent to which dogs accept and interact with humans as cooperative partners. Although the specific cognitive and behavioral changes that occurred during dogs' domestication continue to be debated (Hare & Tomasello, 2005; Lazzaroni et al., 2020; Udell et al., 2010), along with multiple theories about the nature of the selection process leading to domestication (Coppinger & Coppinger, 2002; Serpell, 2021), investigating (a) the process of domestication and (b) the nature of the behavioral and cognitive changes it produces can provide powerful insights about the *mechanisms* of cognitive and behavioral evolution.

Notably, some researchers have proposed that the process of domestication in dogs resulted in convergent evolution with humans, with selection favoring social skills for cooperation in dogs that were also important in the evolution of our species (Hare & Tomasello, 2005; MacLean et al., 2017; Topál et al., 2009). Indeed, some provocative hypotheses suggest that selection for "friendliness" may be a driving force in the physical and cognitive changes seen in domestication (Trut, 1999) and that recent human evolution can perhaps be characterized as "self-domestication," a similar but self-imposed selective pressure for prosocial behavior resulting in species-wide "friendliness" (Hare, 2017; Wrangham, 2019). A better understanding of dog domestication has potential to illuminate important transitions in the evolution of our own species (but see Range & Marshall-Pescini, 2022).

Soon after dogs were domesticated, humans learned to domesticate other animals and crops (Larson & Bradley, 2014), which in turn altered the social structure of settlements and trade. As globalization made various forms of hunting, farming, and other activities more specialized, dogs too were bred for specific traits and behaviors to enhance their working ability (Parker et al., 2017). More recently, the formation of modern dog breeds for both function and appearance has involved major population bottlenecks, with new breeds often created from a small number of founding individuals and relying on closed breeding pools, giving rise to genetically differentiated subpopulations that are characterized by dramatic phenotypic diversity (vonHoldt et al., 2010). Among mammals, modern dogs are commonly recognized as the most phenotypically diverse species (Ostrander et al., 2019; Vilà et al., 1999), with remarkable intraspecific variation in size, physical appearance, behavior, disease risk, and lifespan.

This genetic diversity (further described next) has been used profitably as a model for understanding the evolution and genetic bases of complex traits in many arenas. Chiefly, genetic polymorphisms associated with breed differences in cognitive processes, including inhibitory control, communication, memory, and physical reasoning are starting to be identified and are further reflected in neuroanatomical variation across breeds (Gnanadesikan et al., 2020; Hecht et al., 2019). Tracing canine lineages via modern breed genetics can also, in some instances, be a useful proxy for investigating historic human population movements and associated cultural variation (Barrios et al., 2022; Bergström et al., 2020; Perri et al., 2021). However, fully leveraging modern dog breed diversity as one of the most significant "real-time" multipurpose evolutionary genetics experiments relies on overcoming the limitations of small sample sizes; coordinated data sharing efforts such as ManyDogs can help to achieve this goal.

Genetic and Environmental Impacts on Health

In recent decades, scientists have developed a new appreciation for the unique features of dogs that confer advantages in preclinical and translational health research (Bódizs et al., 2020; Hoffman et al., 2018; Mazzatenta et al., 2017; Rowell et al., 2011). Compared with inbred strains of laboratory organisms, the genetic and phenotypic variation among dogs provides unparalleled opportunities for understanding the biological bases of complex traits. Additionally, unlike laboratory animals, companion dogs develop and age in the same environments as humans; have access to sophisticated health care; and, like their human caretakers, engage in highly variable lifestyles (Kaeberlein et al., 2016). These factors make dogs a much more realistic model for many aspects of human health than traditional model organisms.

Our emerging understanding of genetic diversity in dogs (Ostrander et al., 2019) has had important implications for varied areas of medical research. For example, dog breeds vary substantially in their risk for specific diseases, which has facilitated the discovery of genetic variants contributing to cancer, epilepsy, thyroid, and autoimmune diseases, to name a few (Sutter & Ostrander, 2004). Dogs have also proven to be a valuable model for studies of human mental health, including obsessive compulsive disorder (Dodman et al., 2010), attention deficit hyperactivity disorder (Sulkama et al., 2021), and Williams-Beuren syndrome (vonHoldt et al., 2017). Last, dogs have recently become an important model in studies of aging (Ruple et al., 2021), and recent work has proposed dogs as a model species for studying the effect of aging on sleep and cognition (Bódizs et al., 2020). Regarding cognition, dogs are susceptible to dementia, which mimic core features of Alzheimer's disease (Head, 2013). The further development of dog models of Alzheimer's disease will require well-validated measures to identify cognitive impairments in aging dogs and to assess the functional consequences of treatments and interventions.

Whereas most medical research to date has focused on a limited number of breeds (Youssef et al., 2016), future work should recruit and test large and diverse samples to characterize normative patterns of cognitive aging and to identify potential risk factors for dementia (Bray, Raichlen, et al., 2022; Bray, Zheng, et al., 2022). These endeavors will benefit greatly from the research infrastructure we envision for ManyDogs.

Social-Cognitive Processes

Arguably, one of the most interesting outcomes of the domestication process is that the human physical and social environment has become dogs' new ecological niche, with dogs interacting with humans as social partners (Miklósi & Kubinyi, 2016). As a result, in the past two decades, the publication rate for research on dog cognition and behavior has accelerated faster than that of cognitive and behavioral sciences in general, and among the research topics addressed with dogs, social-cognitive processes have been a focus of the majority of papers (Aria et al., 2021). In contrast to nonhuman primates, dogs exhibit sensitivity to human social cues (e.g., using human pointing gestures to find hidden food; Krause et al., 2018; McCreary et al., 2022; Miklósi et al., 1998), leading researchers to propose that dogs' social-cognitive abilities were strongly shaped by domestication. As previously noted, some researchers extended these proposals by hypothesizing that aspects of the social-cognitive abilities of dogs may show convergent evolution with those of humans, making them uniquely "human-like" (e.g., Hare et al., 2002; Hare & Tomasello, 2005; Topál et al., 2009). For recent reviews on hypotheses regarding domestication of dogs and comparisons with wolves, see Kubinyi et al. (2022) and Range and Marshall-Pescini (2022).

In the process of testing this "domestication hypothesis," the value of dogs as a unique study system for fundamental questions regarding social cognition became clear. Some studies addressed questions about the origins and nature of dogs' social cognitive abilities at a more ultimate, phylogenetic level by comparing dogs with identically raised wolves on a variety of tasks, ranging from point-following to social referencing to humans during "impossible tasks" (e.g., Lampe et al., 2017; Lazzaroni et al., 2020; Marshall-Pescini et al., 2017; Miklósi et al., 2003; Range & Marshall-Pescini, 2022; Virányi et al., 2008). Relatedly, other studies have leveraged our knowledge of the dog genome to elucidate the genetic basis of behavioral and cognitive traits (e.g., MacLean et al., 2019; Morrill et al., 2022; vonHoldt et al., 2017), particularly the aspects of social cognition that are under genetic control in this species (e.g., Bray, Gnanadesikan, et al., 2021). Studies have also addressed more proximate causes of social cognitive abilities, focusing on the role of ontogenetic experiences such as rearing environment and training on social-cognitive development, both of which can be well documented and, to some extent, easily manipulated in dogs (e.g., Lazarowski & Dorman, 2015; Wynne et al., 2008). Dogs are also particularly amenable to completing cognitive tasks for fMRI while awake and nonsedated (e.g., Berns et al., 2012; Bunford et al., 2017; Karl et al., 2020). There is a developing body of research in canine cognitive neuroscience, leading to the examination of the neural processes underlying dog cognition (e.g., Berns et al., 2012; Bunford et al., 2017; Huber & Lamm, 2017; Karl et al., 2020; Thompkins et al., 2016).

Although dogs have provided a means of examining social cognitive processes from an evolutionary, phylogenetic, and developmental perspective, many questions remain. For example, there is still a need to disentangle the cognitive processes underlying dogs' ability to selectively imitate (Huber et al., 2020; Range et al., 2007), to use informants' past accuracy (Pelgrim et al., 2021) or knowledge (Catala et al., 2017; Maginnity & Grace, 2014) when choosing between information sources, and to take informants' perspective (Lonardo et al., 2021). These issues are all highly contentious, with controversial viewpoints ranging from low-level to high-level cognitive explanations (Huber, 2016; Udell & Wynne, 2011; Wynne, 2016). But importantly, these existing studies often also have ambiguous or contradictory results, partly because of small sample sizes, (hidden) lab differences, dogs with varying breed and training history, different experimental protocols (e.g., the dog owner inside or outside the testing room), and cultural differences in methods of rearing and training the subjects. Thus, to fully leverage the study of dogs to further enhance our understanding of the ultimate and proximate causes of social cognition, we will require multilab collaboration and communication.

Best Practices for Training That Enhance Canine and Human Welfare

Canine science is also an applied science with practical implications; dogs are prevalent in many facets of modern human life, filling myriad societal roles that range from companionship (e.g., pet dogs) to detection and protection (e.g., conservation, search-and-rescue, and police dogs) to assistance work (e.g., guide and service dogs). Scientific studies of canine behavior and cognition can facilitate these roles and relationships by informing the approach of professional handlers, trainers, and breeders. In turn, applied research has started to give insight into typical dog development, such as the normal range and developmental trajectory of behavioral traits, using large-scale owner questionnaires (e.g., Serpell & Hsu, 2001) and behavioral evaluations (e.g., Bray, Gruen, et al., 2021; Serpell et al., 2016; Svartberg, 2005).

Such applied projects within canine science have often aimed to study cognition and behavior in relation to improving the training and breeding of working dogs, to reduce the frequency of "failure" in training programs, and to improve the matching of individual dogs to specific jobs (Bergen-Cico et al., 2018; MacLean & Hare, 2018). At research centers (e.g., Canine Performance Sciences at Auburn University, the Penn Vet Working Dog Center) and individual laboratories, studies examine training protocols (e.g., for scent detection training, see Hall et al., 2021) as well as the cognitive, behavioral, environmental, and genetic factors that contribute to working dog outcomes (e.g., Bray, Otto, et al., 2021; Lazarowski et al., 2021).

Further, organizations such as Guide Dogs for the Blind (https://www.guidedogs.com), Guide Dogs UK (https://www.guidedogs.org.uk), The Seeing Eye (https://www.seeingeye.org), Canine Companions (https://canine.org), Healing Companions (https://healing-companions.org), and Intermountain Therapy Animals (https://therapyanimals.org) have partnered with academic researchers to systematically study questions related to canine behavior within their respective populations and to improve the success rate of their dogs within their training programs (e.g., Bergen-Cico et al., 2018; Bray et al., 2019; Friesen, 2009, p. 1995; MacLean & Hare, 2018; Pfaffenberger et al., 1976; Serpell et al., 2016; Vaterlaws-Whiteside & Hartmann, 2017; Walther et al., 2017). Recent studies have focused on cognitive tasks such as being able to successfully use information given by a human in a social context and reciprocate human social gaze at a very young age (Bray, Gnanadesikan, et al., 2021; Vaterlaws-Whiteside & Hartmann, 2017). One organization, Canine Companions, has even evaluated the use of neuroimaging techniques to predict future working success (Berns et al., 2017). By generating evidence-based recommendations, canine research is providing working dog trainers and breeders with tools to improve outcomes while prioritizing the welfare of the animals involved (Cobb et al., 2021; MacLean et al., 2021).

Canine science is similarly important for companion dogs, as behavioral challenges are one of the most significant reasons for their relinquishment to shelters (Diesel et al., 2010; Kwan & Bain, 2013). Several applied projects in pet dogs promote ethical re-homing and breeding practices. For example, The Functional Dog Collaborative (https://functionalbreeding.org), American Society for the Prevention of Cruelty to Animals (https://www.aspca.org), Dogs Trust (https://www.dogstrust.org.uk), and Good Dog (https://www.gooddog.com) aim to unite and connect breeders, adopters, shelters, and welfare professionals to facilitate successful homing of pet dogs. To achieve these goals, these projects study behaviors like resource guarding (Mohan-Gibbons et al., 2012), as well as health-related factors including veterinary care, genetic inheritance, and aging.

The existence and success of these projects demonstrate the benefits and feasibility of applying canine research methods to address real-world problems. However, current applied collaborations are almost exclusively confined to single organizations and populations, precluding wide-ranging comparisons. In contrast, a project like ManyDogs has the potential to address a strong need in the field, namely, to provide the framework and infrastructure necessary to develop and apply methodological best practices in a standardized way across academic research groups as well as nonprofit organizations. Ultimately, such a strategy will enable direct comparisons across different breeds, populations, and working roles. It will also allow for conclusions to be drawn that are relevant to smaller groups and organizations that do not have the resources or sample sizes necessary to address these questions on their own.

Big Team Science

Although it is unique in its approach, it is important to highlight that ManyDogs does not represent the first or only example of big team science in the field of canine science. Over the past 20 years, at least nine academically affiliated, large-scale canine behavior and cognition projects have been initiated. These large canine science projects have covered a variety of topics and can best be categorized into two types of team structure. Some large projects are led by a few principal investigators (and, in some cases, an advisory board). Members typically include researchers with varying expertise; for example, one member may design behavioral measures while another analyzes DNA samples. Critically, these projects do not involve multiple labs or research groups running the same experimental protocols and submitting data to a large, shared dataset; however, data collected are typically available for subsequent studies. These projects have often focused on integrating behavior, health, and genomic data from the same individuals and taken a longitudinal perspective. They often incorporate data collected from nonacademic members of the community, such as dog owners, with biological analysis done in the researchers' lab. Examples of projects with this type of organizational scheme include Darwin's Ark (https://www.darwinsark.org; Morrill et al., 2022), the Dog Aging Project (https://www.dogagingproject.org; Creevy et al., 2022), the Senior Family Dog Project (https://familydogproject.elte.hu), GenerationPup (https://generationpup.ac.uk; Murray et al., 2021), and the Golden Retriever Lifetime Study (https://www.morrisanimalfoundation.org; Guy et al., 2015).

Other projects have focused on large-scale data collection exclusively via community ("citizen") science. These projects are led by a few principal investigators, again perhaps with an advisory board, but the projects center around data that are collected outside a lab setting, submitted from nonacademic members of the larger community via video or survey responses. Examples of these projects include the Canine Behavior and Research Questionnaire (C-BARQ), which was designed to evaluate dog behavioral problems and trainability via a survey asking owners about dogs' behaviors (Duffy & Serpell, 2012; Hsu & Serpell, 2003; Serpell & Hsu, 2001) and Dognition, an effort to develop a large-scale citizen science platform for dog cognition (Stewart et al., 2015). Large citizen science projects like these help to engage the community and provide large diverse samples that support a broader range of statistical analyses and increase statistical power (Arden et al., 2016; Olsen, 2018).

Until now, a third type of organizational scheme has not been used in canine science, the ManyX project. ManyX projects consist of a consortium of independent researchers, each with their own facilities. These big team science collaborations provide a formalized infrastructure for multiple researchers and institutions to contribute to and collect data for shared research questions, fostering continuing collaboration as novel research questions and projects are proposed. ManyX projects are unique in that any researcher with appropriate resources can join and contribute data, and unlike other big team science frameworks, there is not a fixed, predetermined group of principal investigators.

Data collection for ManyX projects is conducted across multiple research sites, each following the same methodological protocol. As one of the first, ManyBabies (Frank et al., 2017) has explored topics of both theoretical and methodological interest (e.g., exploring both infant-directed speech and sources of variability induced by testing procedure and cultural influences; ManyBabies Consortium, 2020). ManyX projects with nonhuman animal species have facilitated phylogenetic comparisons and countered the challenge of small sample sizes. As an example, ManyPrimates (https://manyprimates.github.io) has examined 176 primates from 12 species (ManyPrimates et al., 2019), and the recently formed ManyBirds (http://themanybirds.com) has already considered more than 71 avian species (Lambert et al., 2022). Two other consortia focused on animal cognition have recently been developed, ManyGoats (https://www.themanygoatsproject.com/) and ManyFishes. Although there are numerous benefits to using the ManyX framework to investigate big team science questions, it is important to highlight that various challenges do exist (Byers-Heinlein et al., 2020; Coles et al., 2022; Forscher et al., 2022). Regardless, there is consensus across ManyX projects that if challenges can be mitigated and barriers can be managed, the benefits of these projects have enormous potential (Forscher et al., 2022). Thus, using the ManyX model, we have created and developed the consortium, ManyDogs (http://manydogs.org/), to address key theoretical, practical, and applied research questions in canine science.

ManyDogs Project

ManyDogs is a canine science-focused research consortium that supports the collaborative exploration of shared research questions by creating clear lines of communication among collaborators and promoting the use of open science tools (e.g., preregistration, open-access publishing, and publicly available data). The consortium fosters an environment that encourages participation across geographic location, career stage, and discipline; employs inclusive authorship practices; and develops easily implementable and affordable methodologies.

The impetus for ManyDogs initially emerged from discussions at a small canine cognition workshop in 2018, building on the desire to collaborate and share expertise across research groups. ManyDogs was founded with five broad scientific aims.

1. Attempt to replicate important studies, especially those with mixed evidence in the literature.
2. Investigate moderators that require large sample sizes (e.g., breed, individual differences, role of training). With each lab contributing a relatively small sample size, this spreads the data collection burden across groups while enabling studies larger than those typically published in canine science.
3. Develop consensus on methodological best practices, both through the process of methods development and standardization for each study and through analyses and reflections on variation among labs, particularly in cases where results are inconsistent across labs.
4. Investigate cultural differences. To date, most individual empirical papers on dog behavior and cognition have been conducted considering dogs from only a single cultural background. However, there are considerable cultural differences in attitudes toward dogs—both within and across countries (Ellingsen et al., 2010; Li et al., 2017; Wan et al., 2009)—and anecdotally, methods of rearing and training also vary widely. How this variation affects dog cognition and behavior, or their measurement, is largely unknown (for a notable exception, see Wan et al., 2009).
5. Set the bar for replicability of studies. As serious as the replication crisis is, we also should not expect real effects to always replicate—both for statistical reasons and for methodological ones (Farrar et al., 2020). ManyDogs will thus shed light on patterns of replicability across labs. To increase transparency and reproducibility in our research, ManyDogs incorporates core tenants of the STRANGE Framework (Social background; Trappability and self-selection; Rearing history; Acclimation and habituation; Natural changes in responsiveness; Genetic make-up; and Experience), designed to identify sampling biases and to improve reporting standards in animal behavior research (Webster & Rutz, 2020).

Since the inception of ManyDogs, the consortium has developed a Leadership Team consisting of elected co-directors and assistant directors that oversee the consortium's functioning and development. This includes administrative goals such as developing project infrastructure, securing funding, and community building across canine professionals in diverse fields. The high-level purpose of ManyDogs is to promote open science and address replicability through single-protocol empirical studies that are carried out simultaneously across multiple research sites around the world. Neither the topics nor methods of these studies are determined by ManyDogs governing board, rather through a democratic proposal selection process including the consortium as a whole. Once a project proposal is taken up for study development, a small group of researchers oversees the design and implementation across research sites, making decisions guided by the framework of ManyDogs but independent of the consortium's Leadership Team. We describe our first, democratically selected study next.

ManyDogs 1

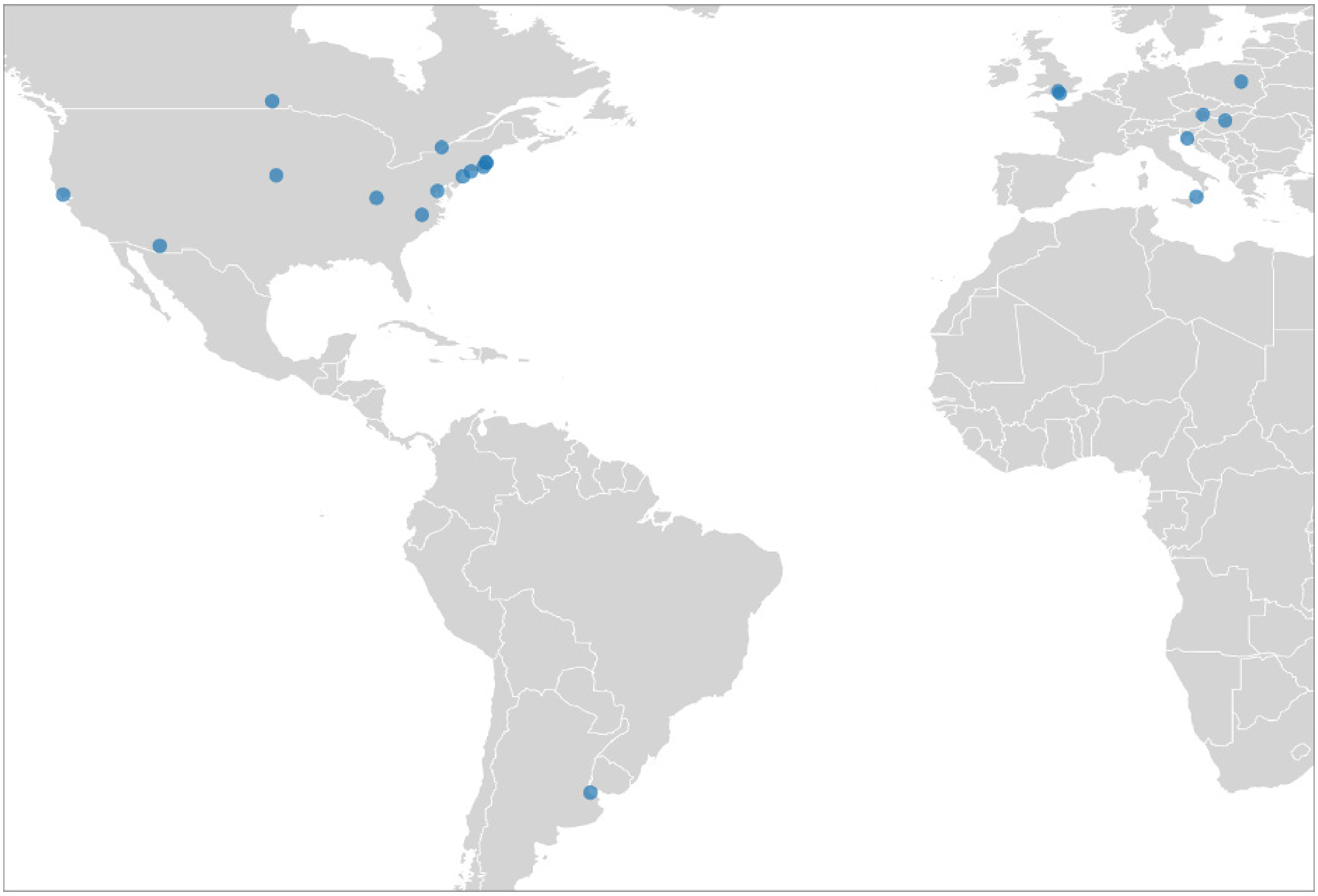
The first study conducted by the ManyDogs, ManyDogs 1 (ManyDogs Project et al., 2021), evaluates domestic dogs' understanding of a common human gesture, the point (for a review, see McCreary et al., 2022).

It demonstrates feasibility of big team science in canine science and of the ManyDogs consortium's ability to address our five aims. To achieve Aim 1's goal of replicating important studies, we selected a seminal research question with mixed results reported in the literature. To directly quantify the impact of key moderators, such as breed differences in point following behavior, we address Aim 2 by recruiting a sufficiently large and diverse sample of participating laboratories. We developed a standardized experimental protocol with initial consensus across select canine cognition groups in North America to address Aim 3. This was followed by a larger global expansion with additional feedback and refinement to facilitate Aim 4's emphasis on understanding cultural differences. To further this aim, ManyDogs 1 currently includes data collection from collaborators in North America, South America, and Europe (Figure 1). This geographic diversity already captures some variability in dog training and rearing practices. Nonetheless, we acknowledge that cultural diversity, particularly outside of Western countries, is an active area for growth that we return to next. Finally, in implementing ManyDogs 1, we fulfill Aim 5, identifying shared values and practices based on transparency and reproducibility in our research. This has guided our decision making and project development, including preregistering our analyses, publishing in open-access journals, and data transparency.

Participation in ManyDogs

As discussed earlier, one of the key values of ManyDogs is to foster participation at all career stages. By this metric, ManyDogs has been quite successful, including involvement from individuals of almost all career stages, as highlighted in Figure 2. Furthermore, beyond involvement in data collection, ManyDogs allows for additional avenues to authorship—in project areas including, but not limited to, data organization, analysis, and writing—that can accommodate a variety of individual needs. Although

Figure 1. Map of current distribution of contributors for ManyDogs.



ManyDogs has substantial undergraduate involvement, especially in data collection, there is currently comparatively little undergraduate representation in contributing to writing. As we continue to develop the consortium, ManyDogs can continue to improve inclusivity by developing more formal mentorship schemes, for instance, to support and train undergraduate students in scientific writing.

Taken together, ManyDogs 1 is a successful case study for accomplishing our scientific aims within a collaborative framework. Throughout this process, we have identified multiple refinements for future ManyDogs projects. Because of ManyDogs' origins within an academic environment, involvement has largely consisted of university-affiliated academics (e.g., students, researchers, educators), pet dogs, and indirectly their owners/guardians (Figure 3). Although this large-scale collaboration is no small feat, it is our hope that future ManyDogs studies increase representation from a larger number of industry, applied, and other professionals. Further, whereas the majority of ManyDogs and ManyDogs 1 contributors are based in North America and Europe (Figure 1), we are currently recruiting additional involvement from other continents such Asia, South America, and Australia. Similarly, the protocol for ManyDogs 1 was designed for pet and working dogs; however, the majority of the world's dogs are free-ranging (Lord et al., 2013). Future studies may be designed for greater flexibility to incorporate free-ranging dogs to better represent the dog community.

Beyond promoting geographic diversity both within the research team and in the areas in which research is conducted, a future direction for ManyDogs includes a greater focus on inclusion, accessibility, and diversity. Of particular note, in recruiting culturally and geographically diverse collaborators, we have been faced with issues such as language barriers when it comes to translating materials and methods. Together, we have been able to translate ManyDogs 1 materials into seven languages: Croatian, German, Hungarian, Italian, Polish, Spanish, and Turkish. However, these challenges highlight the need, in general, for more accessible technological tools, practices, and spaces.

Finally, we pledge our commitment to supporting historically excluded and currently marginalized populations within our community. At present, opportunities are currently available through internship programs (e.g., the NSF-REU program) through our academic contributors and collaborators and targeted at providing undergraduate students from underrepresented minority groups with research experience and mentoring. As we continue to develop and grow the consortium, we are excited about the possibility to establish additional opportunities to improve and promote accessibility, diversity, and inclusion within ManyDogs, but als canine science and ManyX projects.

More generally, as previously highlighted, while adopting a big team ManyX model provides many benefits, it is also accompanied by unique challenges. The first of these is the increased administrative load required to

Figure 2. Bar chart summarizing the distribution of career stages involved in ManyDogs 1 and ManyDogs Intro (the present publication). Note that involvement in both ManyDogs 1 and ManyDogs Intro may fluctuate given these projects are ongoing. These values are accurate as of September 2022.

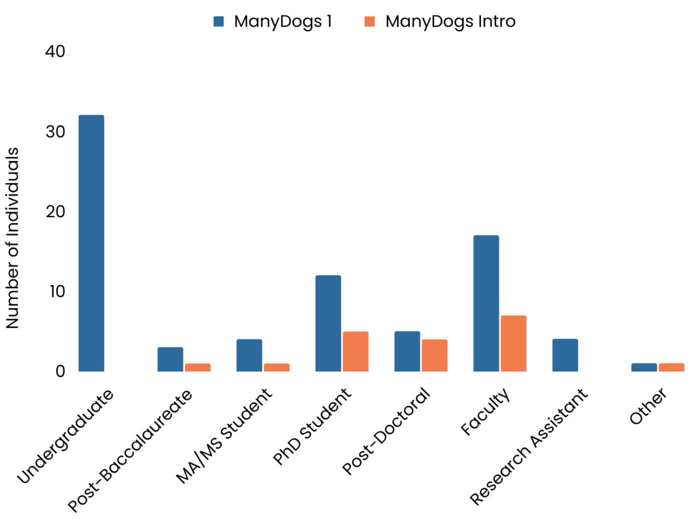


Figure 3. A visual and conceptual representation of who is, and can be, involved in ManyDogs? This figure broadly demonstrates those currently involved in ManyDogs (primarily Academic Professionals and Dogs and Owners, identified in light blue) while highlighting additional canine professionals (Industry Professionals, in yellow; Applied Professionals, in orange; and likely others in The Future, in dark blue) the consortium aims to involve.

organize collaborator contributions, set project milestones, and track progress for subprojects while steering the consortium as a whole. Second, securing funding for big team science projects is difficult, as many traditional funding sources (i.e., government granting agencies, foundations, and educational institutions) do not recognize distributed networks of scientists as eligible recipients. Specialized funding opportunities for big team science projects may help minimize barriers that impede broad-scale participation in science. By supporting collaborative research teams, funding can be used not only to procure specialized training and equipment needed for experimentation but also to maximize inclusion, equity, and diversity at a global level. Finally, current evaluation schemes and authorship conventions in comparative cognition do not incentivize scientists to invest time or effort into team projects with large numbers of coauthors. These challenges have been recently discussed by other ManyX projects, and we recommend referring to their insightful treatises on moving big team science forward (e.g., Coles et al., 2022; Forscher et al., 2022). Regardless of these challenges, ManyDogs provides a platform that allows for a broad, interdisciplinary network in which researchers, industry professionals, applied professionals, pet owners, and others can identify and propose areas of research, contribute to the growth of scientific knowledge, and translate research findings into direct and indirect benefits to both humans and dogs.

Conclusion

In recent years, research on canine science has exploded, revealing dogs as a key study system for understanding human health, evolutionary processes, applied science, and behavior and cognition. From the psychobiology of aging and dementia to the cognitive outcomes of domestication to the training and selection of working and pet dogs, we can address many critical questions by examining this incredible companion species and its relationship with humans. Yet the extensive variation observed in dogs across individuals, breeds, and cultures poses challenges to the systematic study of their behavior. Many important questions cannot be tackled by single labs with limited sample sizes. This is where big team science frameworks are needed.

ManyDogs offers a systematic approach to addressing questions of canine behavior and cognition that were previously unanswerable or whose answers are thus far inconclusive. By developing ideas and generating data through multilab collaborations, we can obtain larger samples to achieve the project's scientific goals of investigating moderators of and cultural differences in behavior and cognition, replicating important studies, developing methodological best practices, and promoting replicable science. ManyDogs can address previous limitations in individual lab studies and previous big team science frameworks to deepen our understanding of canine behavior and cognition. We believe that this approach can provide the tools to develop more complete theories of behavior and cognition as well as improve dog welfare, human healthcare, and the millennia-old canine–human bond.

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