

A Review of Cognitive Abilities in Dogs, 1911 Through 2016: More Individual Differences, Please!

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Abstract

In this review, we pose and respond to three questions concerning canine cognition: How has the history of this field influenced what we currently know about dog cognition? How confident should we be about what we know? Finally, what should we find out next? We begin by presenting two perspectives on canine cognition. We then survey the existing literature by conducting a quantitative summary of over 100 years of empirical work, focusing on power and replicability. Last, we lament the dearth of individual-differences studies in dog cognition (only three since 1911). We claim that a test of dog IQ with good psychometric properties will benefit basic science on dog and human health (including aging and dementia research). As a complement to an existing rich program of ethological investigation, we argue that individual-differences work on dogs should be a research priority.

Keywords

dogs, intelligence, cognition, animal model, dementia, *g* factor, reproducibility

The views of Mrs. Alice James, wife of William James, the “father of psychology,” on having her husband’s student move with his chickens into her cellar are lost to posterity. The accomplishments of that student, who later took his two “most educated” chickens to Columbia University, are not (Dewsbury, 1998). Edward L. Thorndike (1874–1949) was a foundational researcher into animal intelligence. He published work on comparative psychology; his significance here is that he published the earliest work (that we have found) on intelligence in dogs (Thorndike, 1911).

We begin this review of canine cognition by recounting where this research came from, historically. Next, we present a quantitative summary of the extant research. What we know about dog cognition has been brought together in two comprehensive sources (Bensky, Gosling, & Sinn, 2013; Miklosi, 2007); here, we ask how confident we should be in those findings. Finally, we discuss where we could go next in studying canine cognition; we set out our own interests and suggest an application for them.

Scholars exploring animal cognition have surveyed it from two differing perspectives. One perspective is characterized by Thorndike, who took a positivist, behaviorist approach to animal intelligence and later became

interested in children’s cognitive abilities, including their measurement and individual differences. The intellectual descendants of Thorndike are psychometrics-oriented scholars who mostly work on human intelligence, publish in human-subject-oriented journals, and attend conferences concerned with scholarship on variance in cognitive abilities in human animals.

The second perspective on animal cognition research leans closer to that of Konrad Lorenz (1903–1927), whose approach was ethologically oriented. His intellectual descendants are mostly scholars who work on animal cognition at the species level, read the literature on animal behavior, and attend conferences concerned with species-typical behavior in nonhuman animals.

This work accounts for the great majority of canine cognition research; it asks questions such as whether dogs can count or follow a human pointing gesture or

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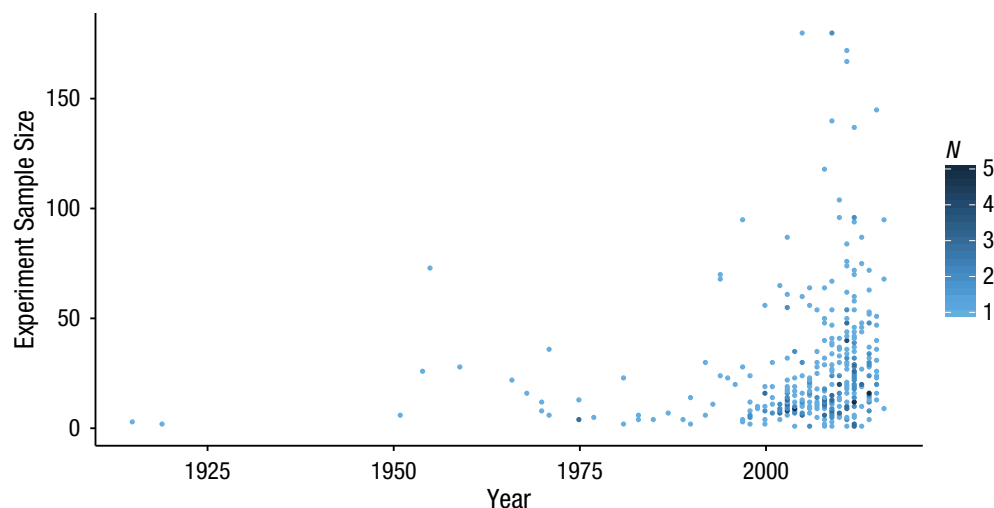


Fig. 1. Empirical reports of dog cognition from 1911 to 2016 by experiment sample size. The color of the points represents the number of experiments with each combination of sample size and year, with darker points indicating greater numbers.

recognize emotions. But how confident should we be in the overall generalizability of the results from these studies? To find out, we extracted the sample sizes from 295 empirical reports on canine cognition published between 1911 and 2016 so that we could get a sense of study design, effect size, and power.

Sample Size and Statistical Power in Canine Cognition Research

We asked, at a basic level, what is the likely overall level of replicability among studies of dog cognition? To find out, we began with a comprehensive literature review of studies on canine cognition from 1911 to 2012 (Bensky et al., 2013). Next, we updated that review to include publications on Web of Science as of March 2016. Then we examined sample sizes in conjunction with various effect sizes. Encouragingly, we found that the field of dog cognition research is growing; most of the extant literature was published after 2000.

We also examined how many dogs were included in these studies. Of the 287 empirical reports in our review, 81 contained multiple experiments. Yet most studies (240, or 84%) had fewer than 50 animals per experiment; 172 studies included 25 or fewer dogs. There were only nine studies with more than 100 dogs. Sample sizes for experiments ranged from 1 to 180, with a mean of 25.7 and a median of 16, and are plotted in Figure 1.

The Reproducibility Project in psychology (Open Science Collaboration, 2012) motivated us to test the likely replicability of findings in dog cognition given the range of sample sizes used in these experimental studies. To evaluate this, we plotted power for various tests: correlational, within-sample difference of means, and between-sample difference of means. Power was plotted against various

sample sizes over a range of effect sizes (see Fig. 2). With the median sample size of 16 that we found for existing canine cognition studies, there would be almost no power to detect even very large effects. Even the largest sample size that we found (180 dogs) has less than 50% power to detect a between-sample effect with a smaller-than-medium effect size (assuming 60 dogs per group, $d = 0.5$ at $\alpha = .001$), and at this sample size, no test had greater than 80% power to detect small ($r \approx .2$ or $d \approx 0.2$) effects. We conclude that most studies are underpowered. While we acknowledge that acquiring data on dogs is more challenging than gathering similar behavioral data from people, our power analysis shows that to be able to draw conclusions with confidence, sample sizes in dog cognition research need to be much larger. The extra effort needed to collect larger samples of canines is worth it: Large sample sizes are well powered even under a strict criterion for statistical significance (e.g., $\alpha = .001$), which promotes higher replicability in animal cognition studies, reduces the number of false positives reported, enables the accurate estimation of all effects both large and small, and allows negative findings to be more conclusive (Gelman & Tuerlinckx, 2000). We note, too, that reporting could be much improved. Out of 287 studies, only 108 gave the sample size(s) in the abstract; even in the main text, it was often difficult to tease out how many animals were actually tested (as opposed to how many were initially sampled). We recommend conducting power analyses when planning study designs, as well as improved reporting of the results.

Studies on Variation in Dog Cognition

We began by describing two perspectives in the history of animal cognition research. What became of the Thorndike-inspired (individual-differences) scholarship?

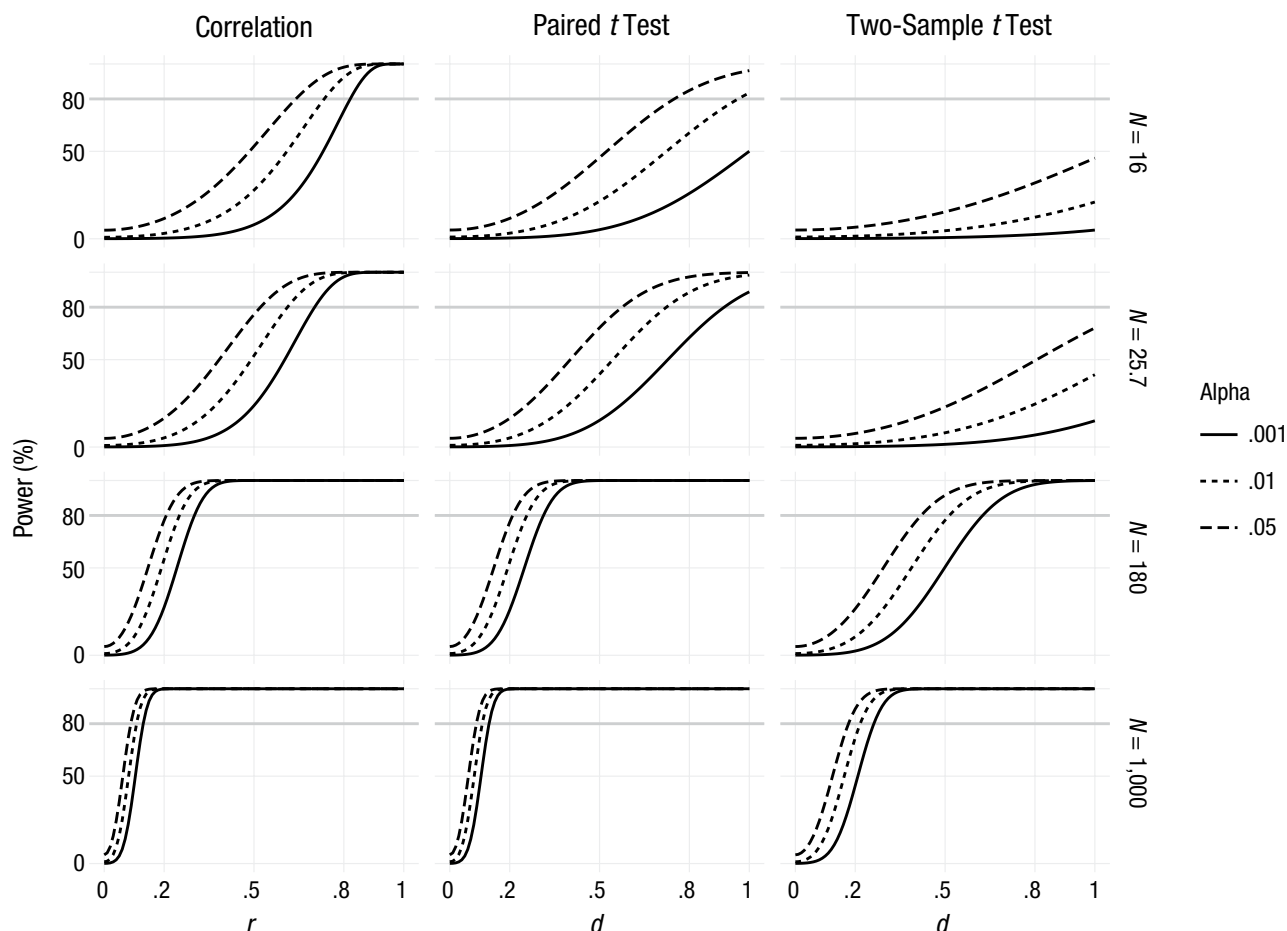


Fig. 2. Power as a function of effect size for three statistical tests commonly used in canine cognition research: correlations (*r* between two measures on *N* subjects), paired-sample *t* tests (Cohen's *d* of within-subjects mean difference of two measures on *N* subjects), and two-sample *t* tests (Cohen's *d* of between-subjects mean difference with *N* subjects divided equally into two groups). Plots show power for the median (*N* = 16), mean (*N* = 25.7), and maximum (*N* = 180) sample sizes in surveyed canine cognition studies, as well as for a hypothetical sample size of an extremely well-powered study (*N* = 1,000), for three significance criteria (α = .05, α = .01, and α = .001). Horizontal lines in the graphs highlight where 50% and 80% power is achieved, and vertical lines indicate small, medium, and large effect sizes.

From 1911 to 2016, we found only three studies that took an explicit individual-differences approach to exploring canine cognition (Anastasi, Fuller, Scott, & Schmitt, 1955; Arden & Adams, 2016; Nippak & Milgram, 2005). This gap in the literature is surprising for several reasons: Dogs are plentiful, varied, tractable, and are easy to test with cognitive tasks. Crucially, exploring intelligence, operationalized as *g*, has been very fruitful in the species whose cognition has been most thoroughly explored: the human animal.

About *g* (for General Intelligence)

The existence of *g* is an empirical finding from thousands of highly powered studies both at the phenotypic and the genetic levels of analysis (Carroll, 1993; Davies et al., 2011; Deary, 2013). This *g* factor is the most reliable and

valid way to operationalize, or index, intelligence because it appears consistently as the common variance among tests, and because it has strong links with important life outcomes. It is fairly stable across the life span (Gow et al., 2011); and its heritability (proportion of the differences within a measured population explained by genes) increases with age (Bouchard, 2014). The *g* factor is not a number on a ratio scale; it does not capture everything there is to know about an individual's intelligence. No test from which *g* emerges is entirely free of all cultural influences, and all tests have some measurement error. Further, *g*, which is an index of the overlap or covariance among test scores, usually accounts for around 40% to 65% of the variance across tasks (Deary, Spinath, & Bates, 2006). This indicates that individual tests each have some specificity. The *g* factor is not biologically unitary (not a blob in the brain; Jung & Haier, 2007). Rather,

it exists at the psychometric and genetic level, like health or beauty, which do not reside in the knees or the nose but instead tap multiple small indicators, each of which is in some measure linked with those constructs. There are unsettled questions concerning *g*. We do not yet know why *g* emerges—why even elementary cognitive tasks, such as reacting to a lit button, correlate positively with vocabulary test scores. Large-scale studies using DNA from unrelated individuals (Davies et al., 2011; Hagenaars et al., 2015) have hinted that pleiotropic mutations (mutations that affect diverse phenotypic traits) may play a role. There is a small literature on *g* in nonhuman animals (reviewed in Chabris, 2007), but there is little phenotypic work on *g* in dogs and no work yet on the genetics of dog *g*.

To avoid confusion, it is crucial to note that *g* is a within-species construct, not a yardstick to measure whether one species is more intelligent than another. Cognitive abilities evolve to solve specific recurrent problems posed by a particular species' ecology. Some species have simpler, more predictable lives entailing less combinatorial complexity than others. The fitness payoff of innovation and insight differs between species and over time and place within species. This results in some species evolving richer suites of cognitive abilities (and concomitant behavioral flexibility) than others. The *g* extracted from each species emerges from different constituent abilities involving different mechanisms and genetic substrates. Scholars use various methods to extract *g* from scores on cognitive-ability tests; factor analysis is commonly used (Carroll, 1993).

The most recent report testing *g* in dogs (Arden & Adams, 2016) tested 68 farm-living Border Collies on six tests (of which four were different types of detour tests). The key finding was that more accurate dogs were also faster (consistent with Nippak & Milgram, 2005), and there was some evidence of a *g* factor. While we found that the data were consistent with a single, higher-order factor explaining the reliable variance of task performance, our study did not contain enough different types of tests to fully explore some alternative models for the structure of canine intelligence. We did not deliver a proven, reliable method of testing *g* in dogs. That will take more work. However, we showed that this is a promising line of empirical research. Given what is known from other species (Chabris, 2007), the prior expectations are strongly tilted toward there being a *g* factor in dogs. As noted elsewhere, it took a long time to work out the problems of test bias, reliability, and validity in human intelligence testing (Bouchard, 2014). Perhaps our key innovation was to develop a test that could be conducted within about an hour per dog. Previous work measuring dogs' cognitive performance has typically taken up about 40 days per dog, owing to intensive training (Callahan et al., 2000). Speed of testing is essential if

we are to scale up dog cognition studies to take advantage of genomics. Why might that be useful?

Developing a test of dog *g* with good psychometric properties would benefit both dogs and people. It would be informative about the range, mean, and distribution of intelligence in dogs (both as a species and by breed). It would allow us to track the cognitive changes that dogs experience over the life course. Such a test would allow us to explore the correlates of *g*. We could ask questions, such as: Are brighter dogs also healthier? Is *g* linked with fitness-related traits, both phenotypically and genetically? Are social and physical learning measurably independent constructs, or do they overlap substantially with *g*? What is the genetic architecture of *g* in dogs?

Individual-differences research with dogs could illuminate one of the most striking findings from human intelligence research: the tendency for brighter people to live longer and have better health (Hagenaars et al., 2015; Whalley & Deary, 2001). This small but discernible association between intelligence and health-related outcomes is widespread in mammals and is suggestive of a fitness factor (Arden, Gottfredson, & Miller, 2009; Houle, 2000). The dog offers an opportunity to test this hypothesis in a species in which variation in intelligence is less likely to be causally confounded by socioeconomic status. Further, dogs are impervious to the lure of alcohol and cigarettes, which have harmful health consequences for people.

Practical Uses of a Dog *g* Test (With Good Psychometric Properties)

Dogs' brains, like ours, decline in various ways with increasing age. As well as experiencing healthy brain aging, dogs are a good natural model of dementia (Bosch, Pugliese, Gimeno-Bayon, Rodriguez, & Mahy, 2011; Head, 2013; Sarasa & Pesini, 2009). Affected dogs' brains experience many of the features of human dementia, including neuronal loss (Insua, Suárez, Santamarina, Sarasa, & Pesini, 2010), amyloid plaques (Bosch et al., 2011; Cummings, Head, Afagh, Milgram, & Cotman, 1996; Head et al., 2010), tau neurofibrillary tangles, inflammation (Smolek et al., 2016), and evidence of oxidative damage to lipids, protein, DNA, and RNA (Braidly et al., 2015; Romanucci & Della Salda, 2015). Disease progression in dogs is similar to that in humans (Satou et al., 1997). Importantly, similarities between dogs and people in dosing, responsiveness, drug tolerance, and metabolism have been exploited in studies on statins (Head, 2013; Martin, Dowling, & Head, 2011). This bodes well for translation from dogs to people, which has been a problem in research based on mouse models of dementia. The life span of a dog ranges from 6 to 16 years, varying by breed (Creedy, Austad, Hoffman, Neill, & Promislow, 2015). This means that a longitudinal study

that includes repeated testing of a non-invasive, quick-to-administer test of intelligence, such as has been described in our work (Arden & Adams, 2016), would be valuable in aging research (Heckler, Tranquilin, Svicerio, Barbosa, & Amorim, 2014; Snigdha et al., 2013; Yu et al., 2011). The development of a fast, reliable measure of *g* should be a research priority. It should be quick to administer, because larger sample sizes are essential for genomic research; the seminal work in canine models of dementia is predicated on a sample of 25 dogs with cognitive test scores (Milgram, Head, Weiner, & Thomas, 1994).

The evidence leads us to recommend the development of individual-differences research in dogs as a complement to the imaginative and fruitful work tackling ethological species-level or group-level (e.g., age or sex differences) questions. We should go forward armed with lessons learned from contiguous fields. The Reproducibility Project has shown the value of independent scholarship confirming key findings (Open Science Collaboration, 2012). The value of informative reporting standards has been elaborated (Cumming, 2014); the benefits of groups working together, such as increased sample sizes and consequent increases in power, has been shown in psychiatric genetics (O'Donovan, 2015). Bringing these scientific practices to bear on canine cognition will have huge advantages. We have an immense amount to learn from these captivating animals. Let's go to the dogs.

Recommended Reading

- Bensky, M., Gosling, S. D., & Sinn, D. L. (2013). (See References). A comprehensive review of the literature on dog behavior and cognition.
- Matzel, L. D., Han, Y. R., Grossman, H., Karnik, M. S., Patel, D., Scott, N., . . . Gandhi, C. C. (2003). Individual differences in the expression of a "general" learning ability in mice. *The Journal of Neuroscience*, 23, 6423–6433. Not on dogs, but a classy study showing a clear empirical approach to the study of intelligence in a nonhuman animal.
- Milgram, N. W., Head, E., Weiner, E., & Thomas, E. (1994). (See References). The seminal article that showed how the dog is a useful model of human aging and dementia.
- Ostrander, E. A., Giger, U., & Lindblad-Toh, K. (Eds.). (2006). *The dog and its genome*. Cold Spring Harbor, NY: Cold Spring Harbor Laboratory Press. A good introduction to dogs and their genetics.
- Smolek, T., Madari, A., Farbakova, J., Kandrak, O., Jadhav, S., Cente, M., . . . Zilka, N. (2016). (See References). Sets out some behavioral and brain-level age-related changes, showing the correspondence between dogs and people.

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Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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