A Case for Methodological Overhaul and Increased Study of Executive Function in the Domestic Dog (*Canis lupus familiaris*)

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Abstract

Executive function allows for self-regulation of behavior including maintaining focus in the face of distraction, inhibiting behavior that is suboptimal or inappropriate in a given context, and updating the contents of working memory. Previous research indicates that, in humans, one's level of executive function can impact academic success, ability to navigate social situations, and engagement in dangerous behavior. Our understanding of executive function in domestic dogs is severely limited despite its relevance to both the modeling of human cognitive function and to canine welfare. In this paper, I review some existing studies related to the dog's executive abilities and emphasize the importance of continued and more rigorous study of abilities such as inhibitory control, cognitive flexibility, and working memory capacity in dogs. In section 1, I present an argument for how both dogs and humans can benefit from the study of canine executive function. In section 2, I provide a theoretical background of executive function and its associated processes and briefly review implications of (un)successful executive function. In section 3, I review and synthesize findings in the current literature relevant to executive function in dogs and consider limitations of these studies that must be addressed in future research. Finally, in section 4, I propose future directions for meaningful research on executive function in dogs.

Keywords: *dogs, canine, cognition, executive functioning, attention*

According to a recent survey by the American Pet Products Association (ASPCA, n.d.) 78 million dogs are owned as pets in the United States with 44% of households owning at least one dog. In modern society, dogs serve not only as human companions but also augment human efforts in sectors including law enforcement, search and rescue, scent detection, service to the disabled, and therapy. Given the dog's pervasive role in human society, it is paramount that dogs be able to behave in a manner appropriate to the current situation. Executive function is critical for dogs to exercise such context-appropriate behavior.

As described by Pennington and Ozonoff (1996), executive function involves "context-specific action selection, especially in the face of strongly competing but context inappropriate responses" (p. 55). It is an intentional, effortful form of self-regulation, sometimes goal-directed, that can enhance long-term consequences by forgoing short-term gratification (Barkley, 1997) and encompasses behavior such as focusing on a goal in the face of distraction, inhibiting behavior that is not appropriate for a given situation, and updating contents of working memory in a dynamic environment. In humans, deficits in executive function can lead to negative outcomes including poor academic performance, trouble interacting with peers, financial troubles, risky behavior, and substance abuse (Moffitt et al., 2011, 2015; Nigg, 2001).

Similar dire consequences exist for dogs. Dogs can be fulfilling companions and diligent workers, but are also relatively large carnivores that can bite, scratch, maul, and cause destruction. Behaviors such as aggression, destructiveness, and disobedience can lead to relinquishment to an animal shelter and, in some cases, euthanasia (Salman et al., 2010). The quality of dog welfare, human safety, and dog-specific legislation depends on the existence of a body of rigorously conducted research on how dogs inhibit natural, but suboptimal, urges and attend to humans amid distraction. While executive function has been studied extensively in humans, only one study to date has explicitly addressed executive function in domestic dogs (Tapp et al., 2003) with several others examining executive abilities like inhibitory control and working memory capacity; however, many of these studies have significant methodological issues that limit the interpretation and applicability of their findings.[1] These issues are not insurmountable, but must be remedied if we are to have an accurate understanding of how dogs regulate (or fail to regulate) their behavior. Researchers going forward can potentially benefit from lessons learned by early cognitive psychologists in their efforts to understand executive function in humans.

The purpose of this paper is threefold: 1) to emphasize the importance of better understanding executive function in dogs in terms of dog welfare and benefits to society, 2) to provide a review of research-to-date, synthesizing findings across studies and critically evaluating the methods and conclusions of canine scientists, and 3) suggest new directions for future research in studying executive function in dogs. This paper begins with an explanation of how research on dog executive function has the potential to benefit both dogs and humankind. I describe the two main traditions – comparative and ethological – by which canine cognition research is studied, and the utility of each in elucidating canine executive function. The former approach leverages similarities between humans and other animals, generally to the benefit of human health, and the latter emphasizes behavior at the species level (i.e. studying dogs for the sake of understanding dog behavior as it occurs in the natural environment).

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[1] One could argue that capacity for executive function presupposes consciousness. Consciousness, the capacity for subjective experience, in nonhuman animals is a historically controversial topic and remnants of this controversy persist in the modern-day era. I am comfortable with this presupposition in discussing canine executive function, given the body of experimental evidence regarding dogs' cognitive and socio-cognitive abilities. In the interest of avoiding anthropomorphism, some researchers will disagree and prefer to frame canine behavior as the result of cumulative rewards and punishments. However, as Panksepp (2010) has stated, "it is theoretically convoluted to explain how external 'rewards' and 'punishments' produce diverse behavioural changes in animals without evoking affective experiences. Of course, the existence of affective *experiences* in animals does not automatically imply that they are consciously *aware* of or think about their experiences" (p. 2906).

The purpose of section 2 is to introduce the reader to executive function by grounding it (and its components) in the theoretical and historical context of cognitive psychology. To illustrate how executive function allows for optimal behavior, I provide an overview of some cognitive and neurophysiological explanations put forth by researchers, focusing on those which distinguish between automatic processes and processes requiring an executive component (e.g., the Supervisory Attentional System proposed by Norman and Shallice, 1986). I also discuss specific components of executive function, including selective attention, working memory capacity, and cognitive flexibility. The section concludes with a brief summary of executive function relates to common human endeavors including academics, social relationships, and engagement in dangerous behavior.

Canine researchers have just begun to shed light on executive abilities like inhibitory control and working memory capacity. I dedicate section 3 to describing and evaluating some of the methods used by these researchers, placing an emphasis on limitations that must be addressed in research going forward. Specifically, the ubiquitous use of small samples, lack of reliability estimates for individual tasks, and assumptions of process purity severely limit the conclusions that can be drawn from existing research. I also consider the different ways by which researchers have conceptualized presumed causal factors like breed, training, and other and ontogenic influences. I conclude with a summary of how researchers have illuminated the phenomenon of canine executive function thus far.

The paper concludes with suggested directions for future research. In particular, task battery development, use of eye-tracking technology, and use of functional magnetic resonance imaging (fMRI) have the potential to further our understanding of canine executive function, showing us how self-regulatory processes in dogs compare to ours and laying a theoretical foundation for better training and breeding practices, evidence-based legislation, and improved dog welfare and human safety.

Section 1: The Importance and Implications of Canine Executive Function

Research in humans has repeatedly shown that deficits in executive function lead to significant negative outcomes (Barkley, 1997; Duckworth et al., 2013; Gardner & Gerdes, 2015) and abundance of executive abilities reaps short- and long-term rewards (Braver, Gray, & Burgess, 2007; Engle, 2002; Lee & Therriault, 2013; Mischel, Shoda, & Rodriguez, 1989; Moffitt et al., 2011). While the human literature on executive function is vast, we are only beginning to understand components of executive function in dogs. Given that dogs are so commonplace in contexts ranging from the human household to police work and therapy, it is imperative that we learn more about what allows dogs to inhibit normal species behavior including chasing, inappropriate mounting and, in some cases, aggression. The recent surge in scientific interest in canine cognition provides an opportunity to delve further into this challenging area of research. Both of the perspectives – comparative and ethological – used to study dogs offer unique insight into how environment, ontogeny, training, and genetics might influence canine executive function, and knowledge obtained through such methods has the potential to benefit both humans and dogs alike.

Increasing Interest in Canine Cognition

Up until the turn of the twenty first century, research on the domestic dog (*Canis lupus familiaris*) was sparse. Because dogs were often seen as an artificial species created by man, scientists did not believe they warranted serious study (see Miklósi, 2011 for a brief discussion). Much of the research using dogs focused on learning via classical conditioning (Pavlov, 1927) with the occasional study examining other aspects of cognition, such as social learning in puppies demonstrated by Adler and Adler (1977). Toward the end of the 1990s, an apparent change of heart occurred and the field of canine cognition has grown exponentially ever since (Arden, Bensky, & Adams, 2016). Dr. Brian Hare at Duke University is generally credited for the recent surge in canine cognition study. His early attempts at understanding inter-specific communicative gestures (Agnetta, Hare, & Tomasello, 2000; Hare, Call, & Tomasello, 1998; Hare & Tomasello, 1999) were followed by other researchers attempting to better understand the dog's seemingly innate sensitivity to human pointing. A considerable portion of the existing research on dogs centers on whether dogs are unique in their ability to follow human gestures and whence this ability came (Hare & Tomasello, 2005; Reid, 2009; Udell, Dorey, & Wynne, 2008).

Thanks to the newly invigorated scientific interest in dogs, we have learned a great deal about how dogs process information and use this information to succeed in their often human-dominated environment. For example, we now have evidence that dogs are less likely to follow direction from an unreliable human relative to a reliable human when trying to locate hidden food (Takaoka, Maeda, Hori, & Fujita, 2015), use our emotional expressions to guide approach and fetching behavior (Borbála, Szántho, Miklósi, & Kubinyi, 2015; Merola, Prato-Previde, Lazzaroni, & Marshall-Pascini, 2014; Ruffman & Morris-Trainor, 2011), are less likely to take forbidden food if they believe we are watching (Call, Braüer, Kaminski, & Tomasello, 2003), and might even be capable of tactical deception (Heberlein, Manser, & Turner, 2017). Some researchers have ventured beyond traditional behavioral measures to learn more about how dogs think: use of touch screens, eye tracking, and functional magnetic resonance imaging (fMRI), seemingly inconceivable technologies by which to study dogs, are being used with considerable success (Andics et al., 2014; Berns & Cook, 2016; Cook, Spivak, & Berns, 2016; Müller, Schmitt, Barber, and Huber, 2015; Rossi, Smedema, Parada, & Allen, 2014).

Far from the useless artificial species they were believed to be, dogs have shown themselves to be valuable resources for studying cognition and cognitive decline in humans, as well as being fascinating subjects for study in and of themselves. As with most nonhuman animals, dogs are generally studied to satisfy one of two ends: 1) to model human cognitive processes (the comparative perspective), and 2) to better understand how dogs behave in their natural environments (the ethological perspective). Both of these perspectives have been useful in helping us to better understand how dogs perceive and react to stimuli in their environment in ways that are both similar and different from our own.

Our Dogs, Ourselves: How Comparative Research Benefits Humans

In presenting his theory of evolution by natural selection, Charles Darwin is believed by some to have helped set the stage for the birth of *comparative psychology*, the scientific study of how various species are similar to and different from each other (Goodwin, 2015). An important part of Darwin's theory was the notion of continuity of biological and mental processes across species (Darwin, 1871). Researchers have since been able to leverage this continuity by using nonhuman animals, who were more compliant and convenient subjects, to model human biological processes and cognition. Darwin, an avid fan of dogs (Townshend, 2009), might have been pleased to see how dogs have been used to better understand ourselves.

In the early years of comparative psychology, Edward Thorndike (1874 - 1949**)** made significant contributions through his meticulous focus on systematic observation and description of behavior, which has allowed animal research to be more empirically-based and less reliant on anecdotes and anthropomorphism, both of which are still tempting to use (especially when describing dog behavior, Horowitz & Bekoff, 2007). Using anecdotes to study animal behavior was not uncommon around this time and was a practice Thorndike abhorred. Thus, he did not get involved with animal research because he found it inherently interesting but, rather, because he thought he could do better than previous researchers. While his unapologetic criticism of existing methods might not have earned him many friends, his empirically-minded methodology led to great advances in our understanding of learning, including the Law of Effect and Law of Exercise. In his early scientific work, he used cats trapped in puzzle boxes to better understand the learning process. He eventually transitioned his focus from learning in cats to learning in humans, becoming a prominent educational psychologist (Goodwin, 2015).

Although Thorndike used cats, the use of mice and rats has become common in modern nonhuman literature. In recent years, dogs have gradually assumed a greater role in the comparative realm for nearly the same reason that they were initially excluded: their close relationship to humans. Humans have domesticated many species, but dogs share a particularly unique relationship with humans, serving as companions, workers, and even surrogate children. While lay people and even some scientists believe domestication was an intentional, human driven process, some researchers have argued for a sort of co-evolution of humans alongside dogs (Miklósi, 2011; Schleidt & Shalter, 2003). According to this view, the environments shared by ancestral humans and dogs led to parallel changes in behavior and systems. Although co-evolution seems a less popular theory than the traditional view of domestication, it has gained empirical support from the field of genetic research. For example, researchers have found that humans and dogs in Tibet have adapted similarly to cope with the extreme environmental conditions posed by high altitude (Wang et al., 2014). Both species possess similar mutation frequencies of the *EPAS1* gene, which allows for greater tolerance of lower oxygen levels. Even more interesting is the finding that humans and dogs exhibit parallel genetic adaptations relating to diet, metabolism, neurological processes, and cancer (Wang et al., 2013). Of particular relevance to this paper is the finding that the *SLC6A4* gene – implicated in aggression, obsessive-compulsive disorder, and depression – was similarly selected in both species. These findings strongly suggest that modern humans and dogs are the product of similar selection pressures arising from a shared environment.

Researchers have also noted similarities between natural human and canid society: both are communal creatures, living in cooperative family groups in which individuals hunt and move together, forge and maintain bonds, and rear young (Mech, 2000; Schleidt & Shalter, 2003). Selection pressures imposed by social living are believed to have shaped cognition in a variety of ways. For example, cooperative hunting requires that members of a group be able to coordinate maneuvers and inhibit chasing behavior until the right moment (Marshall-Pescini, Virányi, & Range, 2015). They must also be able to inhibit impulsive, aggressive behavior for the sake of maintaining group cohesion. Additionally, information processing might become more complex as the social group increases in size. That is, individuals must be able to identify each member of the group and know where each member ranks relative to other members if there is a social hierarchy. Overall, one would expect that compared to solitary animals, animals living in social groups should be capable of more complex cognition and better self-control. Evidence for this notion includes the positive correlation between neocortex size and number of members of the social group in primates (Dunbar, 1998), as well as the greater levels of inhibitory control exhibited by primates living in dynamic "fission-fusion" groups (Amici, Aureli, & Call, 2008). [2] Whether these patterns hold true for canids as well is currently unknown.

[2] The neocortex is an exclusive feature of the mammalian brain and is involved with higher-order cognition.

The myriad similarities between humans and dogs have led researchers to view dogs as a promising model for a variety of cognitive phenomena in humans, including understanding of referential gestures, social learning, and cognitive aging. An advantage of using dogs in comparative research is that dogs possess a greater level of sociality, making them a more appropriate model of human cognition than mice or rats, who do not possess the level of sociality found in humans. Researchers have used dogs extensively in the study of human cognitive aging, and this research has uncovered more similarities between humans and dogs. For example, similar to humans, dogs have more difficulty responding to sudden changes in the environment as they age (Tapp et al., 2003) and show evidence for an canine analogue of ADHD (Vas, Topál, Péch, & Miklósi, 2007).

Research using dogs as models for human cognition provides a starting point for developing methods of testing and analysis based on similarities between human brains and dog brains. Increasing our understanding of executive function in dogs can show us which qualities (and associated brain regions) of this ability are shared between humans and dogs and which are distinct to each species. This will inform the conclusions we can draw from research using dogs as models for human cognition and mental illness. However, understanding cognition – particularly executive function – carries important implications for the dogs themselves. Whereas dogs (and their brains) can be similar to humans, they differ in important ways that must be understood in order to help them optimize their behavior and welfare and increase human safety.

Species-Specific Behavior in the Dog: The Ethological Perspective

Ethology refers to the study of an animal's behavior in its natural environment with a general understanding that this natural behavior is adaptive to the animal's survival (Goodwin, 2015). A notable early researcher in the field of ethology was Konrad Lorenz (1903 – 1989), who became famous for his research on the instinctive imprinting behavior of hatchling geese. Distinguishing learned behavior from that which arose from instinct was a focus of Lorenz's research, a focus that continues in the field to this day.

Another focus in ethology is on species-specific behavior, meaning behavioral repertoires that are shared among members of a species but (generally) different from that of other species (Goodwin, 2015). For example, dogs will often solicit play from a human or another dog by crouching into a 'play bow' while this same behavior is absent in horses. Understanding species-specific behavior allows humans to better predict the future behavior of the animal as well as manage animals, whether domestic or wild.

As pointed out by Arden et al. (2016), most of the existing studies in canine cognition approach the study of dog behavior from an ethological angle, with the goal of understanding dog behavior in the context of its shared environment with humans, both in the present-day and during the process of domestication. Many of the contentions in the current literature have arisen from different views in how factors like domestication and ontogeny have influenced the dog's cognitive abilities, and both of these factors likely influence executive function.

Genetic influences. The influence of genetics on dog behavior is generally studied with a focus on either domestication or on breed. Domestication refers to the process by which a population of animals undergoes genetic changes as the result of selection pressures introduced by humans. Although the differences between dogs and the wolves from which they are presumed to be descended are apparent in terms of appearance and behavior, exactly *how* wolves gave rise to dogs is less straight-forward. A variety of theories exist regarding the domestication of dogs (for a description of five non-exclusive theories of domestication, see Miklósi, 2011), but researchers tend to agree that the process of domestication led to a substantial attenuation in fear of humans as well as physical changes, particularly the neotenization of facial structure (Kruska, 1988; Trut, Plysnina, & Oskina, 2004). In terms of cognition, some researchers have argued extensively that domestication has equipped dogs with a remarkable, innate ability to follow human gestures such as pointing which, in some cases, exceeds the abilities of even our closest primate relatives such as chimpanzees, an idea known in the literature as *the domestication hypothesis* (Hare, Brown, Williamson, & Tomasello, 2002; Hare et al., 2009; Hare & Tomasello, 2005). Whether dogs are truly born with a special sensitivity to attend to, and follow human gestures is still a contentious matter. It is very likely that ontogeny plays an important role in a dog's attunement to humans; as has been found in humans, nature seldom works alone to determine behavior.

Comparing performance of different breeds on socio-cognitive tasks is another way by which researchers have explored the role of genetics in dog behavior. With the goal of creating dogs suitable for specific types of work, humans have created hundreds of different breeds that range dramatically in terms of morphology. Early breeders focused not just on form, but temperament as well. Even though a dog's physique might be optimal for the task it was bred for, an inability to learn, follow direction, or be motivated by humans will render it useless in a working context. Thus, early breeders selected for both physical and temperamental qualities that would make the resulting puppies amenable to guarding the camp, pulling sleds, and herding sheep (reviewed in Miklósi, 2014).

There are a variety of ways researchers have conceptualized "breed." Some have compared behaviors of different breeds as recognized by the American Kennel Club (Jakovcevic, Elgier, Mustaca, & Bentosela, 2010), while others have compared dogs belonging to "working" or "nonworking" groups (Asp, Fikse, Nilsson, & Strandberg, 2015; Wobber et al., 2009) or examined differences based on genetic similarity (Turcsán et al., 2011). The definition of breed tends to vary based on the pursuit of the researchers. Illuminating the influence of breed on behavior is useful given that breed is often a factor in determining whether a dog is adopted and in creating dog-related regulations and legislation. Decisions to adopt a dog, to enforce breed-restrictions in apartments, or to impose city-wide breed-specific legislation (BSL) are based on the assumptions that 1) different breeds are characterized by different behaviors and 2) these characteristics are likely to be present in all members of a given breed.

Research on how breeds differ in terms of sensory, physical, and cognitive abilities has offered mixed results. Some findings converge with general breed stereotypes. In one study, researchers found that dogs that were bred for cooperative work with humans (e.g., sheepdogs and gun dogs) were better at following human pointing than dogs that were bred for independent work (e.g., sled dogs and guard dogs) and mixed breeds (Gácsi, McGreevy, Kara, & Miklósi, 2009). By administering questionnaires to owners regarding their dogs' typical behavior, researchers have found that working breeds are reported to be more trainable, more interested in human interaction, and less fearful than nonworking breeds (Asp et al., 2015), herding breeds are more trainable than toy dogs and non-sporting dogs, and terrier and mastiff breeds are bolder than hunting and herding breeds (Turcsán et al., 2011).

However, other research has yielded null and even counter-intuitive findings. After conducting a meta-analysis, Dorey, Udell, and Wynne (2009) found no breed differences in the ability to follow human points. Even more surprising was the finding by Hall et al. (2015) that pugs were faster to learn odors and able to sense odors at a smaller concentration than German shepherds. German shepherds are often used in scent-detection work, partly for their presumed trainability and partly for the size of their olfactory epithelium relative to brachycephalic (short-headed) breeds. This study calls into question the validity of common breed stereotypes, suggesting that such breed-specific expectations may be rooted more in the historical use of a particular breed of dog than empirical data. Although it is likely that certain breeds differ from each other in terms of sensory, physical, and/or cognitive ability, these presumed differences should be subject to empirical testing. When studying breed as a factor, it is important to take into consideration confounds that also affect various abilities, including head shape and size, placement of the eyes on the skull, body shape and size (Gacsi et al., 2009), and the fact that some breeds are more likely to find themselves in certain contexts (e.g., agility training, scent work, and intensive, cooperative work with humans) than others based on morphology or breed stereotype (Helton, 2010).

Even though empirical evidence for breed stereotypes is mixed, a dog's breed (or perceived breed) is sometimes a deciding factor in its treatment by society. To reduce damage caused by dogs, various types of restrictions have been enacted without sufficient evidence (Berkey, 2009). Many apartment complexes enforce breed restrictions targeting allegedly "aggressive breeds" including German shepherds, Rottweilers, Huskies, and Pit bull-type dogs. Potential tenants who own such breeds can thus be forced to choose between securing a new residence and keeping their dog.

As with other research focusing on breed differences, evidence for the existence of "aggressive" breeds is mixed. One study (Sherman, Reisner, Taliaferro, & Houpt, 1996) examining factors involved in dog-directed aggression found that terrier breeds were more prevalent than others in cases of aggression occurring outside of the household, whereas household aggression was more common among herding and non-sporting breeds and less common among toy and sporting breeds. Another study (Duffy, Hsu, & Serpell, 2008) found that Chihuahuas and Dachshunds scored higher in aggression toward both humans and dogs than other breeds while Akitas and Pit Bull Terriers, supposed “aggressive” breeds, scored higher on dog-directed aggression. The authors point out that in terms of reporting human-directed dog attacks, larger dogs may be over-represented due to their greater ability to inflict harm relative to smaller dogs. That is, a person bitten by a Rottweiler is probably more likely to report a bite and seek treatment than a person bitten by a Chihuahua. The shared finding of higher dog-directed aggression in terrier breeds (which included Pit Bull type dogs) suggests that these breeds might be more prone to territorial behavior, a consideration for human adopters. However, more research needs to be conducted to support this notion. Whether or not “aggressive” breeds are, in fact, more prone to causing damage or harm, they are relinquished to shelters in larger numbers than other breeds, less likely to be adopted, and more likely to be euthanized (Lepper, Kass, & Hart, 2002). Thus, such restrictions might do little to increase human safety and ultimately jeopardize welfare of dogs.

Legislation, local regulations, and even landlord-enacted breed restrictions would greatly benefit from improved knowledge of how breed is related (or unrelated) to executive function. It is possible that low levels of executive function are related to higher levels of aggression in dogs, as has been found to be the case in humans. For example, Sprague and colleagues (2011) found that, in humans, executive function moderated the relationship between perceived stress and aggression but only for individuals low in executive function, such that individuals with low executive function were more likely to respond to perceived stress with physical aggression. They concluded that executive function, particularly inhibitory components, are important in helping an individual manage inappropriate behavioral responses to stressors, as well as regulating emotions that lead to such reactions. This is supportive of the notion that behavioral inhibition might be an underlying factor uniting the various executive function abilities (Barkley, 1997). With a better understanding of the factors underlying executive function in dogs, we might be able to more accurately predict which dogs are at greater risk for responding to stress with aggression. This need not imply an ethical dilemma if certain breeds are found to be more prone to aggression. Breeding dogs with an emphasis on even temperament and even training is a potential intervention to reduce aggressive behavior in dogs.

Ontogenic influences. As we have learned with humans, genetics do not solely dictate behavior, but instead interact with environmental factors. Dogs are exposed to a range of different environments: some are trained rigorously by their owners to compete in dog sports like agility, others work alongside their humans on ranches or in the military, and still others are neither worked nor trained, instead serving as companions. In more unfortunate cases, dogs might be left outside with little human contact, experience severe physical punishment, or be relinquished to a shelter. A dog's experience, especially experience with humans, over the course of its lifetime has been proposed to influence ability to follow human gestures, problem-solving ability, emotional responses, and aggression.

In terms of social cognition, recall the premise of the domestication hypothesis, which states that domestication endowed dogs with a special sensitivity to human gestures such as pointing. Although popular, this view is not shared by all canine scientists. Dr. Monique Udell, in particular, has argued against the domestication hypothesis, proposing instead a *two-stage hypothesis* to explain how some dogs come to understand human gestures (Udell, Dorey, & Wynne, 2010). First, the dogs must be properly socialized to humans during a developmental window when they are puppies, leading them to accept humans as social companions. Second, they must gain accumulated experience with being rewarded by following human points. That is, over time, dogs learn that there is sometimes food or other desired objects at the end of a human's hand or fingertip. Udell does not dismiss the role of domestication or even breed; indeed, domestication increased the developmental window during which dogs can become socialized to humans, and the breeding of dogs for specific tasks might have led some to be more adept at following points than other breeds (Udell, Ewald, Dorey, & Wynne, 2014). She bases this conditioning-focused hypothesis on her findings that human-socialized wolves can perform as well, if not better than, dogs at following points (Udell, Dorey, & Wynne, 2008), shelter dogs with less consistent human experience are less accurate at following pointing than pet dogs (Udell et al., 2010), and that point-following ability is largely absent during the first 21 weeks of the dog's life (Dorey, Udell, & Wynne, 2010). The reader should note that there are many discrepant findings in this area of research, partially stemming from differences in methodology and statistical analysis. Overall, the data suggest that dogs' performance on social cognitive tasks involving a human demonstrator is the product of both genetics and experience.

Given the close relationship dogs share with humans, the dynamic between a dog and its owner is a crucial element of the dog's ontogeny. Clark and Chalmers (1998) argued that, although they are generally discussed as internal processes, cognitive processes extend into our environment. For example, we often use physical aids in memory and problem-solving including calculators, writing, and even the use of language. As such, we "extend" our mind into the environment. In terms of canine cognition, Merritt (2015) agrees with this notion and, further, discusses how dogs use *us* as physical aids, nearly always thinking "with" us. He further argues that researchers should approach the study of canine cognition with an appreciation for the "co-cognition" that takes place between humans and dogs.

As a general rule, humans dictate much of the events in the lives of their dogs. Whether they receive training and what type of training they receive, how much physical and mental stimulation they receive, and even whether they ultimately remain in the home under human directive. The amount and quality of attention owners pay their dogs can influence the development and occurrence of problem behaviors, and thus increase likelihood of aggression, relinquishment, and euthanasia. Researchers have found evidence that humans who relinquish their dogs to a shelter are more likely to be first-time pet owners, young, and have idealistic expectations for how much “work” the dog would require (Salman et al., 1998). Further, very few dogs who were relinquished had received obedience training. Even though many dogs are brought to a shelter due to behavioral issues (Salman et al., 1998, 2010), these issues might be less reflective of a dog’s ability to behave and more reflective of their former owner’s inability to provide proper care, exercise, and training.

In terms of training techniques, one study reported that the use of positive punishment (e.g., striking a dog or rubbing its nose in its own excrement) increased the likelihood of human-directed aggression (Casey et al., 2014). Dogs subject to these type of methods are also more likely to exhibit fear or submission, displays that have sometimes been perceived as “guilty looks” (Horowitz, 2009). These findings mirror some of those found in children subject to harsh parenting (Deater-Deckard, Wang, Chen, & Bell, 2012). In the child psychology literature, researchers have provided evidence that a mother’s level of executive function shapes parenting practices that can ultimately help or hinder the child’s development of executive function. In particular, mothers with low levels of executive function were more likely to get frustrated and use harsh parenting practices than mothers with higher executive function (Deater-Deckard et al., 2010, 2012). Future research could assess potential relationships between owner and dog executive function, as well as how owner executive function influences training and discipline practices. The role human behavior plays in a dog's ability to self-regulate cannot be neglected in the midst of more intuitive factors like breed, training, and current environment.

A Case for Continued, Improved Study of Canine Executive Function

Dogs have proven useful models in understanding of human cognition, but are also important to study to better understand the factors underlying self-regulation of behavior specific to dogs as a species. The dog's understanding of social cues, human emotional expression, and human attention have given us better insight about how dogs modulate their behavior based on our behavior. How dogs regulate (or fail to regulate) their own behavior is also useful knowledge given the dog's ubiquity in human society. Dogs often occupy households with children, other animals, and household items that can be soiled, torn, or eaten. To peacefully coexist with humans in these homes, dogs must be able to inhibit behaviors like eliminating in the house, getting too boisterous with children or other pets, and being destructive. Although training is critical in preventing these unwanted behaviors, a dog's level of executive function likely plays a large role in facilitating such training (Hasher & Zacks, 1979) to allow it to overcome natural urges to obey its owner's expectations for proper behavior.

Failure to meet such expectations not only carries safety implications for the human family, but also for the dog. In fact, one study (Salman et al., 2000) found that the top five reasons cited by owners for relinquishing their dogs to a shelter were biting, house soiling, aggression toward people, escaping, and being destructive indoors, all behaviors related to low levels of inhibitory control. Further, dogs that are relinquished for behavioral reasons are less likely to be adopted than dogs relinquished due to cost or changing home dynamics (Lepper et al., 2002). Of the approximately 3.3 million dogs that are relinquished to shelters in the United

States each year, about 670,000 of these dogs are euthanized (ASPCA, n.d.). Conducting more, and better, research on canine executive function, including the effects of genetics and ontogeny, has the potential to produce several tangible benefits to both humans and dogs, including: reduced relinquishment to shelters, lower rates of euthanasia of otherwise healthy dogs, fewer attacks by dogs on humans and other animals, and the advancement of evidence-based legislation and regulations aimed at dogs and dog owners. I turn now to a discussion of executive function itself, providing a theoretical and historical foundation upon which to base a more meticulous study of this construct in dogs.

Section 2: What is Executive Function?

In day-to-day life, animals (human and nonhuman) are responsible for attending to a variety of tasks that ensure their survival: eating, locomotion, avoidance of danger, and forging and maintaining social ties, to name a few. Some of these tasks become so well-practiced that they can be carried out without conscious awareness (i.e. automatically); others require dedicating one's full attention and adapting one's behavior to accommodate changing circumstances in the environment. Success in these latter tasks relies on *executive function*. Executive function refers to the processes that enable an animal to coordinate behavior in a manner appropriate for a given context, especially in the face of distraction. It operates in a top-down fashion to bias behavior in the direction of a future goal. That is, executive function requires that an organism have a mental representation of a desired outcome (i.e. its "goal"), as well as maintaining in working memory the necessary means to achieve it (e.g., the rules of the task, the to-be-performed behaviors, or to-be-avoided behaviors; Miller & Cohen, 2001).

The body of literature dedicated to executive function, how to measure it, and implications of its successful or unsuccessful function is vast and a full review is beyond the scope of this review. For the sake of brevity, I constrain my discussion of executive function to the following: (1) naming and describing some of the components of executive function proposed by researchers, (2) providing a historical background of the study of executive function and discussing proposed explanations for its operation, and (3) briefly considering some of the consequences of one's level of executive function. The section concludes by transitioning the focus of the paper from the study of executive function in humans to dogs.

Executive Function: A Multi-faceted Phenomenon

To reiterate, executive function allows us to coordinate our thoughts and behaviors in a manner that facilitates our attainment of future goals. It is generally considered to be a higher-order cognitive process like attention and problem-solving (Pennington & Ozonoff, 1996) and limited in capacity, operating under certain circumstances and not others. Researchers have used an array of terminology when referring to executive function, including "cognitive control," "attentional control," "willed" or "deliberate" control, and "effortful control." For the sake of clarity, I use "executive function" in discussing research using these terms, and "executive abilities" to refer to the constellation of processes affiliated with executive function. Like executive function, the terminology surrounding executive abilities varies from paper to paper. Across the literature, general abilities believed to be relevant to executive function include selective attention, cognitive flexibility, inhibitory control, and working memory, all of which rely heavily on the PFC (Miller & Cohen, 2001). Note that these abilities are not completely independent and, in many cases, interact.

Selective Attention to Stimuli. Selective attention refers to the ability to focus on one stimulus in the environment at the expense of others, achieved by an increased focus on the "relevant" stimulus and inhibition of signals from other, "irrelevant" stimuli (Miller & Cohen, 2001). It is needed when there are a variety of salient stimuli in the environment, and is more strongly engaged when environmental interference is prevalent in the environment, reducing interference through attenuated sensitivity to distracting information (Conway, Cowan, & Bunting, 2001; Hutchison, 2011; Hutchison, Bugg, Lim, & Olsen, 2016).

Classic methods of studying selective attention include conflict tasks such as the Stroop task (Stroop, 1935) and the Eriksen flanker (Eriksen & Eriksen, 1974). In each of these tasks, participants are presented with stimuli that contain conflicting elements and must respond to only one of these elements. For example, in the typical Eriksen flanker task, participants are presented with a series of letters or arrows (e.g., ABA or ← → →) on a computer screen and instructed to respond to only the central item in the triplet by pressing the corresponding key on a keyboard. Stimuli can be congruent (e.g., AAA or → → →) or incongruent (e.g., ABA or ← → ←), with responses to incongruent stimuli being slower and less accurate than for congruent stimuli (the "flanker effect"). Accurate performance in such conflict tasks relies on selective attention, as well as the maintenance of the task goal over time. It also requires a certain degree of working memory capacity: Individuals with high working memory capacity are better at focusing on relevant information and suppressing irrelevant information than individuals with low working memory capacity (Conway & Engle, 1994). Researchers have shown that success on both Stroop and flanker tasks is reliant largely on the PFC (De Pisapia & Braver, 2006; Miller & Cohen, 2001; Perret, 1974; Vendrell et al., 1995).

Cognitive Flexibility. Cognitive flexibility (sometimes called "task-switching," "attention switching," or "shifting") requires an individual to disengage attention from one task or set of rules to engage in another. The ability to flexibly attend and respond to stimuli under changing conditions is critical in everyday life and is also considered an important part of executive function (Norman & Shallice, 1986). As with the other components of executive function, cognitive flexibility is assumed to rely, at least in part, on the frontal lobe. Perseveration, the repeating of obsolete or incorrect responses, is often observed in individuals with frontal lobe damage (reviewed by Gazzaniga, Ivry, & Mangun, 2009).

Cognitive flexibility can be assessed using various card-sorting tasks, such as the Wisconsin Card Sorting Task (Berg, 1948). In this task, a participant is given a deck of cards, each of which contains shapes of varying forms, colors, and quantities, and is instructed to sort them based on what is on the cards. The experimenter has pre-selected the sorting criteria (provide an example of criteria) and provides feedback to the participant as to whether he or she is sorting the cards according to this criteria by saying “correct” or “incorrect.” Once the participant has learned the criteria and has sorted the cards appropriately for a given number of trials, the criteria shifts and the participant must adapt to this change by sorting the cards in accordance to the new criteria. This ability to adjust to changing contingencies is sensitive to age-related changes in PFC function and can be indicative of dementia risk (Berg, 1948; Hutchison, Balota, & Duchek, 2010).

Working Memory Capacity. Although its name implies otherwise, working memory capacity involves much more than simply memory, instead relying on executive function. Specifically, working memory capacity refers to the relative ability to direct attention in goal-direction ways and maintaining an active set of information that can be quickly retrieved to meet task goals (Engle, 2002). Engle further described working memory as consisting of two components: short-term memory and executive ability, the latter being correlated with general fluid intelligence. It is typically assessed using one or a combination of complex span tasks.

One example of these tasks is the operation span task (Unsworth, Heitz, Shrock, & Engle, 2005) in which participants sit in front of a computer monitor and are presented with an arithmetic statement such as "(2 x 1) + 5 = 8" followed by a word such as "train." The participant must read the arithmetic statement aloud, state whether it is true or false, and then name the following word which is to be held in memory. After two to seven of these sequences, the participant is asked to recall all the words they saw in the correct serial order. The resulting number of correctly recalled words by the end of the task serves as a measure of working memory capacity. Using tasks such as the operation span, researchers have found that working memory capacity is correlated with general fluid intelligence (Engle, 2002) and the ability to filter out distracting information. Executive function is generally considered to be a component of working memory capacity and has been proposed to be the underlying component that unites executive abilities; additionally, it is this component that is responsible for the correlation between working memory capacity and abilities such as reading comprehension, multitasking, SAT scores, and ability to multi-task (Baddeley & Hitch, 1974; Engle, 2002; Miyake et al., 2000; Shipstead, Lindsey, Marshall, & Engle, 2014; Unsworth & Engle, 2007). As discussed later in this section, working memory capacity has been a focal element in descriptions of executive function for decades.

Inhibitory Control of Behavior. Inhibitory control refers to one's ability to *intentionally* withhold a pre-potent response (one that is well-practiced and has been rewarded consistently in the past). This requires a degree of top-down control to withhold or cease a behavior in favor of one that is novel, less practiced, and/or appropriate for the current situation. Researchers use tasks including the anti-saccade, stop-signal, and go-no go tasks (Hallett, 1978; Pribram & Mishkin, 1955; Verbruggen & Logan, 2008) to examine inhibitory control.

In the anti-saccade task, participants are seated in front of a computer screen and told to focus on the center of the screen. On pro-saccade trials, a flash (typically a white asterisk against the black background) is presented on the left or right side of the screen and participants are told to orient their gaze toward this flash to catch a target (either an upper-case O or Q) that is briefly presented and respond by pressing the corresponding letter on the keypad. On anti-saccade trials, participants are told to orient their gaze to the *opposite* side of the flash to catch and respond to the target. Responding to anti-saccade trials is slower and more erroneous than for pro-saccade trials. Researchers have found that people with high working memory capacity are less often “captured” by the flash in anti-saccade trials (Engle, 2002). In terms of real-world implications, the inability to inhibit is related to engagement in dangerous or unhealthy behaviors (Duckworth et al., 2013), cognitive aging (Balota, Hutchison, Spieler, Duchek, & Morris, 2010), and dementia (Hutchison et al., 2010).

Early Conceptualizations of Executive Function: Controlled and Automatic Processes

A defining feature of executive function is its top-down nature and reliance on the effortful allocation of attention, as opposed to mental processes that operate automatically or without conscious awareness. This distinction between such “controlled” executive behavior and automatic behavior has existed for over 100 years. In 1890, William James distinguished between “ideo-motor acts,” which follow more or less immediately after conception in the mind, and “willed acts” which require an added element of volition for execution. Subsequent researchers have expanded upon the automatic-executive distinction, particularly during the rise of cognitive psychology in the 1970s when several researchers proposed models to explain the process by which we are able to over-ride automatic responses in favor of less-practiced actions more appropriate for the current situation.

One of the early models proposed by Schneider and Shiffrin (1977) was a two-process model in which behavior could be carried out by automatic or controlled mechanisms. According to this model, automatic actions are initiated when a stimulus or event activates a well-learned behavior sequence in long-term memory. They can be carried out in their entirety without attention and do not demand mental resources. Controlled actions, however, rely on a temporary sequence that must be internally maintained by the individual while the behavior is being performed. These actions thus require attentional resources, generally preventing the individual from engaging in other behaviors simultaneously. Hasher and Zacks (1979) proposed a similar framework, replacing the term “controlled” with “effortful,” describing how heredity can contribute to the learning and execution of automatic behaviors, and providing examples for individual differences in engaging executive function.

One of the most prominent elaborations of the automatic-controlled distinction comes from Norman and Shallice’s (1986) thorough, yet elegant, description of how automatic and executive forms of action control act in a complementary fashion to dictate behavior. In keeping with previous models, Norman and Shallice claimed that automatic actions are those that have one or more of the following characteristics: they can be initiated without awareness, they can be executed without awareness, and they can be carried out without interfering with other ongoing tasks (i.e. they are not dependent on a limited resource). One can easily conjure examples of automatic tasks: orienting toward a sudden sound, certain aspects of driving a car, and walking can generally be initiated and carried out with little conscious effort or awareness.

As Norman and Shallice (1986) point out, being able to complete tasks automatically is sometimes beneficial; it enables an individual to behave and respond to the environment in ways that have been effective in the past without requiring sustained attention that could be better used on other tasks. However, because many animals (including humans) live in environments that are constantly changing, automatic responding might occasionally be erroneous and even dangerous. In such situations, the animal must be more conscious of conditions in the environment and be able to respond appropriately, even if this means abandoning an automatic response that had hitherto been effective (Miller & Cohen, 2001). It is in these cases that another form of action control is preferred to automaticity, termed "willed" or "deliberate" actions. These actions are preferred in situations that require planning or decision making, involve some sort of trouble-shooting, are difficult or potentially dangerous, and/or require overcoming a strong, prepotent response (i.e. automatic actions). To prevent the execution of an automatic behavior, the Supervisory Attentional System (SAS) is engaged to bias the activation of less-practiced behaviors that are more contextually appropriate or serve the fulfillment of a goal.

Norman and Shallice (1986) proposed the SAS was biologically rooted in the PFC based on previous research showing that damage to this part of the brain caused deficits or outright failure in behavioral flexibility and sustained attention while leaving well-learned, automatic actions intact. Their proposal has since been backed by a robust body of evidence. Much of this evidence was reviewed by Miller and Cohen (2001) in an effort to integrate the results of existing findings regarding the PFC and explain the neural mechanisms by which the PFC allows for top-down control of behavior.

To reiterate, top-down control refers to internally maintaining one's goal, and means to achieve it, in an active state, as well as the early selection of relevant information among distractors. The name itself refers to the manner by which connections from the PFC project down to other, sensory areas to bias early selection of relevant information. For both human and nonhuman subjects, researchers have found that, in tasks requiring the maintenance of information over a delay or in the face of distraction, subjects exhibit greater sustained activation in the PFC. This greater activation, Miller and Cohen (2001) claim, is due to the PFC acting as a sort of “switchboard operator” to allow for effective behavior. As described in previous models, certain cues in an individual’s environment can initiate a behavior sequence stored in long-term memory and, in some cases, a given cue can initiate multiple sequences that conflict with each other (Norman & Shallice, 1986; Schneider & Shiffrin, 1977). Situations in which multiple sequences are activated or an automatic behavior must be overridden by a less-practiced one require intervention for context-appropriate behavior. It is in these cases that neurons in the PFC bias neural signals between the environmental cue and the regions of the brain responsible for behavioral output, guide activity along goal-appropriate pathways, and establish necessary patterns to perform a novel task.

Miller and Cohen (2001) also explained, neurologically, how novel behaviors requiring top-down control can become automatic: In a dynamic environment, an individual might need to withhold a habitual response in favor of performing a non-habitual (but correct) behavior in response to a specific environmental cue, an act which requires intervention from the PFC, and this action strengthens the pathway between the cue and the new behavior. If this occurs over and over again, the pathway is sufficiently strengthened that the behavior will stop relying on guidance from the PFC and can now be initiated by simply encountering the environmental cue. Seating the SAS within a biological structure has made executive function more tractable to scientific study.

Perhaps most relevant to this paper is the model of working memory proposed by Baddeley and Hitch (1974) in an attempt to explain how short-term memory allows for complex information-processing. The term “working memory” refers to the limited-capacity, short-term memory store in which information is flexibly manipulated based on task demands. Rather than being a unitary construct, Baddeley and Hitch suggested that working memory is made up of three components that allow an individual to successfully manipulate relevant information in short-term memory: the phonological loop, the visuo-spatial sketchpad, and the central executive. The phonological loop allows for the short-term storage of auditory information and its rehearsal while the visuo-spatial sketchpad allows for the short-term storage and use of visual information. Neither of these components are believed to be limited in capacity, and are able to work at the same time without interfering with each other. These components serve as “slave systems” to the central executive which, like Norman and Shallice’s SAS (1986), guides cognitive processes in a manner which facilitates effective, flexible behavior. In addition to coordinating the operation of the phonological loop and visuo-spatial sketchpad, the central executive acts as a gating mechanism by suppressing irrelevant information and amplifying relevant information.

Importantly, there is considerable variation in the ability to filter out distraction and maintain a task goal over time. As reviewed by Hasher and Zacks (1979), some populations are more limited in the capacity for executive function than others. Children, older adults, and individuals with depression tend to perform worse on tasks requiring executive function, displaying deficits that have been argued to arise from differences in working memory capacity. To explain performance differences on both attention and memory tasks, Shipstead et al. (2014) proposed that working memory capacity relies on three specific mechanisms: primary memory, secondary memory, and attentional control (i.e., executive function). Primary memory is the limited, active set of information maintained by an individual to complete a task. The purpose of this memory system is to protect the active set of information from the influence of proactive interference. Because some tasks require more information than can be actively maintained in primary memory (typically 3 – 5 units), the individual must also be able to retrieve no-longer-active information from long-term memory, referred to as secondary memory. Such retrieval poses a challenge, as the individual must maintain the contents of primary memory while actively searching secondary memory for task-relevant information amid task-irrelevant information. Thus, a third mechanism, termed attentional control, is needed to allow selection of relevant information in the face of distraction. Using latent variable analysis, Shipstead et al. provided evidence for these three components of working memory capacity and, further, that their operation largely accounted for the relationship between working memory capacity and general fluid intelligence.

Like working memory capacity, executive function is often discussed as a singular entity, but many scientists characterize it as a multi-faceted phenomenon consisting of a set of related, yet distinct, abilities. For example, Pennington and Ozonoff (1996) described executive function as involving set-shifting, set-maintenance, interference control, inhibition, and working memory. Norman and Shallice (1986) suggested planning or decision making, troubleshooting, performing actions that are novel, dangerous, or technically difficult, an overcoming a strong, habitual response. Miyake and colleagues (2000) empirically tested the existence of multiple executive abilities by having participants complete a series of cognitive tasks proposed to tap into abilities like shifting, updating, and inhibition. They found that these abilities shared some commonality in terms of task performance, but were also distinct from one another. In other words, even though each task in their battery likely relied on specific abilities (e.g., spatial, mathematical, and verbal), performance across all the tasks was, to some degree, reliant on a singular ability.

Miyake et al. suggest working memory capacity and inhibitory control as contenders for the unifying component.

Implications of Executive Function

The importance of executive function can be best realized by observing consequences that follow from its presence or deficit. Data from individuals with attention-deficit hyperactivity disorder (ADHD) has been especially informative in terms of how deficits in executive function can negatively impact day-to-day life. These individuals demonstrate marked deficits in executive abilities including inhibitory control, selective attention, and working memory capacity. Compared to their typically-functioning peers, individuals with ADHD are at a greater risk for academic difficulties, dropping out of school, being expelled, having poor social relationships, aggression, experimentation with and abuse of drugs, unemployment, and risky behavior (reviewed in Barkley, 1997; Duckworth et al., 2013; Gardner & Gerdes, 2015). In addition to the difficulties experienced by the individual, these consequences carry a considerable cost for society in terms of public safety, productivity, and use of social programs like welfare.

In the general population, researchers have observed individual differences in executive functioning. For example, people testing higher in various complex span tasks (referred to as "high spans" in the literature) are better able to respond appropriately to stimuli in a distracting environment than are low spans due to their ability to suppress the distracting information (Engle, 2002). They are also better able to think creatively (Lee & Therriault, 2013) and sustain attentional focus (Braver, Gray, & Burgess, 2007). In sum, research with human participants has provided robust evidence that one's capacity for executive abilities affects problem-solving ability, adapting to novel situations, financial status, social relationships, and health behaviors.

Psychologists have decades of experience studying executive function in humans, but research on canine executive function is still in its fledgling stages. In the next section, I discuss how various researchers have assessed executive abilities in the dog, what they have learned, and current short-comings of their methods and conclusions.

Section 3: Current Research Paradigms and Findings

Executive function has proven a challenging phenomenon to understand in our own species. It should not come as a surprise, therefore, that animal psychologists have met with considerable difficulty in studying this construct in nonhuman animals who do not share our language, our everyday contexts, and even our same perceptual world (called the *umwelt*). "One of the first things that impresses the student of animal behavior," noted Tinbergen (1951), "is the fact that the working of the animal's sense organs is not the same as ours…A careful study of sensory capacities reveals the fact that almost no two species have exactly the same capacities" (p. 16). Thus, we must always consider the unique perceptual world of the animal we are attempting to study. For example, we must acknowledge that, whereas we are a largely visual species, a dog's perceptual world is largely governed by smell (Horowitz & Hecht, 2014), a sense that is comparatively poorly developed in humans (Schoon, 1997).[3] Canine researchers must approach experimental design with the dog's unique perceptual abilities in mind (Horowitz & Hecht, 2014). We will never know what it is like to be a dog but, through careful study and observation, we can speculate which canine behaviors might be instinctual or prepotent (e.g., chasing a squirrel) and which might be more difficult and require a degree of top-down control

[3] Another important precaution in conducting research with dogs is refraining from anthropomorphizing subjects. Anthropomorphism refers to the act of characterizing nonhuman animals or inanimate objects as possessing human characteristics, *especially* when this characterization is unsupported by data (Horowitz & Bekoff, 2007). Even though it is tempting to take traditional tasks validated with humans and slightly modify them for use with dogs, the fundamental differences between human and canine *umwelt* make this strategy unsound.

(e.g., staying at the owner's side while the squirrel dashes into the bushes). We can then use knowledge acquired from naturalistic situations to design experimental tasks that utilize the same processes.

Although the field of canine cognition has largely focused on the dog's understanding of human pointing and emotional expression, executive abilities have received considerable attention in recent years. Hoping to better understand how genetics and ontogeny influence these abilities, researchers have employed a variety of cognitive tasks. Some of these have been adapted from tasks used with other animals (e.g., A-not-B and cylinder task), whereas others were created specifically for use with dogs (e.g., social task and leash task). The purpose of this section is to introduce the reader to some of the tasks that have been used to study canine executive abilities and critically evaluate their utility in studying the abilities they are presumed to reflect. To this end, I describe some of the tasks used by researchers to measure inhibitory control, cognitive flexibility, and working memory, and discuss some of the short-comings of studies using these tasks, as well as issues stemming from the tasks themselves. I conclude the section by summarizing what researchers have learned about canine executive ability and provide suggestions for refining tasks used to study these abilities.

Assessment of Executive Function in Dogs

So far, most of the studies examining canine executive function are dedicated to inhibitory control. In the canine cognition literature, the term "inhibitory control" seems to be used as a substitute for "executive function," being described as "a collection of cognitive processes that are grouped together by virtue of a common function" (Fagnani, Barrera, Carballo, & Bentosela, 2016, p. 1165).[4] Inhibitory control tasks are presumed to measure a dog's ability to

[4] A possible reason for this difference in nomenclature is a desire to avoid anthropomorphism when referring to the behavior of nonhuman animals.

withhold a response that is immediately rewarding, but ultimately counterproductive (Bray, MacLean, & Hare, 2014) and is necessary to behave in ways consistent with human expectations, particularly for dogs in service roles (Fagnani et al., 2016). Therefore, these tasks have the potential to shed light on factors – including genetics and ontogeny – that might make a dog more prone to behaving impulsively.

The Cylinder Task. The cylinder task (see Figure 1) is a type of detour task created by Bray et al. (2014) to assess inhibitory control in dogs. Detour tasks require subjects to overcome a prepotent response of approaching a desired object, such as food, directly in favor of approaching it via a learned "detour." These tasks have been used in a variety of species including male song sparrows (Boogert et al., 2011), horses (Rørvang, Ahrendt, & Christensen, 2015), human infants (Lockman, 1984), and a variety of nonhuman primates (Amici et al., 2008).

The cylinder task tests dogs' ability to successfully retrieve a food reward from inside an open-ended cylindrical apparatus laid on its side and consists of two phases: a familiarization phase and a testing phase. During the familiarization phase, a dog is positioned and gently held in place at a set distance from an opaque cylindrical apparatus. The dog then observes while a human experimenter places a food reward into the apparatus. The food reward is always placed in the center of the cylinder so that it can be retrieved from either side and the baited side is counterbalanced across trials. Once the cylinder has been baited, the dog is released and allowed to retrieve the food reward. This protocol is repeated until the dog meets a pre-set criteria for having "learned" the task (typically four out of five consecutive trials), and then moves on to the testing phase. The testing phase is identical to the familiarization phase with one exception: the cylinder is now transparent rather than opaque. To successfully retrieve the food reward, the dog must inhibit the response of approaching the now visible reward directly (thus contacting the barrier) and instead approach it by using the detour technique learned in the familiarization trials (Bray et al., 2014; Marshall-Pescini et al., 2015). The dog performs ten test trials with the now transparent cylinder apparatus and inhibitory control is measured in terms of the dog's accuracy during the testing trials.

So far, canine cognition researchers have used the cylinder task to examine the effects of domestication (Marshall-Pescini et al., 2015), environmental demands (Bray et al., 2014), and ontogeny (Fagnani et al., 2016) on inhibitory control. Its first usage with dogs was by Bray and colleagues, who tested thirty dogs on a battery of three tasks – the cylinder task, the social task, and the A-not-B task – presumed to reflect a dog's level of inhibitory control. Two findings from their cylinder task data are noteworthy. First, accuracy during test trials was considerably lower than the previously mentioned studies. Because dogs in this study performed the other two tasks prior to the cylinder task, it is possible that this reduction in accuracy is due to fatigue effects. Second, age was negatively correlated with accuracy during test trials, such that older dogs were less accurate than younger dogs. This is consistent with results from another study showing impaired inhibitory control in old dogs relative to young dogs (Tapp et al., 2003) as well as patterns observed in humans, with inhibitory processes breaking down in the later years of life (Spieler, Balota, & Faust, 1996)[5].

To better understand how the domestication process might have affected inhibitory control, Marshall-Pescini et al. (2015) compared the performance of human-reared wolves on the cylinder task with that of trained and untrained pet dogs and human-reared "free-ranging" dogs.

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[5] It is possible that lower performance in older dogs is due to owners holding different expectations for young and old dogs. Specifically, owners might be more likely to use consistent training and correct younger dogs than older dogs based on the notion that "you can't teach an old dog new tricks." However, this potential confound is unable to explain the findings of Tapp et al. (2003) whose entire sample consisted of lab-raised beagles who had, over the course of their lifetimes, been trained on a variety of cognitive tasks to model human learning and aging.

They found that all dogs, regardless of training or housing situation, out-performed wolves and suggested that perhaps dogs were using inadvertent human cues during the cylinder task that led to their successful performance; however, there is conflicting evidence as to whether there exists a difference in the ability to follow human social cues between wolves and dogs (Hare & Tomasello, 2005; Udell et al., 2008; Virányi, et al., 2008). Further, researchers should use caution when comparing the performance of dogs to that of modern-day wolves when trying to understand the effects of domestication. Although wolves are the presumed ancestor of dogs, the populations from which dogs descended are likely extinct (Kruska, 1988), making modern-day wolves the products of a completely different set of recent selection pressures than ancestors of the dog.

Researchers have also examined the possibility of differences between populations of dogs. Because shelter dogs had previously shown decrements in socio-cognitive tasks in comparison to pet dogs (Udell et al., 2010), Fagnani and colleagues (2016) reasoned that perhaps differences in lifetime experience with humans might influence a dog's level of inhibitory control. Residing in a human home tends to require more context-appropriate behavior to co-exist peacefully with human owners. One would then expect that pet dogs would exhibit higher levels of inhibitory control as indicated by better performance on the cylinder task in comparison to shelter dogs. However, data collected from thirteen shelter dogs and 14 pet dogs indicated no difference in performance between the two groups. To explain the lack of effect, the authors suggested the possible influence of a ceiling effect: accuracy rates were 81% and 76% for pet and shelter dogs, respectively. If the task was "too easy" for the dogs, this might have washed out an existing difference between the two groups. The null effect observed by Fagnani and colleagues (2016) could be due to a variety of factors. It is possible that shelter dogs and pet dogs simply do not differ on this measure, but two limitations of this study should be addressed before drawing such a conclusion. First, the researchers used a relatively small sample when collecting their data. As discussed by Arden (2016), many canine cognition studies are too underpowered to detect existing effects. Replicating this study with a larger sample would provide more reliable data and, possibly, differential performance between shelter dogs and pet dogs. Second, accuracy rates are remarkably high for two of the three studies discussed (Fagnani et al., 2016; Marshall-Pescini et al., 2015), even for dogs who did not partake in the familiarization phase (refer to Table 1), leading the researchers to suggest a possible ceiling effect. Future studies using the cylinder task should include modification to make it more challenging. As has been shown in human research, individual differences are more apparent when the task is difficult than when it is easy. Researchers have imposed such difficulty by increasing the amount of information a participant must hold in memory (Conway & Engle, 1994; Turner & Engle, 1989), requiring the participant to engage in self-control before partaking in the task (Baumeister, Bratslavsky, Muraven, & Tice, 1998), and reducing external reminders of the task goal (Hutchison, 2011; Kane & Engle, 2003). Canine researchers could use similar strategies by requiring a dog to engage in self-control prior to completing the cylinder task (refer to the self-control task devised by Miller, Pattison, DeWall, Rayburn-Reeves, & Zentall, 2010 discussed later in this section) or test the dog in a distracting environment, which could increase working-memory load. Dogs' accuracy in Bray et al.'s (2014) study were considerably lower than in the other two studies, possibly because dogs in this sample had already completed two socio-cognitive tasks and were demonstrating a fatigue effect.

Having been first used less than five years ago, the cylinder task is a new measure of inhibitory control. Thus far, there have been no demonstrations of its reliability. Before seeking correlations between tasks that presumably measure the same thing (as was done in all three studies discussed), a researcher must know that the tasks in the battery are reliable (Miyake et al., 2000). That the cylinder task has not been subject to this kind of testing limits its utility, particularly in task batteries.

The Detour-Fence Task. The detour-fence task (see Figure 2 for an illustration) is another detour task in which a small section of fencing is used to separate a dog from a food reward. The food reward is placed on the side of the fence opposite to the dog and the dog must go around the fence to obtain it. In other words, the dogs must first move *away* from the food to obtain it, requiring dogs to overcome the pre-potent response of approaching the food head-on. This task has been used to assess inhibitory control (Marshall-Pescini et al., 2015), but might actually be more reflective of problem-solving ability.

In the previously discussed study (Marshall-Pescini et al., 2015), wolves and dogs were tested on both the cylinder task and the detour-fence task. Although the tasks are thought to be conceptually similar, the researchers failed to find any correlation in performance between the two tasks. This was true for each group of subjects in their study (human-socialized wolves, human-socialized free-ranging dogs, trained pet dogs, and untrained pet dogs). Additionally, they found that wolves outperformed dogs on the detour-fence task while dogs outperformed wolves on the cylinder task.

Did selection for cooperation with humans increase inhibitory control or decrease it? The former possibility would lead to better performance in both tasks by dogs while the latter would lead to better performance by wolves. However, this line of thinking assumes that both tasks are measuring the same thing and that no other factors should significantly influence performance in either task. Given the lack of correlation in performance between the tasks and the evidence for species-level specialization, the data shed little light on the original research question. There is also a possibility that the detour-task is more reliant on another ability, such as spatial problem-solving, than is the cylinder task. Indeed, numerous studies (Bray, MacLean, & Hare, 2015; Marshall-Pescini, Frazzi, & Valsecchi, 2016; Pongrácz, Miklósi, Vida, & Csányi, 2005; Smith & Litchfield, 2010) have labeled the detour-fence task as a measure of problem-solving ability.

Subsequent research using the detour-fence task as a measure of spatial problem-solving has examined the roles of breed, training, and arousal on successful performance. Marshall-Pescini et al. (2016) found that, while uninfluenced by breed group, performance on the detour-fence task was substantially better for trained dogs than untrained dogs. Specifically, 71% of trained dogs successfully navigated the fence to reach the food on the first trial compared to 45% of untrained dogs. Trained dogs also navigated the fence more quickly (however, see Pongrácz, Miklósi, Vida, & Csányi, 2005 for evidence that neither training nor breed influence success on the detour-fence task). Bray et al. (2015) found that subjects trained as assistance dogs performed the detour-task more effectively under high arousal while pet dogs performed better under low arousal. They argued that both training experience and artificial selection by humans help to shape a dog's temperament, which in turn influences the dog's problem-solving ability under high and low pressure. In short, performance in the detour-fence task might be more reflective of spatial problem-solving ability than inhibitory control and researchers should consider omitting this task from studies examining inhibitory control.

The Leash Task. Used in only one study as part of a three-part task battery, the leash task is similar in nature to the cylinder and detour-fence tasks in that it requires dogs to first move away from a desired object in order to ultimately make contact with it. A dog is walked on a leash by a human and encounters a situation in which the leash gets caught on an object, such as a tree or post. The human then calls to the dog and the dog must go around the object to return to the human (Müller et al., 2016). Ultimately, Müller and colleagues (2016) found significant, but weak, correlations between this and two other supposed inhibitory control tasks. They suggested that this might imply context specificity of inhibitory control (similar to the argument presented by Bray et al., 2014 based on similar results). However, one could argue that, like the detour-fence task, the leash task requires a substantial degree of spatial problem-solving ability; dogs might simply not understand how to negotiate the obstacle presented by a tangled leash. This could have negatively impacted correlations between tasks, in addition to possible low reliability of this measure. As with the cylinder task, the leash task is a novel method of testing inhibitory control and has not been subject to tests of its reliability. Reliability must first be demonstrated before searching for evidence of validity (i.e., correlation with other supposedly inhibitory control tasks). Thus, that the leash task reflects inhibitory control should be treated cautiously until it has been subject to such scrutiny.

Delay Discounting. Delay-discounting refers to the devaluing of future rewards relative to immediate ones (Riemer, Mills, & Wright, 2014). Generally, preference for a reward decreases as the delay to achieve such an award increases. Inability to delay gratification can lead to negative outcomes in humans including poor financial habits, obesity, and risky behavior (Duckworth, Tsukayama, & Kirby, 2013; Moffitt et al., 2011). It is also related to various problem behaviors in dogs as reported by their owners (Wright, Mills, & Pollux, 2011).

The use of delay-discounting tasks to assess inhibitory control in dogs is more intensive in terms of time to train and test the dogs, as well as constructing the apparatus, than some of the other tasks discussed in this paper. In these tasks, dogs are allowed to choose between a small immediate reward and a larger, delayed reward. Using delay-discounting as a measure of canine inhibitory control, Riemer, Mills, and Wright (2014) differentiated between cognitive impulsivity (the ability to delay gratification) and motor impulsivity (the ability to inhibit prepotent responses) and used a delay-discounting task to examine how stable these two abilities were over time. Dogs were first given ten forced-choice trials on two different apparatuses. One apparatus dispensed one treat after each press and the other dispensed three treats after a three-second delay. After learning the contingencies, dogs were given free access to both apparatuses for fifteen minutes. During this time, the delay increased on the second apparatus by one second each time the dogs chose the delayed reward. The maximum delay reached by the dogs during the fifteen minutes served as a measure of cognitive impulsivity and the number of extra presses between the first press and the delivery of the reward served as a measure of motor impulsivity. Dogs were tested again six years later in the same manner.

For the ten dogs that completed testing, the maximum delay achieved was stable over the six-year period whereas the number of extra presses increased. In other words, a dog's ability to delay gratification seems more stable than the ability to inhibit prepotent responses, which declined over time. From this finding, Riemer et al. (2014) concluded that cognitive and motor aspects of inhibitory control might be independent. The cognitive aspect might be more of a trait that remains stable over the lifetime whereas the motor aspect might be more influenced by the current environment. Their results are consistent with the notion that inhibitory control, at least the inhibition of prepotent responses, is context-specific (Bray et al., 2014; Fagnani et al., 2016). Additionally, the finding that inhibition of prepotent responses declined with age mirrors the results obtained in the cylinder task.

Self-Control Task. While not directly used to test inhibitory control, Miller and colleagues (2010) created a delay-type task to better understand the mechanisms responsible for ego depletion. Ego depletion refers to the observation that people tend to persist less in a difficult cognitive task after being required to exert self-control (Baumeister et al., 1998). While the causes for this phenomenon have been hotly disputed (Baumeister, 2014; Beurms & Miller, 2016; Inzlicht & Schmeichel, 2012), one theory is that both self-control and performance on difficult cognitive tasks are dependent upon a shared, limited resource. Miller and her team tested blood glucose level as a contender for this limited resource using a sample of dogs.

Dogs in the study were first assigned to one of two conditions: kennel or self-control. Those in the kennel condition were led into a kennel which was then closed by the owner. The owner left the room and the dog remained in the kennel for ten minutes before being released. For dogs in the self-control condition, owners instructed the dogs into a sit-stay position and then left the room such that they were able to view the dog by use of a mirror without being visible to the dog. If the dog broke the sit-stay, the owner walked back in, told the dog to sit and stay again, and then left the room. This continued until ten minutes had passed. An experimenter recorded both the number of sit-stay "breaks" and at what intervals they occurred.

For their first experiment, Miller and colleagues (2010) found that compared to dogs who had spent ten minutes in a kennel, dogs who had to exert self-control during the sit-stay persisted less on an "impossible" task requiring them to retrieve a food reward from a Tug-a-Jug toy (the opening to the toy was blocked such that the dog could see the food reward inside but could not get it to fall out). However, in a follow-up 2 (Condition: Kennel/Self-Control) x 2 (Drink: Sugar-Free/Glucose) factorial design, the researchers found that consuming 2 oz. of a glucose drink erased the difference in persistence between dogs who had been in the kennel and dogs who had been in a sit-stay. For dogs who had consumed the sugar-free drink, exerting self-control still reduced persistence in the impossible task compared to dogs who had been in the kennel. The authors thus argued that both dogs and humans rely on glucose as a limited resource. For our purposes, regardless of how ego depletion functions, engaging in sustained inhibition clearly reduced later persistence in a difficult task. The authors later extended these findings by showing that dogs who held the ten-minute sit-stay were more likely to approach and maintain proximity to an aggressive caged dog, suggesting that engaging in self-control can also increase risky, impulsive behavior (Miller et al., 2012).

Although this self-control task was intended as a manipulation, it seems to reflect executive function in its own right. Remaining in a seated position for ten minutes is challenging for most dogs (Miller et al., 2010; 2012) and likely requires sufficient WMC to maintain the goal of obeying the “stay” command in absence of the commanding human. This task might be useful in assessing WMC, with number of “breaks” and time elapsed prior to the first “break” used as dependent measures. It could also be used to remedy ceiling effects reported in the cylinder task. Having dogs engage in self-control using this method prior to engaging in these tasks could increase subsequent task difficulty and increase the likelihood of observing individual differences in inhibitory control.

Wait-for-Treat Task. This task was used by Müller and colleagues (2016) as a part of an inhibitory control battery. In the wait-for-treat task, a food reward was placed on the floor in front of a dog and the owner commanded the dog to “wait.” After a brief period of time passed, the owner said “go” and the dog was permitted to approach and consume the food reward. The delay between the “wait” and “go” command then became progressively longer with each successive trial. This task was intended to measure a dog’s ability to delay gratification in a shorter, simpler manner than the delay-discounting task mentioned earlier in this section. It is conceptually similar to the self-control task and might also be useful in examining WMC.

Because the authors acknowledge that performance on the wait-for-treat task might rely partly on its level of trainability, training history should be taken into account when using and interpreting findings from this task. Additionally, researchers should report the range of maximum delays achieved by the subjects to evaluate task difficulty, as well as the influences of breed and training.

Reversal Task. The reversal task measures a dog's ability to learn stimulus-response contingencies as well as the ability to overcome the urge to perform a pre-potent response when these contingencies change. It consists of two phases: an acquisition phase and a reversal phase. In the acquisition phase, subjects are trained to overturn one of two presented objects (either the larger or the smaller of the two) to obtain a food reward. To move on to the reversal phase, dogs must satisfy a two-stage criterion. First, the dog must show 90 – 100% accuracy on one day or 80% on two consecutive days. Second, the dog must show 70% or better accuracy for three consecutive days following the satisfaction of the first stage. Once subjects meet this two-stage criterion, the contingencies are reversed such that the dog is only rewarded by overturning the block that had *not* been previously rewarded. This task is analogous in nature to card-sorting tasks used with humans (Berg, 1948) and delayed response/alternation tests used in other species (reviewed by Gazzaniga et al., 2009).

Tapp and colleagues (2003) tested young, middle-aged, old, and senior laboratory-raised beagles on this task to assess the effect of aging on size-learning and reversal-learning. Results indicated that young and middle-aged dogs were able to learn the initial discrimination more quickly than old and senior dogs, and were also more successful in responding to the change in contingencies. Whereas younger dogs were able to quickly adapt to the new contingency, older dogs took markedly longer to respond correctly to the reversal. Although both old and senior dogs showed difficulty in reversing, they showed different patterns of responding, leading authors to suggest different mechanistic failures underlying each group's performance. Specifically, old dogs showed impairment in learning stimulus-response (S-R) contingencies, whereas senior dogs showed impairment in withholding responses to previously rewarded locations. The finding that inhibitory control diminished with increasing age in this study mirrors patterns shown in aging humans and those diagnosed with dementia of the Alzheimer's type (Hutchison et al., 2010). These results also suggest that older dogs are more susceptible to the effects of proactive interference, a process by which information from previous trials interferes with performance on the current trial. In humans, overcoming proactive interference requires attention during encoding of the new S-R contingency as well as retrieval during subsequent trials (Kane & Engle, 2000). Resilience in the face of proactive interference thus relies on executive abilities made possible by proper functioning of the PFC which has been shown to deteriorate during the aging process of both humans and dogs, especially for individuals with dementia of the Alzheimer's type or its canine analogue, canine cognitive dysfunction syndrome (Hutchison et al., 2010; Landsberg, Hunthausen, & Ackerman, 2003; Landsberg, Nichol, & Araujo, 2012; Ruehl et al., 1995).

A-not-B Task. The A-not-B task measures a dog's ability to inhibit a pre-potent response and typically consists of two phases: training and testing. In the training phase, a dog observes the experimenter place a food reward under one of three opaque cups. The dog is then released and permitted to search for the food reward and eat it (if it is found on the first attempt). Across ten trials, the dog observes as the same cup (cup B) is baited with the food reward. If the dog successfully retrieves the reward during six of ten trials, it moves on to the testing phase. In the ten testing trials, the dog once again watches as a human experimenter baits cup B with a food reward. Then, the dog watches as the experimenter removes the reward from the baited cup (container B) and places it under the other cup (container A). The subject is then released and permitted to attempt to retrieve the food reward. The subject must avoid approaching the now empty cup B and instead approach cup A to be successful. The dog's accuracy rate across the ten test trials serves as a measure of inhibitory control (Bray et al., 2014; Cook et al., 2016; Fagnani et al., 2016). This task is conceptually similar to the reversal task.

The subjects tested by Bray et al. (2014) performed exceptionally well, with the mean accuracy being 83%. In fact, 24 of the 30 dogs did not commit the A-not-B error on the first testing trial. The authors reported no effect of age or sex on accuracy. The pet dogs tested by Fagnani and colleagues (2016) performed similarly with a mean accuracy of 78%. In this study, performance of shelter dogs and pet dogs was compared for both the cylinder task and the A-not-B task. Although the two groups performed similarly on the cylinder task, pet dogs outperformed shelter dogs on the A-not-B task, exhibiting an accuracy rate that was twice as high (mean accuracy for shelter dogs was 39%).

Previous researchers have argued that the A-not-B task is not a strong measure of inhibitory control, but instead relies on the dog's ability to follow human social cues (Kis et al., 2012). Specifically, dogs could be following inadvertent cuing by the human experimenter during the testing trials. However, authors of two separate studies (Bray et al., 2014; Fagnani et al., 2016) used the same precaution to minimize the effect of inadvertent cuing; after baiting cup A, the experimenter stepped away from the cups and faced the wall opposite the dog making cuing impossible. That the A-not-B error reflects proactive interference or a failure of inhibitory control seems the most likely conclusion.

Overall, the A-not-B task seems to be a shorter version of the reversal task mentioned earlier in this paper. Unlike the reversal task, it has not yet been shown to be influenced by age. This finding should be interpreted with caution as it is based on one study (Bray et al., 2014). Also, there seems to be ceiling effect for pet dogs in both studies. Thus, it is possible that the task is too easy to make age differences readily apparent.

Future research should examine why shelter dogs exhibit such difficulty on this task. Is this finding due to lower inhibitory control in shelter dogs, the consequences of which led to their relinquishment? Might the stresses inherent in the shelter environment deplete a dog's capacity for inhibitory control as the resource theory of ego depletion might suggest (Baumeister et al., 1998)? As with the cylinder task, future studies using the A-not-B task should 1) assess reliability of this measure, 2) use a larger sample size than did Fagnani and colleagues (2016), whose study included only thirteen shelter dogs and fourteen pet dogs, and 3) explore the effects of proactive interference on inhibitory control in dogs.

Social Task. The social task was devised and first used in the battery created by Bray et al. (2014) and requires dogs to overcome approaching a nearby human who never provides food rewards in favor of approaching a human further away who always provides food rewards. Like many other tasks, it consists of a learning phase and a testing phase. During the learning phase, subjects are permitted to interact with two humans that have food rewards in order to learn the "reputation" of each human. The "generous" human is willing to provide the food reward to the dog whereas the "stingy" human is unwilling to share the food rewards with the dog. Once the dogs have learned the reputations of these humans, the testing phase begins. During this phase, the generous and stingy humans are alternated between positions that are close to and far from the subject. The subject is released and permitted to approach only one of the humans. To obtain the food reward, the subject must approach the generous human even if he/she is further away from the dog than stingy human.

In their study, Bray and colleagues (2014) found no effect of age or sex on a dog's tendency to approach the generous human when they were further away. Additionally, performance on this task was uncorrelated with performance on the other two tasks in the battery. The authors took this as evidence that inhibitory control is context-specific and that a dog's ability to exert inhibitory control in a social context with humans might not transfer to other, non-social tasks. However, as mentioned before, one must avoid interpreting null correlations between tasks in the absence of demonstrated task reliability.

Visual Displacement Task. Working memory in dogs has been studied considerably less than inhibitory control. The following task developed by Fiset, Beaulieu, and Landry (2003) is similar to the Brown-Peterson task used to examine working memory capacity in humans (Brown, 1958; Peterson & Peterson, 1959). In this task, the dog watches as an experimenter "hides" a desired object (such as a toy) behind one of four boxes. The dog's view of the boxes is then obstructed by an opaque screen. After the passage of a pre-specified delay (ranging from 0 seconds to over two minutes), the screen is removed and the dog is permitted to search for the object. This task requires the dog to encode *and* maintain information about the object's location over a delay.

Using this task, researchers (Fiset et al., 2003) found that all dogs in their sample performed at above-chance levels across all delays (ranging from 0 to 240 seconds); however, performance was significantly worse at longer delays. In their first experiment, accuracy was significantly higher at delays of 0 and 10 seconds than at delays of 30 and 60 seconds. In their second experiment, performance was significantly better at 0 and 30 seconds than at 60, 120, and

240 seconds. This pattern suggests that dogs experience greater difficulty holding spatial information in working memory for durations surpassing 30 seconds which could be due to surpassing the limits of a dog's short-term memory capacity. However, it could instead reflect proactive interference from previous trials (see Keppel & Underwood, 1962), which increases at longer current trial delays by impairing temporal discrimination between current and recent trials (Bjork & Whitten, 1974). In tasks using nonhuman animals, proactive interference is inferred on any given trial when a subject revisits the location rewarded on the previous trial. Researchers found no evidence of proactive interference in either of the two experiments. Specifically, the dogs were no more likely to search the box rewarded on the previous trial at long delays than short delays. Further, only two out of eleven and two out of eight dogs (from Experiment 1 and Experiment 2, respectively) searched a previously rewarded box at above chance levels, suggesting proactive interference was not a significant issue in this task. According to the authors, using the visual displacement task including the introduction of an opaque screen can be a useful method for examining an animal's working memory for disappearing objects. Although their results are compelling, this study should be replicated with a larger sample.

Insights and Limitations of Previous Studies

So far in this paper, I have presented an argument for more rigorous study of executive function in dogs, provided a brief background of executive abilities and their study in human subjects, and described research methods aimed elucidating canine executive function. I now summarize what researchers have learned thus far (i.e., what we know) and limitations of the current body of research (i.e., what we do not know).

First, researchers have provided preliminary evidence that the aging process affects dogs and humans similarly (Bray et al., 2014; Tapp et al., 2003). Specifically, older dogs have a harder time inhibiting prepotent responses (Bray et al., 2014), learning new tasks, and flexibly adjusting their responding based on changing environmental conditions (Tapp et al., 2003). These findings carry important implications for owners of aging dogs. People with senior dogs might become concerned or frustrated when their trained, housebroken dog begins to occasionally eliminate indoors and engage in destructive behavior, barking, or fearful aggression as a response to change in its environment. These owners might be more able to properly accommodate their aging dogs' needs if they understand that this behavior is the result of cognitive decline rather than defiance or lack of training. Because smaller and larger dogs age at different rates, future research could examine whether dogs demonstrate different trajectories of cognitive decline based on their relative size.

Second, it is possible that shelter dogs possess lower inhibitory control than pet dogs (Fagnani et al., 2016). Although performance was not significantly different between these two groups on the cylinder tasks, pet dogs performed twice as well on the A-not-B task as shelter dogs. If this finding reflects a true deficit of inhibitory control in shelter dogs, it is of practical importance that this deficit be examined more closely. Whence does this deficit emerge? Is it possible that the stressful environment of the shelter places a sort of "load" on these dogs, making it difficult for them to exert inhibitory control? Does the reduced level of human contact, sometimes both quantitatively *and* qualitatively, lead to this deficit? Is this deficit pre-existing, with low levels of inhibitory control being the reason for relinquishment? These hypotheses are not mutually exclusive, and further exploration of the root of this deficit carries practical implications for owners, shelters, and the dogs themselves. If inhibitory control can be somehow increased through training, relinquishment can be attenuated, likelihood of adoption can be enhanced, and length of stay at the shelter can be shortened.

Although all of the studies mentioned in this paper ask (and attempt to test) important questions regarding canine executive function, myriad methodological issues limit the interpretation of the findings contained therein. I have already discussed many of these issues, but briefly reiterate them here. The recurrent issues I find in the current body of research are consistently small sample sizes, lack of reliability assessment of measures, weak or absent attempts to address the task-impurity problem, and inconsistency in conceptualizing factors like breed and training.

First, the use of small sample sizes in dog research must be mitigated, especially when researchers are testing potential differences between groups. The first concern is statistical. Using a small sample can prevent a researcher from detecting existing effects *or* lead to the finding of spurious effects that do not truly exist (Arden et al., 2016; Button et al., 2013). This can lead to low replicability of findings and even contradictory findings, even when using *the exact same methods*. This slows the acquisition of knowledge in the field and can create misperceptions of dogs' abilities. The second concern is both ethical and economical. If the use of small samples provides unreliable and even incorrect data, the researcher has wasted the considerable resources – in terms of time and money – that went into conducting the study. In an attempt to quickly publish positive results, the researcher is essentially "spending a dime to save a nickel" as the accumulation of such wasted resources across several underpowered studies is likely substantial. Additionally, the subjects themselves can be viewed as wasted resources, a problem that violates reduction, one of the "three R's" imposed by the Institutional Animal Care and Use Committee. Animal researchers are encouraged to use as few animals as possible to address their research question. Instead of conducting several small studies, researchers could instead conduct one large study. Power analysis can be a useful tool in guiding researchers' efforts to arrive at an appropriate sample size.

Second, some of the tasks currently being used to measure executive abilities have not been tested in terms of their reliability. The cylinder task, the leash task, and the wait-for-treat task are examples of measures new to the field of canine cognition which have been used, sometimes repeatedly, without knowledge of its reliability. This problem is not unique to dog research; Miyake et al. (2000) describes several studies used in human cognition research without adequate inquiry regarding their reliability. In particular, this poses a problem interpreting the null or weak correlations observed in various test batteries. The use of unreliable tasks will attenuate correlations between tasks, even if the tasks measure the same ability. This might explain why, for example, there were no correlations among tasks in batteries that included the cylinder task. Assertions made by researchers that inhibitory is context-specific are thus premature. Reliability estimates must be obtained before a task is included in a battery.

Third, some of the existing tasks used to measure inhibitory control in dogs likely reflect other abilities including spatial problem-solving and trainability. For example, dogs who are better at inhibiting suboptimal responding might have a higher level of inhibitory control *or* might simply have a stronger training history. In particular, the wait-for-treat task seems to rely on a dog knowing both "sit" and "wait" commands. Additionally, the detour-fence task and leash task seem to heavily rely on spatial awareness and problem-solving ability. A dog that cannot untangle its leash from a tree might have high inhibitory control, but lack the spatial skills required to free itself. As has been learned by human cognitive researchers, no task is "process-pure," measuring only the ability of interest. Even classic, reliable cognitive tasks require more than just executive function: successful performance on the Stroop task requires color vision and the Ospan requires a degree of mathematical ability (Hutchison, 2007). The use of larger task batteries and latent variable analyses can help canine researchers extract underlying abilities that are common across tasks.

Finally, our knowledge of the effects of genetics and training are limited by the variety of ways by which these factors are defined across studies. For example, Marshall-Pescini and colleagues (2016) found that trained dogs were faster and more accurate at navigating the detour-fence tasks than untrained dogs. This finding should be considered in light of two things: 1) the detour-fence task was used in this study as a measure of problem-solving, not executive or inhibitory ability and 2) the researchers defined “trained” dogs as those who had carried out agility or another dog sport at a competitive level or were certified as working dogs (police dogs, guard dogs, et cetera) whereas “untrained” dogs had either no training at all or only basic obedience level training.[6] These definitions are not problematic in and of themselves, but should be considered by readers when interpreting the data. When examining the impact of genetics, researchers often use breed as a factor. However, breed can be defined in many different ways. Researchers can use AKC designations (e.g., Great Dane), breeds grouped based on genetic similarity (e.g., Mastiff-type), or breeds grouped by intended function (e.g., herding breeds). Again, it is not necessarily problematic that researchers conceptualize “breed” differently, but is a fact that should be taken into account when comparing results of different studies and drawing conclusions on how breed might (or might not) determine abilities like inhibitory control or working memory capacity.

[6] Also, size and baseline speed of the dogs were not accounted for. The speed by which dogs were able to complete the task might have been an artifact of the physical attributes of the dog rather than a reflection of training or cognitive ability (Helton, 2010).

Section 4: Future Directions

Because of dogs' unique niche in human society, we can study them to better understand how to improve their behavior and welfare, and to better understand ourselves. However, their continued success in our society will be enhanced if we dedicate more research to learning which factors influence their ability to behave in appropriate ways. The following are suggestions for future research that could allow us to better understand how executive function works in "man's best friend."

Task battery Development and Latent Variable Analysis

In both dogs and humans, executive function seems to be more of a multi-faceted phenomenon rather than a unitary construct (Miyake et al., 2000; Müller et al., 2016; Pennington & Ozonoff, 1996). Because of executive function's complexity, human researchers have used methods including task batteries and latent variable analysis to learn how executive abilities contribute to the use of semantic memory, aggression, and general fluid intelligence (Hutchison, 2007; Sprague et al., 2011; Unsworth, Fukuda, Awh, & Vogel, 2014). When used properly, these methods help researchers uncover how much of the variance observed in performance among participants is due to specific factors, such as primary memory, secondary memory, and attentional control (Shipstead et al., 2014; Unsworth et al., 2014). Given the utility of latent variable analysis demonstrated in the human literature and the repeated calls for task batteries measuring executive abilities in dogs (Marshall-Pescini et al., 2015; Bray et al., 2014; Fagnani et al., 2016), this is a fruitful direction for future research.

To conduct a latent variable analysis, researchers first have participants complete several cognitive tasks that have been shown to measure specific cognitive abilities, then conduct an exploratory factor analysis to find commonality in task performance. For example, participants in the study by Miyake et al. (2000) completed nine tasks. Of these nine tasks, three were used as measures of cognitive flexibility ("shifting"), three were measures of "updating," and three were measures of inhibitory control ("inhibition"). Hutchison (2007; see also Hutchison et al., 2014) developed a battery consisting of anti-saccade, Stroop, and Ospan tasks to measure executive function (termed "attentional control"). In a more recent study, Unsworth et al. (2014) had participants complete nineteen tasks to explain the relationship between working memory capacity, its components, and general fluid intelligence. The reason behind using such a large number of tasks is the task-impurity problem; using several tasks allows researchers to extract what is common among the tasks in terms of underlying ability. For instance, in Hutchison et al.'s (2014) battery, one component (termed "attentional control") was extracted from the three tasks that accounted for 48% of the overall variance in performance. That is, nearly half of the differences in performance across the three tasks observed in the sample could be explained by differences in attentional control. Because of variance introduced by task-specific abilities irrelevant to the underlying construct of interest, latent variable analysis has been described as a more "pure" method of assessing complex abilities like executive function than using only one task (see Conway, Kane, & Engle, 2003 for a discussion).

As previously discussed, task batteries created for use with dogs have centered on inhibitory control and show either weak or null correlations. Although "context-specificity" has become the favorite explanation for these findings, the pattern seems reminiscent of problems encountered by cognitive psychologists in studying executive function in humans. As discussed by Miyake et al. (2000), some of the tasks being used to measure executive function were not well-validated and, further, had low reliability. The authors warn against testing correlations between such tasks as unreliable tasks will necessarily be unlikely to correlate with other tasks.

Nonetheless, researchers at this time used a similar explanation as some canine researchers (Bray et al., 2014; Fagnani et al., 2016), that the measures did not correlate because independent processes were being used for each. Given that reliability estimates for tasks used in recent inhibitory control batteries in dogs are unknown, Miyake's explanation seems more likely.

The careful construction of task batteries and use of latent variable analysis has the potential to shed light on the structure of executive function in dogs and whether it is, indeed, context-specific. The utility of such methods is contingent on researchers addressing problems well-known to researchers studying human cognition, as well as those unique to the canine cognition field. First, any task included in a battery must first be shown to be reliable. Test-retest reliability seems most feasible for tasks like the cylinder task and the A-not-B whereas split-half reliability could be used for the visual displacement task; however, measures of executive function tend to be most valid when the task is novel (Miyake et al., 2000), a fact posing a potential challenge to assessing reliability of tasks used with dogs. Additionally, the reliability of a measure depends on researchers using the same methods when conducting their studies. Second, larger samples must be used. The consistent use of only a few dozen subjects in canine research can hinder a researcher's power to uncover an existing effect. This problem is compounded when task reliability is tenuous. Finally, researchers can test the possibility of context-specificity. As described by Bray et al. (2014), their devised social task might have been more difficult for socially motivated dogs whereas the cylinder and A-not-B tasks might have been more difficult for food-motivated dogs. A variety of questionnaires have been created to assess traits in dogs including trainability, extraversion, and excitability (Hsu & Serpell, 2003; Ley, Bennett, & Coleman, 2008; Mirkó, Kubinyi, Gácsi, & Miklósi, 2012). If Bray et al.'s proposal is correct, we should expect that dogs rated high on extraversion or affection-seeking should perform better on the social task than dogs rating lower on these factors. In conclusion, meticulous battery creation and discovery of latent executive function variables could be an invaluable way to learn about relationships between executive function and factors like breed, training, and environmental demands, as well as predicting a dog's potential success in a working role, general trainability, or likelihood of adoption from a shelter.

Training Executive Function

Because shelter dogs have shown evidence for lower inhibitory control than pet dogs, it is of practical and ethical interest whether dogs suffering from low levels of inhibitory control can overcome this deficit through training. Some researchers in the human domain have shown that, despite having a strong genetic component, executive function can be improved through training (Rueda et al., 2005). However, others argue that the benefits of such training are limited to short-term, task-specific abilities (Redick et al., 2015). Some canine researchers have found evidence that training can increase problem-solving ability (Marshall-Pescini et al., 2008), but the effects of training on executive function are, as of yet, unexplored. Learning whether training can positively influence executive abilities like inhibitory control has the potential to lead to the development of interventions that could enhance the bond between a dog and its owner, increase successful adoptions, and reduce euthanasia rates at shelters.

Eye-tracking

Eye tracking technology has been used in human research since the 1960s and uses an apparatus that reflects infrared light off the retina to observe changes in ocular activity such as pupil dilation and gaze fixation in response to presented stimuli. Researchers using this technology have found, for example, that changes in pupil diameter correspond to changes in task difficulty and effort exertion (Beatty, 1982; Peavler, 1974). Specifically, pupil diameter increases when an individual is engaging in a challenging task, relative to an easy task. Pupil dilation is also greater in response to emotionally arousing auditory stimuli than to neutral auditory stimuli (Partala & Surakka, 2003). The use of eye trackers has been useful in understanding not only effortful cognitive processing, but also affective processing in humans (reviewed in Goldwater, 1972), and could potentially shed light on such processes in dogs.

Although the use of eye trackers with dogs might seem implausible, at least two apparatus have been successfully used to study visual perception in dogs. Researchers in Finland (Sanni et al., 2012) were able to use a contact-free eye tracker created for use with humans to examine dogs' gaze patterns when looking at stimuli on a computer screen. This study was intended to inform the debate as to whether dogs can perceive visual information presented in pictures. They found that dogs focused their gaze on information-rich areas of the pictures, such as the eye regions of dogs and humans, and preferred dog faces to human faces. The researchers concluded that dogs are amenable to study with the use of eye tracking technology and that data from such studies could shed light on visual perception in dogs, including how they attend to humans and other dogs. Even more recently, a team of researchers at Indiana University in Bloomington developed a head-mounted, portable eye tracking apparatus for use with dogs (Rossi et al., 2014). This apparatus has the advantage of being portable, making it possible to study dogs in a variety of settings outside the lab. A disadvantage is the challenge of finding dogs that are tolerant of wearing such a device.

Eye tracking technology has the potential to provide insight regarding dogs' visual behavior in social situations with dogs and humans and during cognitive tasks that is unattainable through behavioral methods. For example, researchers could measure where dogs look as a human demonstrator places a treat under a cup or in a transparent cylinder or measure exerted effort during progressively longer durations in the visual displacement task. Important for researchers to consider is that, for both contact-free and portable devices, some dogs might be more tolerant of the apparatus (introducing the same potential for bias as mentioned by Berns & Cook, 2016).

fMRI

Another departure from strictly behavioral methods emerged through the ingenious work of Gregory Berns at Emory, who has shown it is possible to study dogs via functional magnetic resonance imaging (fMRI) without the use of sedation. His team has successfully studied how reward-pathways are related to the human-dog relationship, striatal responses to olfactory, auditory, and visual cues, and even executive function and decision making (reviewed in Berns & Cook, 2016). In examining executive function, the researchers found greater activation in the frontal lobe when a dog successfully inhibited a response during a go/no-go task. Further, dogs who performed better on the go/no-go task in the fMRI scanner committed fewer errors in the A-not-B task performed outside of the scanner, leading the researchers to suggest that dogs display similarly consistent individual differences in executive function as humans.

Using fMRI provides previously inaccessible information of the dog's perceptual world and how it differs from ours. For example, future use of fMRI could allow for more educated creation of tasks to study the human-dog relationship, executive function, and social behavior. For example, researchers could see how performance and brain activity during a cognitive task relates to behavior outside of the scanner, such as owner-reported aggression and impulsivity or level and type of training. As Berns and Cook (2016) suggest, it could also be used to determine which dogs might be best suited for working roles, potentially reducing the high costs associated with training dogs who are ultimately "unemployable." Importantly, the authors caution the reader to be mindful of the possible bias inherent in data drawn from dogs willing to undergo fMRI scanning. Firstly, training a dog to willingly sit in a scanner, which is a noisy, enclosed space, requires two to four months of extensive shaping and training. Because not all dogs will be suited for such training, the dogs whose data end up being used and published might be more trainable, more intelligent, or less reactive than the dogs to whom the results are generalized. Further, as dogs are always "on-task" in the scanner, it can be difficult to ascertain differences between baseline and experimental trials, particularly when it comes to executive function tasks.

Conclusion

Executive function is a multi-faceted phenomenon that impacts successful daily functioning for better or worse in humans. The current literature suggests that the same is true for dogs; however, many existing studies are significantly limited by problems such as small sample sizes and unreliable measures. Refinement in current research practices when it comes to studying canine executive function is overdue, and addressing these issues is crucial in furthering scientific knowledge of canine executive function. Increased knowledge in this arena has the potential to positively influence dog welfare and human safety by allowing us to 1) reduce unwanted behavior in pet dogs including improper elimination, destruction, and aggression, 2) reduce relinquishment and euthanasia rates at shelters, 3) improve public safety through the implementation of evidence-based legislation, and 4) teach us the influence and limits of breed, training, and current environmental conditions. Further, canine researchers are no longer limited to behavioral measures and can now add technologies such as eye-tracking and fMRI to their toolkit for examining cognitive abilities including executive function.

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Table 1.

Information from studies using various executive function with dogs including authors, year of publication, number of dogs in the sample, characteristics of each sample, and mean performance, when available (standard error, when available, is presented in parentheses).

Presumed Ability	Task	Authors	Year	N	Sample	Performance
Inhib. control						% Accuracy
	Social Task	Bray et al.	2014	30	Pet dogs	46 (4)
	Cylinder	Bray et al.	2014	30	Pet dogs	70 (5)
		Marshall-Pescini et al.	2015	14	Free-ranging dogs	95 (6)
				12	Pet dogs (trained)	98 (1)
				12	Pet dogs (untrained)	94 (3)
				13	Pet dogs (no training phase)	86 (6)
		Fagnani et al.	2016	13	Shelter dogs	76
				14	Pet dogs	81
	A-not-B	Bray et al.	2014	30	Pet dogs	83(6)
		Fagnani et al.	2016	11	Shelter dogs	78
				13	Pet dogs	39
						# Trials to Switch
		Cook et al.	2016	13	Pet dogs	4.8
	Leash task	Müller et al.	2016	36	Pet dogs	NA
					Range of Max. Delay/# Paw Presses/sec	
	Delay-discounting	Riemer et al.	2014	10	Pet dogs (2006)	7 – 23/.51
				10	Pet dogs (2013)	10 – 25/.89
	Self-control	Miller et al.	2010		Pet dogs	NA
		Miller et al.	2012		Pet dogs	NA
	Wait-for-treat	Müller et al.	2016	39	Pet dogs	NA

						Latency to Success
	Detour-fence	Marshall-Pescini et al.	2015	13	Pet dogs	34.13 (5.7) sec
						Mean % Correct
WMC	Visual displacement	Fiset et al.	2003	11	Pet dogs	NA
			2003	8	Pet dogs	NA
Cog. Flexibility	Reversal	Tapp et al.	2003	55	Lab-reared dogs	NA

Figure 1. Photograph of a dog performing a training trial with the opaque apparatus during the cylinder task (Marshall-Pescini, Virányi, & Range, 2015, p. 7).

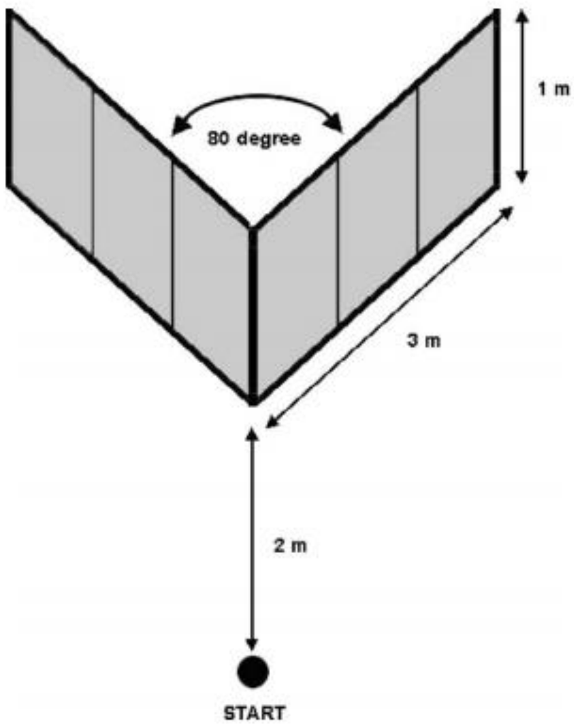

Figure 2. Diagram of a typical set-up for the detour-fence task (Pongrácz, Miklósi, Vida, & Csányi, 2005, p. 313).