DOES INCREASED TASK DIFFICULTY REVEAL INDIVIDUAL DIFFERENCES IN EXECUTIVE FUNCTION IN THE DOMESTIC DOG?

by

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DEDICATION

I dedicate this project to Grace, Doodlebug, Herman, and Misty, who patiently gave me my earliest and most important lessons on dog behavior and cognition.

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ABSTRACT

Pet dogs are carnivores that inhabit a largely human-dominated context, in which certain normal canid behaviors (e.g., resource-guarding, barking, mounting) are considered undesirable and even dangerous. Safety and welfare implications of human-dog interaction have recently led researchers to take an interest in canine executive function. Two tasks have become particularly popular in this area of study: the cylinder task and the A-not-B task. Because canine cognition tasks are not typically subjected to the same scrutiny as those used in human research, it is unclear whether these tasks indeed measure what researchers expect them to. Even though they ostensibly measure canine inhibitory control, task performance seldom correlates between the two, and researchers have suggested that they might be too easy to reflect effortful processes. Further complicating the matter are lack of reliability estimates and frequent use of under-powered samples.

In this study, I evaluated the reliability and construct validity of the cylinder task and A-not-B task. Across two experiments, I tested modified forms of the cylinder task to make it more difficult and thus more reflective of individual differences in executive function. In Experiment 1, subjects completed the cylinder task under normal conditions and following self-control exertion. In Experiment 2, subjects performed the cylinder task either with or without practice retrieving a treat from an opaque apparatus. Subjects in both experiments performed the A-not-B task with removal of ostensive human cuing. Performance on behavioral tasks was compared to owner-reported measures of impulsivity, inattention, behavioral regulation, responsiveness, and aggression.

In Experiment 1, performance was negatively affected by self-control exertion, but only to the degree that dogs exhibited self-control. This suggests that the cylinder task reflects an effortful, limited-capacity process. In Experiment 2, subjects performed worse when practice was omitted, suggesting that cylinder task performance partially reflects the ability to transfer the strategy learned during practice to the test trials. Across both studies, performance during the cylinder task and A-not-B task was uncorrelated. Further, the cylinder task showed high reliability whereas the A-not-B did not. Implications of these results and suggestions for future directions are discussed.

CHAPTER ONE

GENERAL INTRODUCTION

According to recent estimates, between 36 and 44% of all US households include at least one dog (HSUS, n.d.). Given their pervasiveness in human society, it can be easy to take peaceful cohabitation between dogs and humans for granted. Despite the tendency of dogs to be prosocial, highly trainable, and strongly attuned to human behavior, they can also cause significant damage and distress to humans and other animals. Normal canid[1] behaviors such as chasing, barking, boisterous play, aggression, and mounting are generally considered inappropriate by humans. In extreme cases, such behaviors can lead to relinquishment and, sometimes, euthanasia (Lepper, Kass, & Hart, 2002; Salman et al., 1998, 2010). Thus, the success of the human-dog relationship relies partly on dogs being able to inhibit behaviors that are part of their natural repertoire and attend to human commands in the face of distraction. Such abilities fall under the domain of *executive function*.

Executive function has long defied formal definition and remains a contentious topic for cognitive and developmental researchers. Generally, researchers view it as a set of distinct yet related processes including *inhibition* of suboptimal or inappropriate behavior, *working memory*, and *cognitive flexibility* which contribute to adaptive behavior and provide the foundation for complex activities like planning, problem-

[1] Although the terms “canid” and “canine” include several carnivores including dogs, wolves, coyotes, jackals, and dingoes, they will be used in this manuscript to refer to pet domestic dogs unless otherwise noted.

solving, and behavioral regulation (Diamond, 2013; Jurado & Rosselli, 2007; Miller & Cohen, 2001; Zelazo, 2015). To study executive function, researchers have devised a variety of tasks that presumably tap into each of the aforementioned processes (e.g., Stroop task, go/no go task, span tasks). Such tasks have been subject to empirical scrutiny in terms of both their reliability and construct validity. That is, researchers have tested whether they indeed measure what they intend to measure (i.e., construct validity) and provide consistent measurements for the same individuals over time (i.e., reliability).

In recent years, there has been an increased interest in scientific understanding of canine executive function, with researchers adapting existing experimental paradigms or devising new ones to measure abilities such as inhibitory control, cognitive flexibility, and attention (reviewed by Olsen, 2018). However, many of these tasks are used without demonstrations of their reliability or construct validity. Additionally, performance is often uncorrelated, or weakly correlated, on tasks that presumably measure the same process (Bray, MacLean, & Hare, 2014; Brucks, Marshall-Pescini, Wallis, Huber, & Range, 2017; Fagnani, Barrera, Carballo, & Bentosela, 2016; Marshall-Pescini, Virányi, Range, 2015; Müller, Riemer, Virányi, Huber, & Range, 2016).

Although humans and dogs are certainly different animals, I propose that the canine cognition field stands to benefit from wisdom gleaned by human cognitive researchers in previous decades. Specifically, the field is wanting of more rigorous, theory-driven development of tasks and task batteries, assessments of task validity and reliability, and less assumptions of process purity within and between tasks. In the current work, I attempted to partially address these issues with respect to the unique

challenges of studying the minds of nonverbal, nonhuman animals like dogs. I begin in Chapter 2 with a brief description of executive function and its associated abilities. In Chapter 3, I review evidence for executive function in dogs, as well as how they might manifest in everyday contexts. In Chapter 4, I familiarize the reader with the challenges inherent in studying nonhuman animal cognition, as well as more specific issues surrounding how executive function in dogs is studied. Finally, in Chapter 5, I introduce the motivations behind my current investigation, as well as the experimental paradigms on which it is centered.

CHAPTER TWO

EXECUTIVE FUNCTION OVERVIEW

Determining the structure of executive function has proven to be a controversial endeavor in human cognitive research. Early models such as Baddeley's (1986, 1996) central executive and Norman and Shallice's (1986) Supervisory Attentional System (see also Shallice, 1988) characterized it as a unitary construct that facilitates context-appropriate behavior through engaging attentional resources. Contemporary researchers view it as a set of distinct, yet related, abilities (see Diamond, 2013, for a review). Nevertheless, there is a general scientific consensus that executive function (a) is critical for animals living in dynamic environments, (b) follows an inverted U-shaped trajectory across development (Cepeda, Kramer, & Gonzalez de Sather, 2001; Davidson, Amso, Anderson, & Diamond, 2006; Luna, 2009; Luna, Garver, Urban, Lazar, & Sweeney, 2004; Zanto, Rubens, Thangavel, & Gazzaley, 2011), (c) relies heavily on the frontal lobes (reviewed in Miller & Cohen, 2001), and (d) is impaired by states of fatigue (Lim & Dinges, 2008; Meldrum, Barnes, & Hay, 2015), stress (Arnsten, 1998; Liston, McEwen, & Casey, 2009; Oaten & Cheng, 2005), multi-tasking (Strayer, Watson, & Drews, 2011), and certain mental disorders (Cotrena, Branco, Shansis, & Fonseca, 2016; Watkins & Brown, 2002).

Because executive function has been reviewed extensively elsewhere (Diamond, 2013; Friedman & Miyake, 2017; Jurado & Rosselli, 2007), this chapter's purpose is to create a conceptual framework, based on human cognition, from which we can

understand the nature of canine executive function. To achieve these ends, I describe the most commonly cited executive functions, their general patterns of development, some foundational abilities that permit their execution, and how they interact with each other.

Primary Executive Functions

Researchers of human cognition posit that executive function subsumes three core functions or processes: working memory, inhibitory control, and cognitive flexibility (Friedman & Miyake, 2004; Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003; Miyake et al., 2000; Riviere & Lecuyer, 2003). Although conceived as distinct entities, they rely on similar neural networks and often interact to produce behavior (Diamond, 2013).

Working Memory

Working memory is the process of holding a set of information in a temporarily active state while manipulating it or concurrently engaging in another activity (Baddeley, 2003; Jarrod & Towse, 2008). Because it involves maintaining and working with information no longer present (Baddeley & Hitch, 1994), working memory relies on achieving a developmental milestone known as *object permanence*. Object permanence refers to an individual's ability to understand that an object continues to exist, even when it is not perceivable (Piaget, 1954). Its development progresses in stages, from being able to visually track an object being hidden to being able to locate a hidden object after a period of distraction (Kramer, Hill, & Cohen, 1975). The later stages require the individual to not only understand that the object still exists, but to mentally represent the object and information about its location over a delay.

Additionally, working memory is a limited-capacity system; that is, we can only hold and manipulate a finite amount of information at any given time (Cowan & Rouder, 2009; Rouder et al., 2008; Zhang & Luck, 2008). Following achievement of object permanence, infants under a year old can hold and update one or two items in working memory (Diamond, 1985, 1995), and this capacity increases over time, leading to higher performance on traditional working memory tasks into early adulthood (Cowan, AuBuchon, Gilchrist, Ricker, & Saults, 2011). Performance decreases in late adulthood, likely due to reduced ability to inhibit the influence of distracting or irrelevant information (Zanto et al., 2011).

The development of working memory is due partly to underlying maturation (and eventual deterioration) of the prefrontal cortex. The prefrontal cortex plays an important role in supporting goal-directed, flexible behavior, including working memory (Miller & Cohen, 2001). It is heavily recruited when information has to be held in short-term memory over a delay, or in the context of a distracting environment (De Pisapia & Braver, 2006; Fuster & Alexander, 1971, 1973; Goldman-Rakic, Cools, & Srivastava, 1996; Kubota & Niki, 1971). The ventrolateral region is primarily involved in maintenance, whereas the dorsolateral region is involved in manipulation of information (Crone, Wendelken, Donohue, Leijenhorst, & Bunge, 2006), and that the latter shows little activation during a working memory task until after adolescence. That is, as children get older, they more effectively draw upon the neural circuits that facilitate

performance. In later life, reduced volume and efficiency of the prefrontal cortex can lead to age-related deficits in working memory[2] (Rympa & D'Esposito, 2000).

Inhibitory Control

It is important to note that stimulus-driven behavior, such as habit formation, can be adaptive by allowing us to behave appropriately while conserving attentional resources for specific situations (James, 1890); however, habits can become a liability when environmental conditions change (Reason & Mycielska, 1982). In these situations, *inhibitory control* is critical for appropriate responding. Inhibitory control enables suppression of irrelevant or distracting stimuli (both internal and external) and withholding of prepotent, yet inappropriate, behaviors. A simple example of how inhibitory control works is the Stroop task (Stroop, 1935). In this task, participants view a series of color words (e.g., BLUE) presented in different font colors on a computer screen and are told to respond by naming the color in which the word is presented, rather than reading the word itself. In order to respond accurately, the prepotent response of word-reading, practiced over one's lifetime, must be inhibited and replaced with a novel response color-naming. The inverse of inhibitory control is *impulsivity*, the hasty performance of actions that are inappropriate or poorly planned.

Development of inhibitory control is similar to that of working memory; it assumes an inverted-U shape, increasing from infancy into young adulthood, then declining in old age (Davidson et al., 2006; Darowski, Helder, Zacks, Hasher, &

[2] However, age-related reductions in functioning of specific regions can be attenuated through compensatory mechanisms (see Kirova, Bays, & Lagalwar, 2015 for a review).

Hambrick, 2008; Hasher, Stolzfus, Zacks, & Rypma, 1991; Luna, 2009; Luna, Garver, Urban, Lazar, & Sweeney, 2004). That is, pre-adolescent children and older adults have a harder time inhibiting context-inappropriate behavior and distraction than young adults. Infants and young children struggle with tasks in which they must override a habitual response (Davidson et al., 2006; Wright & Diamond, 2012) and, relative to young adults, older adults show similar capacity for selectively attending to stimuli, but diminished ability to inhibit irrelevant stimuli and withhold habitual responses (Alain & Woods, 1999; Barr & Giambria, 1990; Darowski et al., 2008; Gazzaley, Cooeny, McEvoy, Knight, & D'Esposito, 2005; Zanto, Toy, & Gazzaley, 2010).

As with working memory, inhibitory control is proposed to rely heavily on the prefrontal cortex, with the anterior cingulate cortex aiding in the detection of conflict. De Pisapia and Braver (2006) showed the interactivity of these two regions in the context of the Stroop task. When conflict was detected, the researchers observed an increase in activation of the anterior cingulate cortex, which was closely followed by increased activation of the prefrontal cortex (see Kerns et al., 2004 and MacDonald, Cohen, Stenger, & Carter, 2000 for similar findings). Thus, the presentation of a to-be-ignored dimension signaled the need for increased control over responding, namely suppression of word-reading. Additionally, individuals with frontal lobe damage tend to exhibit poor performance on tasks requiring inhibitory control including the Stroop task (Perret, 1974; Vendrell et al., 1995) and go/no-go task (Crawford & Higham, 2016).

Cognitive Flexibility

Cognitive flexibility refers to the ability to properly shift our attention and/or behavior to accommodate changes in the environment (Eslinger & Grattan, 1993). Complex problem-solving, multi-tasking, creative use of language, and identifying novel solutions to problems are all contexts in which cognitive flexibility come into play (Ionescu, 2012). Flexibility is often contrasted with *perseveration*, in which an individual continues to perform a response that is no longer beneficial or relevant for a given context (Sandson & Albert, 1984; Schultz & Searleman, 2002).

While assuming a similar developmental trajectory, cognitive flexibility emerges much later in life than working memory and inhibitory control (Cepeda et al., 2001; Davidson et al., 2006; Garon, Bryson, & Smith, 2008), presumably because it is supported by the prior development of these abilities (Diamond, 2013). To successfully change our response patterns, we must update the contents of working memory to reflect the new demands of a task or the environment, as well as inhibit thoughts and behaviors that, while previously relevant, are now obsolete.

As with the previous two functions, scientists have emphasized the role of the prefrontal cortex in flexible responding and the anterior cingulate cortex in conflict monitoring (O'Reilly, Noelle, Braver, & Cohen, 2002; Rougier, Noelle, Braver, Cohen, & O'Reilly, 2005; Sakai, 2008). Evidence for the importance of the prefrontal cortex comes partly from experiments using the Wisconsin Card-Sorting Task as a measure of cognitive flexibility. Individuals with damage to this part of the brain tend to perseverate longer on an obsolete sorting criterion than individuals without such damage (Milner,

1964; Rossi, Rotter, Desimone, & Ungerleider, 1999). Despite repeated feedback about their inaccuracy, they are unable to change their behavior pattern from one that was previously correct. Perseveration has long been viewed as a manifestation of compromised cognitive flexibility (Scott, 1962).

Interactivity of Executive Functions

Like most cognitive faculties, executive functions do not operate purely in isolation but, rather, interact with each other depending on environmental demands. Thus, tasks presumed to measure one function might also measure aspects of the others. This is an important point when devising and using executive tasks, as no task is process-pure (Jacoby, 1991).

Particularly challenging to tease apart are the relative contributions of working memory and inhibitory control. For example, some researchers view them as being different facets of the same construct, or one subsuming the other (Conway & Engle, 1994; Engle, 2002; Hanania & Smith, 2010; Kane & Engle, 2000, 2002; Miller & Cohen, 2001; Munakata et al., 2011). Others have argued that working memory and inhibitory control are dissociable, with the former enhancing focus on relevant information and the latter suppressing or dampening irrelevant information (Davidson et al., 2006; Zanto et al., 2011).

Regardless of one's perspective, working memory and inhibitory control are clearly intertwined, often supporting each other during demanding or novel tasks and relying on similar underlying networks (Awh & Jonides; Diamond, 2013; Gazzeley &

Nobre, 2012; Stedron et al., 2005). For example, recall that working memory involves maintaining or manipulating information in the face of distraction. To accomplish this, one must successfully *inhibit* extraneous information. Conversely, inhibitory control involves the suppression of automatic responding in favor of a different, context-appropriate response. Maintaining information regarding behavior to engage in (or refrain from) requires working memory. Thus, observed parallels in development make sense; enhanced development of working memory likely leads to enhanced inhibitory control and vice versa (Davidson et al., 2006; Hale, Bronik, & Fry, 1997).

Successful execution of cognitively flexible behavior invokes both working memory and inhibitory control. Failures during cognitive flexibility tasks have been attributed to deficits in quantity and quality of information held in working memory (Blackwell, Cepeda, & Munakata, 2009; Kloo, Perner, Kershhuber, Dabernig, & Aichhorn, 2008), as well as insufficient inhibitory control (Kirkham, Cruess, & Diamond, 2003). In particular, inhibitory control (or lack thereof) has been implicated in attentional inertia, in which an individual experiences difficulty switching from one response to another when reward contingencies change (Kirkham et al., 2003).

Summary

Executive function is proposed to encompass three main functions: working memory, inhibitory control, and cognitive flexibility. Working memory allows us to maintain relevant information over delays and in distracting environments. Inhibitory control is involved in the suppression of a stronger, well-practiced response in favor of a

weaker response that is more context-appropriate. Cognitive flexibility allows us to disengage from one pattern of action or thought to engage in a new one. Although they are conceptualized as distinct entities, these functions follow similar developmental trajectories, rely on similar brain regions (namely the prefrontal cortex and anterior cingulate cortex), and interact with each other to produce adaptive, flexible thought and behavior patterns.

CHAPTER THREE

THE THREE CORE FUNCTIONS IN DOGS

A person's ability to focus on selected information in the face of distraction, withhold impulses, and flexibly adjust to changes in the environment carries significant consequences, ranging from optimal to disastrous. Canine psychologists have provided compelling evidence that the same is true for dogs; however, capacity for higher-order cognition (e.g., intentionality, consciousness) in dogs is still occasionally contested. It is premature to assume that the structure of canine executive function parallels that of humans, but we can reasonably apply the three core executive functions to situations in which dogs might find themselves. Placing the core functions in the light of everyday contexts can be informative in the construction and evaluation of behavioral tasks used to study canine executive function.

Executive Function is Important for Dogs, Too

A large body of research has shown the importance of executive function in day-to-day human activities. For example, low executive function is associated with obesity, engagement in risky behavior, substance abuse, poor financial decisions, and violent behavior (Denson, Pederson, Friese, Hahm, & Roberts, 2011; Duckworth, Tsukayama, & Kirby, 2013; Moffitt et al., 2011). Conversely, high executive function is implicated in higher educational achievement, good physical and mental health, and better quality of life (Brown & Landgraf, 2010; Crescioni et al., 2011; Davis, Marra, Najafzadeh, & Lui-

Ambrose, 2010; Duckworth et al., 2013; Miller, Barnes, & Beaver, 2011; Moffitt et al., 2011).

Given the myriad ways dogs have become interwoven in our society and their capacity for both harm and assistance, researchers have taken an increased interest in understanding canine cognition and behavioral regulation. For example, dogs selected for service animal roles must be attentive to their owners, non-aggressive, and be able to carry out various functions even in the most distracting, crowded environments (Lucidi, Bernabó, Panunzi, Villa, & Mattioli, 2005). Pet dogs unable to withhold behaviors like barking, chasing, mounting, and destruction at their owners' command risk punishment, rehoming, or relinquishment. Destructiveness, aggression, and disobedience are among the most frequently-cited reasons for relinquishing dogs to a shelter (Salman et al., 2000; Segurson, Serpell, & Hart, 2005).

Increased understanding of canine executive function has wide-ranging implications, from efficacy of service dog production (Lucidi et al., 2005) and improved outcomes for dogs housed in shelters (Hennessey et al., 2001) to increased human safety. The three core executive functions identified in humans likely play important roles in a dog's relative ability to respond appropriately to its environment. However, some readers might be dubious about the existence of such higher-order processes in nonhuman species, including dogs.

Regardless of approach or motive, studying nonhuman animal psychology remains precarious ground. Scholars tread carefully when attempting to understand the behaviors or, more controversially, mental lives of nonhumans lest they be accused of

exhibiting *anthropomorphism*, the act of ascribing human characteristics to nonhuman entities. Thomas Nagel (1974) eloquently described the challenge of understanding nonhuman minds when we have only the human subjective experience from which to draw. He also noted that the subjective experience of another animal might be so incomprehensible to us that we avoid empirical discussion about that animal's mental states altogether[3]. Indeed, some have advocated for this approach. In the realm of canine cognition, Clive Wynne has argued extensively that anthropomorphism "should have no place in an objective science" (2007, p. 125), going so far as to say that researchers should be cautious in suggesting the existence of consciousness in other animals (Wynne, 2004).

Nevertheless, prominent animal researchers have claimed that anthropomorphism is not only an inevitable part of trying to understand animals, but can be practiced critically enough to permit scientific exploration (Bekoff, 2000; Burghardt, 1991; de Waal, 1997). For example, Burghardt distinguishes *critical* from *uncritical anthropomorphism*, arguing that the former can provide a basis for generating testable hypotheses and improving animal welfare. Engaging critical anthropomorphism requires a thorough knowledge of the species in question (e.g., evolutionary history, ecological niche, current body of behavioral and neuroscientific literature) paired with careful, systematic observation used in any other scientific endeavor. As such, it is not merely superimposing human processes and behavioral proclivities upon individuals in a species,

[3] "Facts about what it is like to be an X are very peculiar, so peculiar that some may be inclined to doubt their reality, or the significance of claims about them." (p. 437)

but rather seeking to understand what drives a behavior based on environmental conditions, selection pressures, and previously-demonstrated abilities of said species.

The following descriptions of canine executive function, as well as the subsequent experiments, are mediated by critical anthropomorphism. From this stance, we can critically evaluate the presence of executive functions in dogs by asking specific questions. How might the evolutionary history of dogs have selected for executive functions? Do dogs possess prerequisite abilities that permit the operation of a specific function? Finally, what situations would invoke such processes in the domestic dog, a species quite different from our own?

Working Memory in Dogs

First, let us recall the definition of working memory provided by researchers of human cognition: Working memory allows us to temporarily hold and manipulate a finite set of information. It is particularly important when we are attempting to multi-task or ignore distraction. How, then, can we identify working memory in dogs? Conceptually, dogs must show evidence of 1) maintaining information over a delay when the information is not perceivable and 2) maintaining information in a distracting environment.

Both of these abilities carry significance for dogs, both in the context of their shared evolutionary heritage with other canids and that of human society[4]. In the wild,

[4] When discussing canine cognition, it is important to acknowledge that results obtained in samples of pet domestic dogs might not generalize to free-ranging domestic dogs that make up the majority of the world's domestic dog population. Additionally, determining the origins of traits observed in dogs is better informed by considering *several* related canids (coyotes, dogs, wolves, dingoes, and jackals are all

both hunting and maintaining contact with other members of the group are critical elements of survival and rely upon tracking and locating individuals that periodically go out-of-view (Fiset, Beaulieu, & Landry, 2003). Pet dogs also make use of working memory when attending to their owners' commands in distracting environments like dog parks and navigating obstacles while simultaneously attending to human cues in sports like agility. Additionally, service dogs must focus on meeting their human caretaker's needs while filtering out extraneous information in the environment.

Because object permanence is foundational for the operation of working memory, achievement of this ability must be demonstrated to argue that dogs possess working memory. Several researchers have done exactly this, reporting that dogs can form and maintain mental representations of objects no longer in view (Miller, Gipson, Vaughan, Rayburn-Reeves, & Zentall, 2009; Triana & Pasnak, 1981), as well as an object's trajectory as it was being hidden (Gagnon & Doré, 1992). Further, these results cannot be merely attributed to olfactory or inadvertent human-provided cues.[5]

Extending upon this research, Fiset et al. (2003) tested for the existence of working memory in dogs using a visual displacement task. Each subject watched as an experimenter "hid" an object behind one box in an array of four boxes. Then, a screen was placed between the subject and the array to occlude its view of the baited box. The delay between occlusion and permission to search ranged from 0 to 60 seconds in Experiment 1, and 0 to 240 seconds in Experiment 2. In order to successfully retrieve the

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interfertile) rather than just the dog's presumed direct ancestor, the wolf (Coppinger, Coppinger, & Beck, 2016).

[5] However, Miller and colleagues suggested that a dog's ability to locate a hidden object could be due to either mental representation *or* higher-order conditioning.

object, the subject needed to (1) understand that the object continued to exist even when not in view (i.e., object permanence) and (2) hold information regarding the hidden object's location in an active state over increasing delays. Subjects in this study were able to locate the object on the first try at above chance levels at all durations; however, accuracy declined with increasing delays. Demonstrations of working memory in dogs are not limited to search behavior. As Fugazza and Miklósi (2013) recently described, dogs can also maintain a sequence of actions performed by a human over a delay of 90 seconds.

Inhibitory Control in Dogs

Inhibitory control allows us to withhold a behavior that, while immediately gratifying, might not be appropriate for a given situation. It also allows us to withhold behaviors elicited by a salient environmental cue in favor of performing a more appropriate action. For dogs to demonstrate inhibitory control, they must be able to (1) refrain from performing a practiced or previously-rewarded behavior and (2) perform a novel or less-practiced action instead.

The demands of living in social groups necessitate inhibitory control (Amici, Aureli, & Call, 2008; MacLean et al., 2014). For example, preserving group cohesion and facilitating cooperation requires refraining from excessive aggression. Withholding impulsive behavior is also critical during hunting and foraging, which involves coordination with other group members (Bailey, Myatt, & Wilson, 2013). Wild canids tend to live in such social groups, ranging from mated pairs to larger packs consisting of

about a dozen animals (Mech & Boitani, 2010). Range and Virányi (2015) propose that dog behaviors supporting the remarkable dog-human relationship in modern societies have their roots in selection pressures faced by the dog's wild relatives.

Although they seldom need to hunt for their own food or compete for mates, pet dogs need inhibitory control to be successful in human society. Chasing, mounting, barking, and boisterous play are species-typical behavior for dogs, but are seldom encouraged by humans. As previously mentioned, these very behaviors can be grounds for relinquishment to animal shelters, and even euthanasia in severe cases (Kass, New Jr., Scarlett, & Salman, 2001; Kwan & Bain, 2013; Lepper et al., 2002; Siracusa, Provoost, & Reisner, 2017). Thus, identifying factors involved in canine inhibitory control (e.g., training, breeding, and temperament) will be informative in terms of reducing danger to both dogs and humans stemming from undesirable behavior.

Despite the relative explosion in canine inhibitory control research, insight about causal factors, individual differences, and even adequacy of testing methods remains elusive. Marshall-Pescini and colleagues (2015) tested both dogs and wolves on two detour-reaching tasks to learn the effects of domestication on inhibitory control. According to the canine cooperation hypothesis (Range & Virányi, 2015), wolves should outperform dogs, given the extraordinarily cooperative nature of wolf packs in hunting, relocating, and rearing young. Conversely, the domestication hypothesis (Hare & Tomasello, 2005) holds that domestication enhanced the domestic dog's ability to understand and respond to human cues, which should lead to higher inhibitory control performance relative to wolves. The data were inconclusive; dogs outperformed wolves

on the cylinder task, and wolves outperformed dogs on the detour-fence task. Another study (Fagnani et al., 2016) examined the influence of environment, comparing owned dogs to dogs residing in a shelter. Both samples were tested on two ostensible inhibitory control tasks: the cylinder task and the A-not-B task. Shelter dogs demonstrated poorer performance than owned dogs during the A-not-B task, but no differences were observed in the cylinder task.

Because performance on each task is influenced by forces aside from inhibitory control (e.g., problem-solving ability, trainability, experience navigating barriers), researchers have constructed a variety of task batteries with the goal of identifying a singular underlying construct that explains performance across all tasks (Bray et al., 2014; Brucks et al., 2017; Müller, Riemer, Virányi, Huber, & Range, 2016). Correlations across tasks tend to be small or completely absent, leading researchers to conclude that, rather than being a singular ability that influences behavior across environments, inhibitory control is context-specific. That is, a dog that can cease chasing a squirrel at his owner's command might not be able to refrain from jumping up in his excitement to greet visitors at home. Although plausible, this hypothesis requires empirical support.

In addition to behavioral tasks, questionnaires have been developed to assess the inverse of inhibitory control, impulsivity (Hsu & Serpell, 2003; Vas, Topál, Péch, & Miklósi, 2007; Wright, Mills, & Pollux, 2011). Researchers have cited the advantages of questionnaires over behavioral measures, namely that they are more time-efficient and less costly (Kubinyi, Gosling, & Miklósi, 2015). Furthermore, owners' reports on their dogs' behavior draw from a more extensive time period than behavioral tests – which

typically last an hour or so – and are not limited by the scope of a researcher's operational definition of what inhibitory control looks like.

Cognitive Flexibility in Dogs

Cognitive flexibility allow us to shift thought and behavior patterns that have previously been reinforced to a new pattern based on environmental change. It relies on the prior development of both working memory and inhibitory control. To demonstrate cognitive flexibility, dogs must be able to withhold the performance of a previously-rewarded response and perform a new, contextually-appropriate response instead.

Flexibility is critical for wild canids given the variability inherent in natural environments. Wolves, for instance, live in packs that are constantly fluctuating. Pack members disperse, interlopers join, and occasionally, one or both members of the dominant pair are overthrown, resulting in significant changes in pack dynamics (Boyd & Jimenez, 1994; Mech & Boitani, 2010). Contrary to popular belief, wild wolves do not follow a rigid linear hierarchy. Instead, social dominance is context-specific and also varies between any given pair of wolves in the same pack (Mech, 1999). Thus, even in a stable pack there is a need to adjust behavior accordingly across contexts and relationships to reduce aggression, promote cohesion, and prevent injury.

For pet dogs who frequently move between different environments, expectations for appropriate behavior often vary between contexts. For example, rowdiness and barking are typically deemed acceptable at off-leash dog parks, but are discouraged inside a human home. In some homes, dogs are permitted on the furniture whereas in

other homes they are not. Flexibly adapting to different environments allows dogs to avoid reprimand and obtain human attention and praise.

Research using dogs as models for human cognitive aging has revealed individual differences in canine cognitive flexibility, paralleling patterns observed in humans. For example, relative to younger dogs, old dogs show more perseveration when contingencies change. Specifically, they are less flexible in modifying their strategies to meet task demands, have greater difficulty updating the contents of working memory, and withholding previously-rewarded responses (Adams et al., 2000; Chan et al., 2002; Tapp et al., 2003a). Given the similarities in age-related cognitive decline between dogs and humans, researchers have proposed that dogs can serve as a model for early dementia detection and possible interventions (Adams, Chan, Callahan, & Milgram, 2000; Studzinski et al., 2006).

Summary

Although canine executive function might assume a different structure than that outlined in humans, research supports the existence of the three core executive functions – working memory, inhibitory control, and cognitive flexibility – in domestic dogs. Behavioral regulation and flexibility have been selected for in the dog's evolutionary history and, in the case of pet dogs, by human preference or need. When properly developed and cultivated, these functions have the ability to advance both human and canine interests.

CHAPTER FOUR

CURRENT CHALLENGES AND A PATH FORWARD

Given the difficulty of studying executive function in our own species, how can we hope to understand such a complex, high-order process in a nonverbal species that inhabits a vastly different perceptual world than us, and has sometimes been argued to lack consciousness and intent? Fortunately, the current scientific climate permits exploration via behavioral tasks, owner questionnaires, imaging, and physiological measures. Despite the recent explosion in imaging-based studies, behavioral tasks are still frequently employed, and many of these have not been evaluated for their reliability or construct validity. Although researchers cannot approach canine and human executive function in exactly the same way, I argue that the canine cognition field can become more generative by heeding wisdom from early researchers of human cognition. In particular, classic cognition literature can inform canine researchers regarding avoidance of process-purity assumptions, the importance of behavioral tasks providing reliable *and* valid measures of executive function, and ethical mitigation of inadequately-powered experimental designs (i.e., insufficient sample sizes).

Process-Purity Assumption

Both human and nonhuman researchers have used cognitive tasks as measures of hidden processes such as intelligence, processing speed, implicit bias, and executive function. Although such tasks are often used to measure a specific process (e.g., the

Stroop task is often used to measure inhibitory control), Jacoby (1991) famously cautioned against falling prey to the *process-purity assumption*, in which researchers equate task performance with the efficiency of a given process. For example, an individual's poor performance on the Stroop task might be assumed to reflect deficient inhibitory control. The point here is not that the Stroop task does not adequately measure inhibitory control, but that we must acknowledge that factors besides inhibitory control can affect Stroop task performance, such as visual acuity, presence of color-vision, reading ability, goal maintenance in memory, and whether participants are being tested in their native language (Burgess, 1997; Phillips, 1997). In some cases, the contribution of the ostensibly-tested process is quite small; Kane and colleagues (2007) showed that performance on the *n*-back task – commonly used by neuropsychologists as a measure of working memory – only weakly correlated with other, more robust measures of working memory (span tasks).

The same principle applies when studying canine cognition. Although a given task might seem like an appropriate measure, neither behavior nor cognition operate outside the influences of environment, previous experience, or sensory acuity. For pet dogs in particular, many human-imposed factors can shape cognition during a task. For example, training influences how dogs allocate attention and perform on socio-cognitive tasks (Marshall-Pescini, Passalacqua, Barnard, Valsecchi, & Prato-Previde, 2009; Marshall-Pescini, Valsecchi, Petak, Accorsi, & Previde, 2008). There is also accumulating evidence that characteristics of dog owners, such as training methods, consistency, and personality, can powerfully shape dog behavior inside and outside of the

lab (Arhant, Bubna-Littitz, Bartels, Futschik, & Troxler, 2010; Blackwell, Twells, Seawright, & Casey, 2008; Jargoe & Serpell, 1996).

Given that each cognitive task reflects more than just the process of interest, cognitive researchers have developed and used task batteries to measure executive function with more precision (Conway, Kane, & Engle, 2003). In these studies, participants engage in several tasks that presumably measure aspects of the same ability. Then, researchers use latent variable analysis to extract the common variance in performance across tasks. Task batteries and latent variable analysis have been valuable tools for cognitive psychologists investigating complex processes like executive function (for examples, see Hutchison, 2007; Hutchison et al., 2014; Miyake et al., 2000; Unsworth, Fukuda, Awh, & Vogel, 2014).

Over the past five years, canine researchers have developed various task batteries to study inhibitory control in dogs (Bray et al., 2014; Brucks et al., 2017; Fagnani et al., 2016; MacLean et al., 2014; Marshall-Pescini et al., 2015; Müller et al., 2016). Encompassing two to five tasks, these batteries have been used to provide a more pure measure of canine inhibitory control than using only one task. However, results consistently yield low to null correlations in performance across tasks, leading researchers to propose that canine inhibitory control is context-specific. That is, a dog that can inhibit inappropriate behavior in one environment might not be able to inhibit it in another. Brucks and colleagues (2017) recently provided support for this hypothesis using latent variable analysis. From their five-task battery, they extracted three

components that accounted for 63% of the variance in performance, suggesting that canine inhibitory control might be multi-faceted, rather than unitary, in nature.

It is important to note that conducting a latent variable analysis requires a robust sample size and use of appropriate statistical methods. Most of the studies cited here used considerably smaller samples with fewer tasks, and only used correlations to test for a unitary inhibitory control factor. In these cases, there are other explanations for null correlations aside from context-specificity, namely the reliability and construct validity of tasks within the battery.

Reliability and Validity of Behavioral Tasks

Despite the assumption that tasks in their batteries measure the same thing, canine researchers generally find that performance does not correlate across tasks. This recurrent pattern of results might be vexing to researchers interested in understanding how dogs regulate their behavior; however, they are not without empirical precedent. Low or zero-order correlations across tasks is a familiar challenge to cognitive researchers, who themselves proposed context-specificity as the culprit (Miyake & Shah, 1999).

Using multiple indicators of executive function is better than using only one; however, it is vital to first ensure that each task actually measures what it has been designed to measure (i.e., the task is valid) and that it will provide the same measurements for a given participant over time (i.e., the task is reliable). Miyake et al. (2000, p. 53) have cautioned,"…low zero-order correlations among executive tasks could

be a reflection of low reliabilities of the measures themselves, rather than a reflection of independence of underlying executive functions tapped by individual tasks." In other words, two tasks might in fact measure a similar ability (e.g., inhibitory control), but one task (or both) might be an unreliable indicator of the ability, masking any detectable relationship between the tasks (see also Salthouse, Toth, Hancock, & Woodard, 1997).

To ascertain task reliability, researchers use indices such as test-retest reliability, inter-method reliability, and split-half reliability (Carmines & Zeller, 1979). Test-retest reliability involves testing a subject more than once on the same task and provides an estimate of how stable an individual's performance is over time. Split-half reliability tests the internal consistency of a measure and requires only one administration. Finding reliable measures of executive function provides a unique challenge, given the complexity of this construct. For some aspects of executive function, such as working memory, performance remains stable over time (Kane, Conway, Hambrick, & Engle, 2007). For others, continued exposure to the task might bolster the use of stimulus-response learning and thereby reduce the task's reflection of executive function, leading to low reliability (Kabadayi, Krasheninnikova, O'Neill, van de Weijer, Osvath, & von Bayern, 2017; Rabbitt, 1997b). In these cases, initial task performance (i.e., performance on the first few trials) might be a stronger indicator of executive function than overall task performance across several trials.

An additional challenge is ensuring that target abilities are being adequately captured by task performance; that is, tasks must demonstrate *construct* validity, providing sound reflections of what scientists are trying to measure. Construct validation

can be approached in a variety of ways. In cross-validation, researchers compare performance on a given task with that during another, validated task used to assess the ability of interest (e.g., intelligence, Crawford, Parker, Stewart, Besson, & De Lacey, 1989). Additionally, researchers can assess the congruence between behavior and reports from the participant or someone close to the participant (Kubinyi et al., 2015; Riemer, Mills, & Wright, 2014). Establishing construct validity of a task allows researchers to draw broader, more practical conclusions from task performance. Ideally, task performance should correspond to, and even predict, real-world behavior.

The Challenge of Adequately-Powered Studies

Studies using nonhuman animals are overseen by each research institution's Institutional Animal Care and Use Committee (IACUC) per federal regulation. Guiding the approval of every study are the "three R's" of animal research: Replace, Refine, and Reduce. Researchers must provide evidence that they have: Replaced the use of nonhuman animals with other methods whenever possible, Refined their methods to inflict the least amount of discomfort possible, and Reduced the number of subjects needed to meet their research objective. The latter principle presents a unique challenge for striking a balance between type 2 error likelihood and ethics, particularly if the study involves invasive methods or sacrificing subjects at the end of the study. Ethically, it is preferable to use as few animals as possible. Statistically, data from small samples can result in spurious effects that might not be replicable (type 1 error) or failing to find an existing effect when the null hypothesis is false (type 2 error; Button et al., 2013).

Arden and colleagues (2016) have shown that many studies in the canine cognition field are underpowered, meaning they lack the necessary sample size to properly support or reject the null hypothesis. While it might be tempting to criticize the authors of the studies, one must consider the difficulty of getting a large-scale study approved by the IACUC, as well as the time and resources needed to test dozens of dogs on several tasks. One possible solution is the careful use of power analyses. Briefly, *power* is defined as a study's ability to reject the null hypothesis when it is truly false. Researchers can use tools including power tables and software to identify the sample size needed to appropriately reject or retain the null hypothesis, as well as justify the use of animals to the IACUC (Cohen, 1988; Mayr, Erdfelder, Buchner, & Faul, 2007). Another promising avenue is collaboration between different labs, which can reduce the workload of a study and make it easier to achieve a highly-powered sample.

Summary

Our knowledge of canine executive function, particularly predictors and outcomes of this ability, has been limited by inadequate assessment of behavioral tasks and low sample sizes. Unfortunately, these seemingly theoretical dilemmas can directly impact practical spheres such as breeding and selection of working dogs and evaluating suitability for adoption in shelter dogs (Hennessey et al., 2001; Mornement et al., 2010; 2014; van Rooy, Arnott, Early, McGreevy, & Wade 2014). Bolstering efforts to better design and evaluate measures of canine executive function, and use adequately-powered studies will allow the field to progress more effectively and yield more accurate data.

CHAPTER FIVE

MOTIVATIONS FOR THE CURRENT STUDY

The purpose of the current study is to further our understanding of canine executive function by evaluating the reliability and construct validity of two commonly used tasks in canine cognitive research: the cylinder task and the A-not-B task. Both have origins in Piaget's (1954) object permanence research using human infants and have since been adapted for use in several nonhuman species including nonhuman primates (Amici et al., 2008), parrots (Kabadayi et al., 2017), goats (Langbein, 2018), and dogs (Bray et al., 2014; Fagnani et al., 2016; MacLean et al., 2014; Marshall-Pescini et al., 2015). Although several tasks have been developed to assess canine executive function, these tasks have become especially popular in recent years, having been used to study effects of environment (Bray et al., 2014; Fagnani et al., 2016) and domestication (Marshall-Pescini et al., 2015) on canine inhibitory control, as well as the evolution of inhibitory control across 36 different species (MacLean et al., 2014).

Despite their frequent use, neither the cylinder task nor the A-not-B task have been scrutinized regarding their efficacy in measuring canine executive function. Over the years, researchers have cited myriad issues with both tasks, calling into question their utility in studying canine cognition. For example, a recurring issue with the cylinder task is that performance is often at ceiling, suggesting that it might be too easy to measure individual differences, or to adequately measure inhibitory control at all (Fagnani et al., 2016; Marshall-Pescini et al., 2015). Further, while both tasks are presumed to measure

the same ability – inhibitory control – performance on these tasks is consistently uncorrelated (Bray et al., 2014; Fagnani et al., 2016; Marshall-Pescini et al., 2015).

Similar issues have been observed in human research. First, individual differences in cognition are most evident when task difficulty is high. For example, the effect of working memory capacity on "inhibitory control" in the Stroop task (1935) is only apparent when there are few external reminders of the task goal (Kane & Engle, 2003). To manipulate task difficulty, the researchers created lists that were either 75% incongruent or 25% incongruent. In the 75% incongruent lists, each incongruent trial served as a reminder of the task goal (i.e., to name the color the word was presented in rather than reading the word itself), whereas in the 25% incongruent lists, such reminders were infrequent. Thus, in the 25% incongruent lists, participants had to maintain the task goal in working memory throughout the task. Kane and Engle found that, while task performance was equivalent for participants with high and low working memory capacity in the 75% incongruent condition, participants with low working memory capacity did significantly worse in the 25% incongruent condition. This suggests that these individuals were less able to internally maintain the task goal; it also suggests that the Stroop task is not a pure measure of inhibitory control, but measures working memory to some degree as well. Thus, identifying differences in inhibitory control between populations (e.g., owned dogs versus shelter dogs) might only be possible if the cylinder task is made sufficiently difficult.

Second, although the recurrent finding that task performance does not correlate seems perplexing on the surface, it parallels previous findings in human research.

Research with human infants has shown that performance on both the cylinder task and the A-not-B task tends to improve across the first year of an infant's life (Matthews, Ellis, & Nelson, 1996). Thereafter, performance diverges (Bell & Fox, 1992; Matthews et al., 1996), possibly due to accumulating environmental influence on the abilities needed for the respective tasks (e.g., memory, working memory, inhibitory control). Given that most dogs completing these tasks are over six-months-old, environmental factors like training, adoption status, nutrition, and environmental stressors might influence performance in ways unique to each task.

Some researchers have proposed that the cylinder and A-not-B tasks reflect a similar ability, but each measures unique, context-specific facets of it (Bray et al., 2014; Marshall-Pescini et al., 2015). Human executive function has been shown to be multi-faceted, so it is possible that the same is true for dogs. Conversely, the tasks might in fact measure qualitatively different abilities, despite the assumption that they primarily measure inhibitory control. This calls into question the construct validity of the tasks. Before interpreting data from any behavioral task, researchers must assess reliability and validity (Sinn, Gosling, & Hilliard, 2010), a critical step that seems frequently omitted in the current body of canine cognition research. If we have not yet provided evidence that these tasks are reliable and measure the same construct, any explanations for null correlations remain speculative. Validating the tasks against other methods (e.g., validated behavioral tasks and questionnaires) can provide insight about what these tasks are truly measuring. It is also possible that any existing correlation is being masked by task unreliability (Miyake et al., 2000). That is, task performance will not correlate if

performance on one or both tasks is erratic. If we assume that the cylinder task and the A-not-B task both measure the stable, underlying ability of inhibitory control, dogs should respond in a fairly consistent fashion during both tasks.

The lack of reliability and construct validity estimates for these tasks complicate interpretation of resulting data and cloud our understanding of canine executive function. Thus, I designed two experiments to elucidate the appropriateness of the cylinder and the A-not-B tasks in studying canine executive function. Broadly, my goals were to (1) make the tasks more difficult, and thus more reflective of individual differences, (2) validate the measures against owner-reported measures of canine executive function, and (3) estimate the tasks' reliabilities. I also used power analyses prior to data collection to reduce the possibility of type 2 error while also using as few subjects as possible.

In Experiment 1, I employed a depletion paradigm (Miller et al., 2010, 2012, 2015) to increase the difficulty of the cylinder task. Subjects performed the cylinder task after sitting alone in a kennel or room for ten minutes and after trying to hold a ten-minute "sit-stay." Subjects also performed the A-not-B task with the removal of ostensive human cuing. Owners completed a questionnaire with items relating to their dogs' impulsivity, inattention, behavioral regulation, responsiveness, and aggression. Then I compared these ratings with task performance for validation purposes. I also explored whether behavior during the sit-stay manipulation itself might serve as an informative measure of executive function.

In Experiment 2, subjects performed the cylinder task either with or without practice removing a food reward from the apparatus. Again, subjects performed the A-

not-B task without human cuing. Owners completed the same questionnaire as in Experiment 1 in order to validate task performance.

CHAPTER SIX

EXPERIMENT 1: DOES EXERTION OF SELF-CONTROL REDUCE SUBSEQUENT INHIBITORY CONTROL PERFORMANCE?

The primary purpose of my first experiment was to test whether imposing pre-test self-control can be used to reduce ceiling effects observed in the cylinder task, thus making individual differences more apparent. Thus, I predicted that (1) cylinder task performance would be worse following the sit-stay than being alone in a kennel or room, and (2) cylinder task performance would correlate more strongly with A-not-B task performance following the sit-stay than being alone in a room. I also examined relationships between behavioral measures from the cylinder task, A-not-B task, and sit-stay manipulation and owner-reported measures. Further, I tested the potential influences of age and formal training on performance during the behavioral tasks. Finally, I estimated the reliability of the cylinder task and the A-not-B task, critical information that is currently missing in the literature.

Method

Subjects

To avoid problems related to under-powered studies (Arden, Bensky, & Adams, 2016; Button et al. 2013), I determined my sample size by conducting a power analysis using GPower (Mayr et al., 2007). I used data obtained by Miller et al. (2010) to estimate the effect of the self-control manipulation on inhibitory control performance. The

authors reported a large effect (d = 1.55) of the self-control manipulation on their dependent measure, subsequent task persistence. The power analysis determined that a sample of 16 subjects would provide satisfactory power ($\beta = 0.8$) to detect such an effect.

I recruited subjects using word-of-mouth and flyers posted in the community (including Bozeman, Livingston, and Belgrade, Montana). Dog owners were required to complete a pre-screening questionnaire (see Appendix) relating to their dogs' typical behavior prior to being accepted into the study. The questionnaire included seven items related to aggression (e.g., "my dog acts aggressively when an unfamiliar person approaches its owner or member of the owner's family at home"), five related to fearfulness (e.g., "my dog acts anxious or fearful when unfamiliar people visit our home"), and four relating to trainability (e.g., "my dog is motivated by food during training"), with all but one of the items drawn from the assessment developed by Hsu and Serpell (2003). I also collected demographic variables for each dog (e.g., breed and age) and contact information of the owner. All subjects participating in the study were up-to-date on canine parvovirus, distemper, canine hepatitis, and rabies (designated as core vaccines by Paul et al., 2006), as well as canine tracheobronchitis ("kennel cough").

To ensure the safety during data collection, as well as suitability of subjects for the experiment, I set omission criteria based on information provided during pre-screening and behavior exhibited during the experiment. I identified the following scores on the pre-screening questionnaire as indications of potential danger for me, discomfort for the subject, and lack of requisite training or food motivation, respectively: 14 points or more on the aggression subscale, 10 points or more on the fear subscale, or 11 or less

on the trainability subscale. Additionally, subjects were to be omitted if they displayed signals of anxiety, fear, or aggression upon my arrival to the owner's home, during set-up, or at any time during the procedure. Signals resulting in termination of the experiment and omission from the study were: baring of teeth and/or growling at any point during the experiment, barking in conjunction with refusal to approach me, continuous whining, or refusal to approach me during three consecutive experimental trials.

Procedure

Upon acceptance into the study, subjects were randomly assigned to a task order, such that seven subjects completed the depletion condition first and eight completed the control condition first. A period of at least two weeks separated the two testing sessions to reduce the possible influence of practice effects. Three separate visits were scheduled to test subjects in both conditions of the cylinder task (counterbalanced) and the A-not-B task to reduce the influence of fatigue. I requested that owners refrained from feeding the subjects for at least two hours prior to testing to ensure proper food motivation. On the final visit, the owner completed a questionnaire pertaining to the subject's typical behavior and training history. Experimental sessions were video recorded using a camcorder mounted on a tripod.

Cylinder Task. To measure inhibitory control, I assessed each subject's ability to successfully retrieve a food reward (hereafter referred to as a "treat") from inside an open-ended cylinder apparatus. The apparatus consisted of a transparent plastic cylinder

(19 cm long and 14 cm in diameter) mounted on a wooden base (18 cm wide x 31 cm long) with screws for stability. The layout of the cylinder task is depicted in Figure A.

All subjects were tested in their owners' homes and given a brief period to habituate to both the apparatus and my presence before the experiment commenced. During this habituation period, the cylinder was placed on the floor to allow the subject to investigate the apparatus. While the subject habituated, I briefly described the task to the owner to allow him/her to properly facilitate data collection. Habituation was considered achieved when the subject willingly approached me without solicitation.

The cylinder task consists of a familiarization phase and a testing phase. During the familiarization phase, subjects learn to retrieve a treat from an opaque cylinder. Rather than using two different apparatus, I used a piece of black craft paper to occlude the subject's view of the treat after the cylinder was baited during the familiarization phase. At the start of the familiarization phase, I assumed a kneeling position approximately 40 cm behind the apparatus while the owner held the subject gently by the collar 1.5 m from the cylinder. Each trial began with my getting the subject's attention by calling its name and showing it a treat. While the subject watched, I placed the treat in one end of the cylinder (counterbalanced across subjects), then said "okay," at which point the owner released the subject. In the event that the subject looked away during baiting, I recaptured its attention by calling its name again. If the subject's muzzle entered either side of the apparatus within 30 s of being released, a correct response was recorded and the subject was permitted to eat the treat and receive verbal praise. If the subject's muzzle first touched any other part of the apparatus (e.g., the front or the top),

an incorrect response was recorded and the treat was removed from the apparatus to prevent the subject from consuming it. Finally, if the subject failed to make a choice within 30 s or approached me directly, a "no choice" response was recorded, at which point the owner called the subject back and the trial was repeated. Once the subject had successfully retrieved the treat on four of five consecutive trials, it was permitted approximately one minute to rest and receive attention from its owner.

During this time, I removed the black paper from the apparatus to make it transparent for the testing phase. The testing phase was identical to the familiarization phase, with the exception of the treat now being visible from the front after it was placed. In this phase, the subject must avoid approaching the food from the front, thus contacting the barrier, in favor of the "detour" learned during the familiarization phase. A total of ten test trials were conducted using the same scoring criteria as in the familiarization phase to obtain a measure of inhibitory control. The cylinder task lasted approximately ten minutes. Variables recorded for later analysis were (1) percentage accuracy across the ten test trials and (2) number of incorrect responses preceding the first correct response (i.e., perseveration).

A-Not-B Task. The A-not-B task requires subjects to avoid performing a previously-rewarded response in favor of a new, correct response and consists of a training phase and a testing phase. During the training phase, subjects learned to retrieve a treat from beneath one of three red plastic cups (13 cm in height and 10 cm in diameter). These cups were spaced 1 m apart, with the subject held in position 1.5 m

from the central cup during baiting. A treat was taped to the top of each cup to control for odor cues. The layout of the A-not-B task is depicted in Figure B.

The training phase began with me getting the subject's attention by calling its name, showing it the treat, and baiting either the left- or right-most cup (cup A). The baited cup was counterbalanced across subjects with approximately half of subjects experiencing the left cup being baited and the other half experiencing the right cup being baited. I then turned my back, at which point the owner led the subject to cup A, allowing it to overturn the cup and eat the treat. The owner then verbally praised the subject and led it back to the starting position, where it was held in place while the next trial commenced in the same fashion. When I turned my back, the owner released the subject. If the subject attempted to retrieve the treat from cup A by touching it or overturning it with its paw or nose, the owner called out "choice" and the subject was allowed to consume the treat and receive verbal praise. If the subject failed to approach cup A, the owner led it to cup A to consume the treat. This procedure was repeated until the subject immediately approached cup A upon release, at which point the subject advanced to the testing phase.

The testing phase was conducted in a manner similar to that used by Cook, Spivak, and Berns (2016). I visibly baited cup A for three consecutive trials. On the fourth trial, I visibly baited cup A, then immediately removed the treat from cup A and placed it under the cup on the opposite side of the array (cup B). After baiting cup B, I turned my back and the subject was permitted to approach the cups. When the subject touched a cup with its nose or paw, the owner called out "choice." If the subject touched

or displaced the cup covering the treat with its nose or paw, a correct response was recorded and the subject was permitted to eat the treat and receive verbal praise. If the subject touched or displaced any cup other than the one covering the treat, an incorrect response was recorded and the treat was taken from under the cup. If the subject did not touch any cup within 30 s of release, or if it approached me directly, a "no choice" response was recorded and the trial was repeated. To obtain a measure of task reliability, subjects experienced up to eight of these four-trial sequences, for a total of 32 trials. The A-not-B task lasted approximately 20 minutes. The variable recorded for later analysis was the number of incorrect responses preceding the first correct "switch" (i.e., perseveration).

Depletion Manipulation/Sit-Stay Task. This manipulation is identical to the self-control manipulation used by Miller and colleagues (2010, 2012, 2015) and was administered prior to completing the cylinder task. For the depletion condition, the owner led the subject into a room, commanded the subject to "sit" and "stay," and then left the room. The subject was visible to me and the owner via a strategically-placed video camera. Once the owner had left the room, I began tracking time with a stopwatch until ten minutes had elapsed. If the subject came out of the seated position, the owner went back into the room to get the dog back into a sit-stay, and once again left the room. I recorded a "break" whenever the subject's backside came off the floor or its torso lowered toward the floor to lay down. When ten minutes had elapsed, the owner went into the room to provide verbal praise and release the subject from the sit-stay, then led the subject into another room to habituate prior to commencing the cylinder task.

For the control condition, the owner placed an appropriately-sized kennel in the same room used for the depletion condition, or used a gate or door to keep the subject in the room if a kennel was not available. The owner led the subject into the room or kennel, closed the door, and left the room, at which point a ten-minute period commenced, timed using a stopwatch. When ten minutes had elapsed, the owner went into the room, provided verbal praise, and released the subject prior to commencing the cylinder task. Variables recorded for later analysis were (1) total number of sit-stay breaks, (2) mean interval between sit-stay breaks, and (3) time elapsed preceding the first break.

Owner Questionnaire. Upon completion of the behavioral tasks, owners completed a questionnaire relating to their dog's typical behavior and training history. The purpose of the questionnaire was to learn whether owners' reports of canine executive function relate to performance on behavioral tasks. The questionnaire included demographic information (e.g., breed, neuter status), as well as two previously-validated scales relating to attention, behavioral regulation, and impulsivity.

The Dog Attention Deficit Hyperactivity Disorder rating scale (Dog ADHD-RS) was developed to examine whether dogs could serve as valid animal models of the disorder (Vas et al., 2007). Modified from a rating scale used to assess ADHD in humans (DuPaul, 1998), the 13-item scale can be divided into two subscales: one measuring inattention and one measuring activity-impulsivity. Both reliability and construct validity of the scale have been demonstrated and replicated (Lit, Schweitzer, Iosif, & Oberbauer, 2010), and validated against genetic data (Kubinyi et al., 2012).

The Dog Impulsivity Assessment Scale (DIAS; Wright et al., 2011) was developed as an alternative to behavioral methods of testing canine impulsivity and has been validated against behavioral and physiological data (Riemer et al., 2014; Wright et al., 2012). It consists of 18-items and provides four measures: an overall measure of impulsivity as reflected by a dog's total score on the questionnaire and three distinct subscale scores relating to (1) behavioral regulation, (2) responsiveness, and (3) aggression/response to novelty. Although not common, using multiple questionnaires to assess tendency toward suboptimal behavior might provide insight regarding convergent and divergent factors relating to executive function in dogs (Kubinyi et al., 2012).

Finally, owners provided information about their dogs' training history using a scale developed by Wallis et al, (2014). This scale provides a continuous, rather than categorical (Lit et al., 2010; Marshall-Pescini et al., 2015), measure of training history and allows owners to report both frequency of training and type of formal training completed (e.g., basic obedience, agility). The full questionnaire is shown in the Appendix.

Design

The effect of depletion on inhibitory control was measured within-subjects, with two measures of cylinder task performance serving as dependent variables: Accuracy across the ten test trials and the number of test trials preceding first correct response. The former provides an overall measure of the subject's inhibitory control (Amici et al., 2008; Bray et al., 2014; Fagnani et al., 2016; MacLean et al., 2014; Marshall-Pescini et al.,

2015; Wallis, Dias, Robbins, & Roberts, 2001) and the latter is a continuous measure of perseveration (Cook et al., 2016, Fagnani et al., 2016).

In exploratory analyses, I examined how inhibitory control (in both conditions) related to other behavioral and owner-reported measures of executive function. Behavioral measures were drawn from the A-not-B task which is presumed to reflect a similar underlying process to the cylinder task, and the ten minute sit-stay, a novel and potentially useful measure of self-control or working memory (Miller 2010, 2012, 2015; Olsen, 2018). From the A-not-B task, I used the number of trials preceding first correct switch as a measure of perseveration (Cook et al., 2016). From the sit-stay task, the total number of breaks, the time interval preceding the first break, and the mean interval between breaks served as dependent measures. Owner-reported measures were subscale scores from the Dog ADHD scale and the DIAS. Specifically, the factors of Inattention, Activity-Impulsivity, Overall Impulsivity, Behavioral Regulation, Responsiveness, and Aggression/Response to Novelty served as dependent measures. Additionally, I assessed the reliability of the cylinder, A-not-B, and sit-stay tasks. Finally, I explored the influence of age and training history on behavioral and owner-reported measures of executive function.

Ethical Note

All procedures were approved by the Montana State University's Institutional Animal Care and Use Committee (Protocol # 2017-13).

Coding and Analyses

All data were analyzed using SPSS Statistics 25 (IBM Corporation). Prior to data analysis, I used the Kolmogorov-Smirnov test to assess the normality of both cylinder task accuracy and perseveration. The distribution for cylinder task accuracy was normal, D (15) = .13, $p > .05$, but perseveration was non-normal, D (15) = .22, $p < .05$. Therefore, I tested the effect of cognitive depletion by using a paired-samples *t*-test for accuracy, and a Wilcoxon signed-rank test for perseveration. Prior to quantifying the effect of depletion, I examined whether previous experience with the cylinder apparatus influenced performance. That is, did subjects show better performance during the second cylinder session, regardless of condition? To this end, I conducted a repeated-measures analysis of variance (ANOVA) with Condition (Control/Depletion) measured within-subjects and Order (Control First/Depletion First) measured between-subjects. I also tested for possible within-session learning effects for both conditions of the cylinder task and the A-not-B task. I compared accuracy (cylinder task) and perseveration (A-not-B task) from the first half of the test trials to the last half of the test trials using paired-samples *t*-tests.

To test for relationships between behavioral and owner-reported measures of executive function, I conducted Spearman correlations. Given the differences in how executive function was assessed across tasks and questionnaire items, I first *z*-transformed variables from the cylinder task, A-not-B task, sit-stay task, ADHD RS, and DIAS (see Brucks et al., 2017). This technique allows comparison of the various executive function measures on the same scale.

To examine the possible influence of age and training on the various measures of executive function, I ran linear models using age and formal training score as predictors and variables from the cylinder task, A-not-B task, and sit-stay task as outcomes. Finally, I assessed reliability of the cylinder task and the A-not-B task using Cronbach's alpha for both tasks, and intraclass correlation between the control and depletion conditions of the cylinder task. For the sit-stay task, I assessed the split-half reliability using the Spearman-Brown formula.

Results

I recruited seventeen subjects for Experiment 1. One subject refused to approach me or the apparatus upon arrival to the home, and another contracted giardiasis before all three visits were completed. These subjects were omitted, and analyses were performed on 15 subjects of various breeds, ages (*range* = 2.5 – 9 years, *M* = 5.4), and formal training score (*range* = 0 – 27, *M* = 6.5). Demographic information of subjects used in Experiment 1 are displayed in Table 1.1. Descriptive statistics for behavioral and owner-reported variables are displayed in Table 1.2. All effects and relationships described as significant were associated with an alpha level of .05 unless otherwise reported.

Effect of Depletion on Cylinder Task Performance

Subjects demonstrated no practice effects from the first cylinder test session to the second. Although accuracy was lowest for subjects completing the depletion condition first, planned comparisons indicated that accuracy under depletion did not differ reliably between the two order conditions. These observations were supported by the absence of

an Order effect or Order x Condition interaction (Fs < 2.72, ps > .13). This pattern is displayed in Figure 1.1. I found no evidence for within-session learning effects for either condition in the cylinder task (ts < 1.98, ps > .06) or the A-not-B task (t < 1, p > .37).

Ten of the 15 subjects showed the predicted depletion effect, with accuracy lower following in the depletion condition than the control condition. However, this difference was only marginally significant, t (14) = 1.68, p = .06, r = .41. Perseveration did not differ reliably between the two conditions, T = 4, p = .39, r = -.16. Patterns of accuracy and perseveration are shown in Figure 1.2.

Relationships Between Behavioral and Owner-Reported Variables

Cylinder Task. The correlation matrix for all dependent measures appears in Table 1.2. Subjects with higher accuracy in the cylinder task following depletion waited less time between sit-stay breaks and committed their first break earlier in the depletion manipulation. These observations were supported by negative correlations between cylinder task accuracy following depletion and mean interval between sit-stay breaks (r_s = -.52) and time elapsed preceding the first sit-stay break (r_s = -.54) and are shown in Figure 1.3 (graphs *a* and *b*). Also, in both conditions, cylinder task accuracy was positively associated with Inattention subscale scores, such that subjects with higher cylinder task accuracy were reported to be more inattentive by their owners (control: r_s = .52; depletion: r_s = .62). These relationships are depicted in Figure 1.3 (graphs *c* and *d*).

A-Not-B Task. One subject with an A-not-B *z*-score of 2.9 was omitted from this set of correlational analyses as an outlier.[6] Regardless of Condition, neither accuracy nor perseveration in the cylinder task was correlated with mean perseveration in the A-not-B task (ps > .28). However, perseveration in the A-not-B task was related to two owner-reported measures, Behavioral Regulation (r_s = -.56), and Responsiveness (r_s = -.59), such that subjects that perseverated more during the A-not-B task were reported to be less behaviorally regulated and less responsive than subjects showing less perseveration. These relationships are depicted in Figure 1.4.

Sit-Stay Task. Subjects who committed more breaks during the 10-minute sit-stay were rated by their owners as low in Behavioral Regulation and Responsiveness. Subjects who waited for shorter intervals between sit-stay breaks were rated by their owners as being high in Inattention. These observations were supported by correlations between the total number of breaks committed and both Behavioral Regulation (r_s = -.56) and Responsiveness (r_s = -.59), and between mean break interval and Inattention (r_s = -.70). These relationships are depicted in Figure 1.5.

Influence of Age and Training History on Executive Function

To learn whether performance on the behavioral tasks was influenced by age or formal training, I ran separate linear models for each dependent measure. Age was not associated with performance on any of the behavioral tasks (*p*s > .07). When analyzing

[6] Inclusion of this subject in the analysis did not qualitatively alter correlations between A-not-B perseveration and other measures. Specifically, OQS and behavioral regulation remained significant (*r*s of .61 and .64, respectively), responsiveness became marginally significant (*rs* =.-.51, *p* = .053), and mean break remained negative, but was no longer significant (*r*s = -.39, *p* = .15).

the effect of training, one subject was omitted as an outlier due to having a significantly higher training score than the other subjects. Surprisingly, in the depletion condition, training was negatively related to cylinder task accuracy (LM: β = -4.5, *SE* = 1.6, *t* = -2.8, $p < .05$, unstandardized) and positively related to perseveration (LM: β = 0.4, *SE* = 0.1, *t* = 2.6, $p < .05$, unstandardized). These relationships are depicted in Figure 1.6.

Reliability of Behavioral Tasks

Performance on the cylinder task was highly reliable in both control (Cronbach's $\alpha = .92$) and depletion conditions (Cronbach's $\alpha = .86$). The cylinder task also showed excellent test-retest reliability, with an intraclass correlation of .78 with a 95% confidence interval from .33 to .92, $F(14, 14) = 4.44$, $p < .01$. Because some subjects did not complete all eight A-not-B sequences, I used the method recommended by Weaver and Maxwell (2014) to estimate the task's reliability when taking into account missing data. The A-not-B task demonstrated poor reliability (Cronbach's $\alpha = .59$).

To estimate reliability for the sit-stay task, I calculated the number of sit-stay breaks during each minute interval during the 10-minute period. Next, I calculated the split-half reliability using the Spearman-Brown coefficient. The split-half reliability was acceptable ($\rho = .78$), suggesting stability of the measured construct across the course of the task.

Post-Hoc Analysis

It was surprising that the predicted depletion effect failed to reach significance, given observations during data collection. Specifically, two-thirds of the sample showed

lower performance following the sit-stay than being in a room alone (i.e., a "depletion effect"). Further, subjects committing more breaks tended to exhibit higher performance than subjects better able to hold the sit-stay without repeated reminders. These observations were borne out in the statistical data; subjects with less time between breaks, and those who committed their first break early, tended to have higher accuracy than other subjects.

Given these observations, the amount of depletion subjects experienced should be influenced by the amount of self-control exerted during the sit-stay task. Self-control exertion is an effortful, metabolically-taxing process, and can reduce performance on a subsequent, demanding task (Baumeister, 2014; Miller et al., 2010, 2012). Thus, this depletion manipulation is only effective if subjects actually engage in self-control during the sit-stay period. If engaging self-control and working on difficult tasks both rely on the same limited resource, as researchers suggest, then the amount of that resource consumed during self-control exertion should direct relate to the availability of that resource during the task that follows. In the context of Experiment 1, I would therefore expect that a subject's performance in the depletion condition would suffer only to the extent that it engaged self-control during the sit-stay.

To test this hypothesis, I re-examined the effect of the depletion manipulation on accuracy, taking into account self-control exertion during the sit-stay using a mixed ANOVA with Condition (Control/Depletion) measured within-subjects and number of sit-stay breaks as a covariate. In this revised model, the effect of Condition was indeed significant, with worse accuracy in the depletion condition than the control condition, *F*

(1, 13) = 6.69, $p < .05$, $\eta p^2 = .34$. The Condition x Breaks interaction was marginally significant, F (1, 13) = 3.82, $p = .073$, $\eta p^2 = .23$. Accuracy as a function of Condition and Breaks is illustrated in Figure 1.7.

Discussion

In both dogs and humans, self-control exertion reduces subsequent performance on a mentally-demanding task (Baumeister, 2014; Miller et al., 2010, 2012, 2015). In the current study, I tested whether self-control exertion reduces performance in a task presumed to measure inhibitory control, a core executive function, in dogs. Additionally, I tested whether this depletion manipulation increases the difficulty of the cylinder task to potentially reveal individual differences that have not been apparent in previous investigations (Fagnani et al., 2016; Marshall-Pescini et al., 2015).

My primary prediction was that subjects would show reduced performance on the cylinder task after engaging in a ten-minute sit-stay. Although the initial analysis showed only a marginal effect in the predicted direction, post-hoc analyses indicated that the deleterious effect of the depletion manipulation was related to the number of times a given subject broke the sit-stay. In other words, subjects exerting less self-control during the manipulation tended to show smaller (or absent) depletion effects, whereas subjects that maintained the sit-stay showed larger depletion effects. When statistically controlling for the number of sit-stay breaks a dog committed, a main effect of condition was revealed, such that subjects showed worse performance in the depletion condition

than the control condition. This suggests that the cylinder task reflects, at least in part, an effortful process that is disrupted by earlier self-control exertion.

I also expected to find that increased difficulty in the cylinder task would make it a more valid measure of inhibitory control, leading to a stronger correlation with A-not-B task performance. Despite the efficacy of the depletion manipulation, no correlation between the tasks emerged. This finding is consistent with previous investigations showing no relationship between the tasks in dogs (Bray et al., 2014; Fagnani et al., 2016; Marshall-Pescini et al., 2015; but see also MacLean et al., 2016 for evidence of possible correlation between the tasks). Given the current body of evidence, there seems to be two reasonable conclusions. The first is that these tasks do not measure a similar, underlying process as researchers have proposed. The second is that they *do* test a similar process, but such a process accounts for little variance in performance across the two tasks and is undetectable with smaller sample sizes. Further, this weak relationship might be masked by the questionable reliability of the A-not-B task. Thus, a relatively large sample size would be required to find a correlation between the tasks, if one exists at all.

In exploratory analyses, I aimed to validate the three behavioral tasks – cylinder, A-not-B, and sit-stay – against two validated questionnaires used to measure qualities such as inattention, impulsivity, behavioral regulation, responsiveness, and aggression. Correlations emerged between these owner-reported measures and behavioral measures, some more intuitive than others. A-not-B perseveration was related to two measures from the DIAS: Behavioral Regulation and Responsiveness. Specifically, subjects that

had a harder time overriding a previously-rewarded, but now obsolete, response tended to be rated as having less control over their own actions and diminished responsiveness to human and environmental stimuli.

Relationships were also observed between performance during the sit-stay manipulation and owner-reported metrics. Dogs committing fewer sit-stay breaks were reported by their owners to have higher Behavioral Regulation and Responsiveness, and dogs who had shorter intervals between breaks were reported to be higher in Inattention. Additionally, I found evidence for stability in performance across the 10-minute period. Although researchers have used this manipulation as a way of examining the so-called "Baumeister effect," I used it as not only a manipulation, but also as a measure of executive function in its own right. Imposing a ten-minute sit-stay might provide a novel measure of working memory capacity; specifically, the ability of a dog to internally maintain a command over a prolonged period of time (Olsen, 2018). It could also measure inhibitory control, such that the dog must override the urge to do something more favorable (i.e., lay down, get up to find its owner) in favor of obeying its owner's command. Thus, needing fewer external reminders of the to-be-performed action might be evidence of higher working memory capacity, and possibly the ability to withhold contextually-inappropriate actions. Findings discussed above provide preliminary support for this argument.

Less straightforward was the relationship between cylinder task performance in both conditions and the owner-reported trait of Inattention. Overall, more "inattentive" subjects exhibited better performance than subjects rated low in inattention. To better

understand what might underlie these associations, I examined correlations between cylinder task performance and individual items from the Inattention subscale (all *z*-transformed). For accuracy in the control condition, a significant relationship was found with only one item ("my dog solves simple tasks easily, but has difficulties with complicated tasks"). In the context of Experiment 1, highly accurate subjects were more likely to be reported as having difficulty with complex tasks. For accuracy in the depletion condition, significant relationships were found with three items ("my dog solves simple tasks easily, but has difficulties with complicated tasks," "it's easy to get my dog's attention, but my dog loses interest quickly," and "my dog doesn't listen even if he/she knows someone is speaking to him/her"). Thus, highly accurate subjects were reported to have more difficulty with complex tasks, lose interest quickly, and willfully ignore their owners. It is currently unclear why higher scores on these items relate to higher cylinder task performance. If one accepts the premise that cylinder task performance partially reflects inhibitory control, perhaps dogs with higher inhibitory control are more "independent" workers. That is, these dogs prefer to complete tasks on their own without assistance from others (including their owners) or, if the task proves too difficult, not at all. Such a proclivity is desired in certain working dogs, such seeing-eye dogs and search and rescue dogs that work with little guidance from their handlers (see Fenton, 1992 and Tachi et al., 1978 for descriptions of "intelligent disobedience). However, this explanation is purely speculative and requires further empirical support.

Based on previous observations that dogs and humans show parallel development and decline in cognitive abilities (Mongillo et al., 2013; Tapp et al., 2003; Wallis et al.,

2014; 2016), I examined whether age influenced performance on the three behavioral tasks. No effects emerged as significant. This finding conflicts with those of Bray et al. (2014) and Wallis et al. (2014), who found reduced performance on cognitive tasks in older dogs, relative to younger dogs. However, both studies had larger samples (N = 30 and N = 44) with wider age ranges (1 – 11 years and 3 – 12.5 years, respectively) than the current experiment, which might have allowed age differences to be more perceptible. With the oldest subject in my sample being nine years old, it is possible that none of the subjects were old enough for age-related deficits in executive function to be apparent. Also relevant is the method of analysis used; I tested for a linear relationship between age and performance, whereas a quadratic relationship might have been more appropriate. Certain cognitive traits in dogs have assumed quadratic functions, including selective attention (Wallis et al., 2014)

A dog's ability to hold a sit-stay, follow human social cues, and withhold suboptimal behavior could reasonably be affected by the amount of training it has completed. Using linear models, I tested whether formal training influenced performance on the three behavioral tasks. Results indicated that more formal training was associated with worse performance on the cylinder task, but only in the depletion condition. This was true for both accuracy and perseveration. If one assumes that training can improve general cognitive ability, then the finding that formal training is a liability to inhibitory control performance, rather than an asset, is unexpected. However, training might lead to stronger reliance on the owner as a source of information regarding the task-at-hand. For example, Marshall-Pescini and colleagues (2009) found differences in human-oriented

behaviors during both solvable and unsolvable puzzle tasks between dogs without training, dogs trained for search and rescue, and dogs trained for agility competitions. Of the three groups, dogs trained for agility not only looked to a human more during both tasks, but showed a clear preference for the owner as an informant than the unfamiliar experimenter. Search and rescue dogs only referred to humans when the task was unsolvable. These results suggest that training by itself does not affect attentional allocation toward humans, but that the specific *type* of training does. For dogs trained for independent work, information-seeking might not occur until the task becomes exceedingly difficult. For dogs trained in more cooperative tasks like agility, humans (particularly owners) might be seen as essential collaborators across most tasks. When it comes to inhibitory control tasks, highly trained dogs might have a difficult time responding effectively when cooperation with humans is not an option.

Table 1.1
Demographic characteristics of subjects in Experiment 1 at the time of data collection.

Dog	Age (years)	Sex	Breed (if known)
Archer	3	NM	Doberman pincher
Axlotl	5 ½	NM	Labrador retriever
Beau	6 ½	NM	Dutch shepherd
Butters	6	NM	German shepherd
Igor	9	NM	Husky/Heeler
Kallie	4	SF	Border collie X
Kemah	5	SF	Golden retriever
Laszlo	4	NM	Husky
Missy	6	SF	Pit bull
Nuka	7 ½	NM	Border collie
Rain	7 ½	SF	Border collie X
Rex	5 ½	NM	Golden retriever
Tilly	6	SF	Terrier X
Wilson	2 ½	NM	Standard poodle
Zaidee	3	SF	Standard poodle

Note. NM = neutered male, SF = spayed female.

Table 1.2
Descriptive statistics for dependent measures in Experiment 1.

Measure	Minimum	Maximum	Mean (SE)	Std. Dev
Cylinder Task				
Familiarization trials (Control)	4	6	4.5 (0.2)	0.7
% Accuracy (Control)	0	100	71.3 (8.9)	34.6
Perseveration (Control)	0	10	1.5 (0.7)	2.6
Familiarization trials (Depletion)	4	13	5.9 (0.8)	3
% Accuracy (Depletion)	0	100	58.7 (8.6)	33.4
Perseveration (Depletion)	0	10	1.9 (0.7)	2.8
A-not-B Task				
Familiarization trials	1	1	1 (0)	0
Mean perseveration	0.1	5	1.2 (0.3)	1.3
Sit-Stay				
Number of breaks	4	25	11.9 (1.7)	6.4
Mean interval between breaks	23.3	125.8	51.4 (6.7)	25.9
Seconds elapsed to first break	1	110	35.7 (8.2)	31.7
Dog ADHD-RS				
Inattention	6	17	10.7 (0.8)	3.1
Activity-Impulsivity	6	17	12.3 (0.9)	3.6
DIAS				
Impulsivity (OQS)	0.41	0.62	0.5 (0.02)	0.08
Behavioral Regulation	0.34	0.70	0.51 (0.03)	0.11
Responsiveness	0.36	0.72	0.6 (0.02)	0.09
Aggression/Response to Novelty	0.24	0.52	0.39 (0.02)	0.08)

Note. Items on the Behavioral Regulation and Responsiveness subscales of the DIAS were reverse-scored. Thus, higher scores on these subscales indicate lower levels of the measured construct.

Table 1.3

Spearman correlations between behavioral (cylinder task, A-not-B task, and sit-stay task) and owner-reported (Inattention, Activity-Impulsivity, OQS, Behavioral Regulation, Responsiveness, Aggression/Response to Novelty) measures.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Control Acc.	1													
2. Control Persev.	-.74**	1												
3. Deplete Acc.	.6*	-.53*	1											
4. Deplete Persev.	-.25	.14	-.74**	1										
5. A-not-B	.06	-.15	.27	.01	1									
6. Sit-Stay Breaks	-.12	.14	.39	-.5	.28	1								
7. Break Interval	-.2	.13	-.52*	.44	-.39	-.72**	1							
8. First Break	-.03	-.13	-.54*	.61*	-.15	-.52*	.46	1						
9. Inattention	.52*	-.27	.62*	-.32	.26	.44	-.7**	-.36	1					
10. Act-Imp	-.07	.05	.09	.06	.37	.37	-.23	-.08	.34	1				
11. OQS	-.15	.06	.23	-.21	.61*	.48	-.14	-.10	.13	.50	1			
12. Beh. Reg.	.03	.05	.15	.02	.64**	.56*	-.41	-.09	.47	.77***	.77***	1		
13. Respons.	.35	-.33	.58*	-.35	.51	.59*	-.43	-.18	.52*	.3	.66**	.56*	1	
14. Agg/Novelty	-.36	.16	-.32	.28	-.31	.26	.1	.1	-.19	-.08	.12	.06	0	1

Note. * p = .05 or less; ** p = .01 or less; *** p = .001 or less.

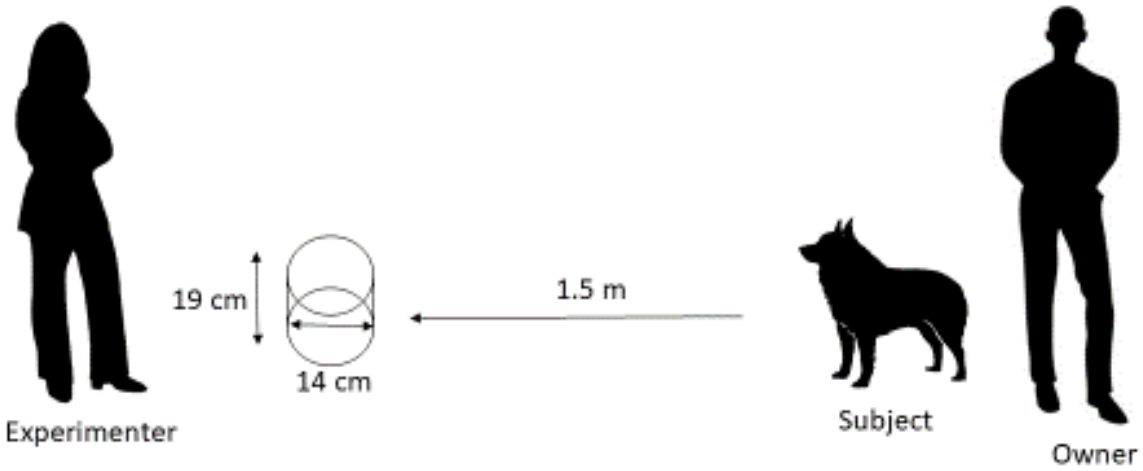


Figure A. Testing layout of the cylinder task used in Experiment 1 and Experiment 2.

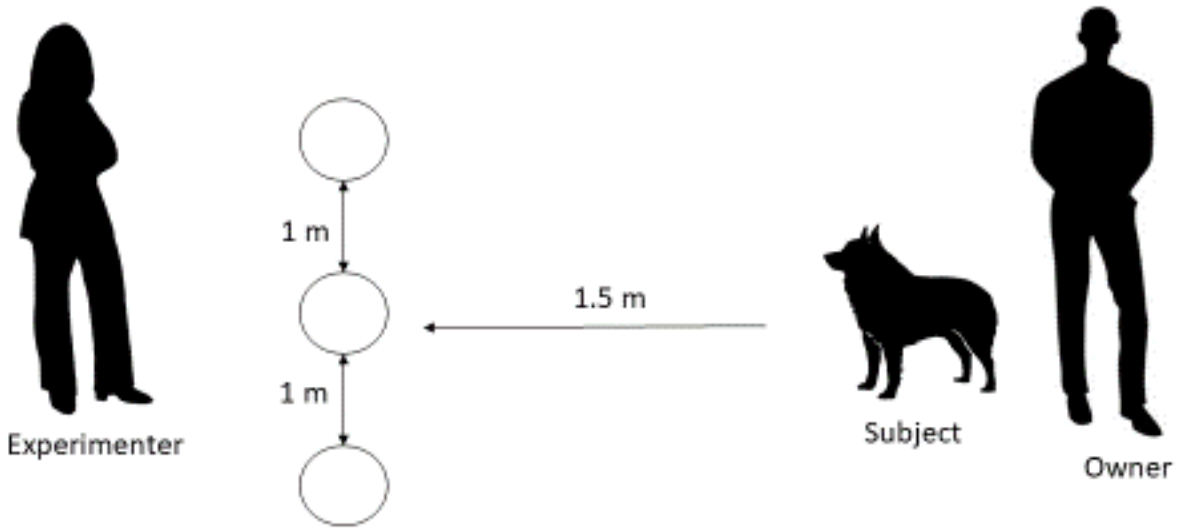


Figure B. Testing layout of the A-not-B task used in Experiment 1 and 2.

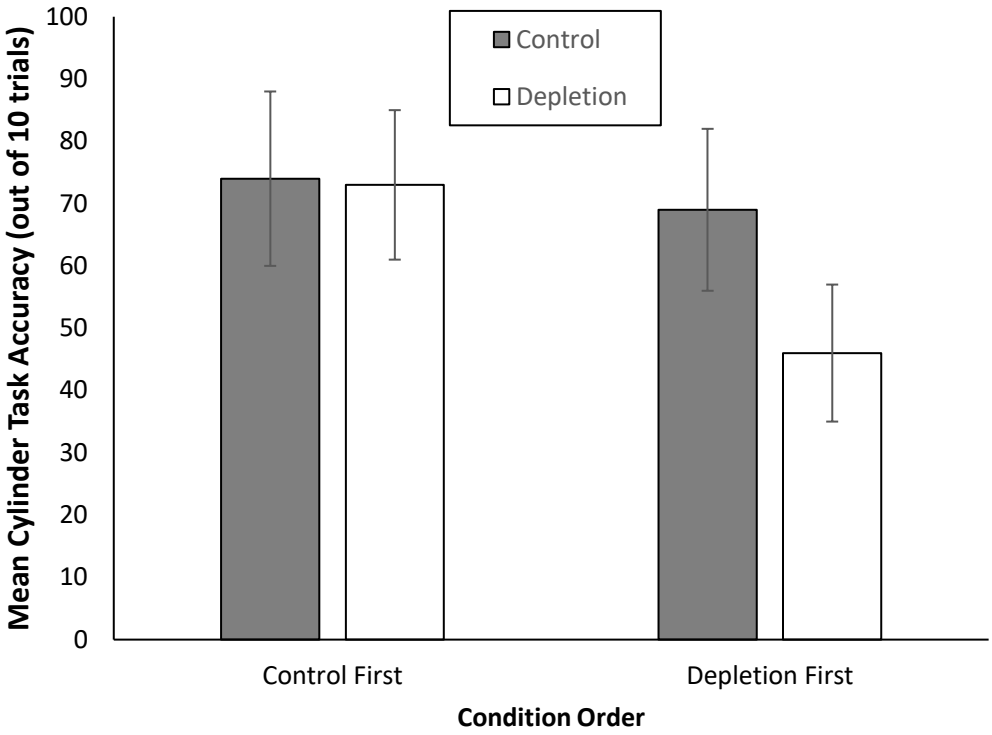


Figure 1.1. Accuracy as a function of Condition (Control or Depletion) and Order (Control first or Depletion first). Error bars represent standard error of the mean.

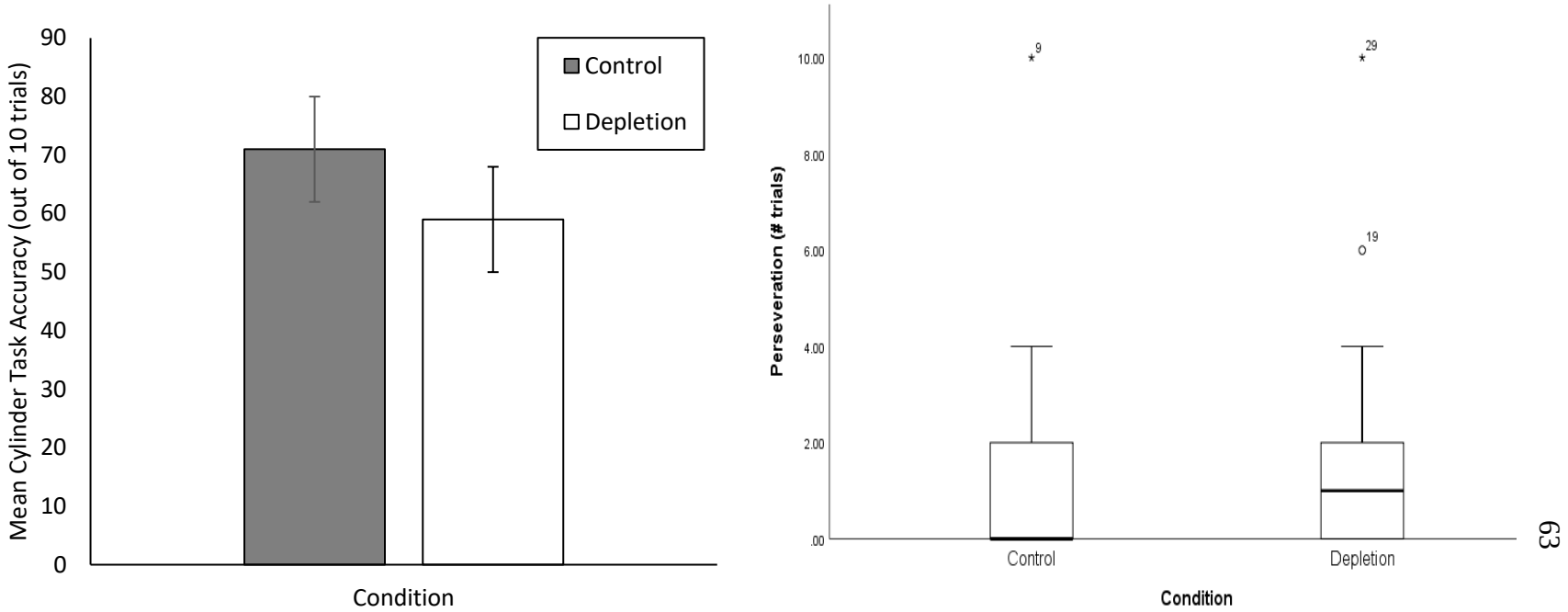


Figure 1.2. Patterns of mean Accuracy (left) and Perseveration (right) as a function of Condition. Error bars (left) represent standard error of the mean.

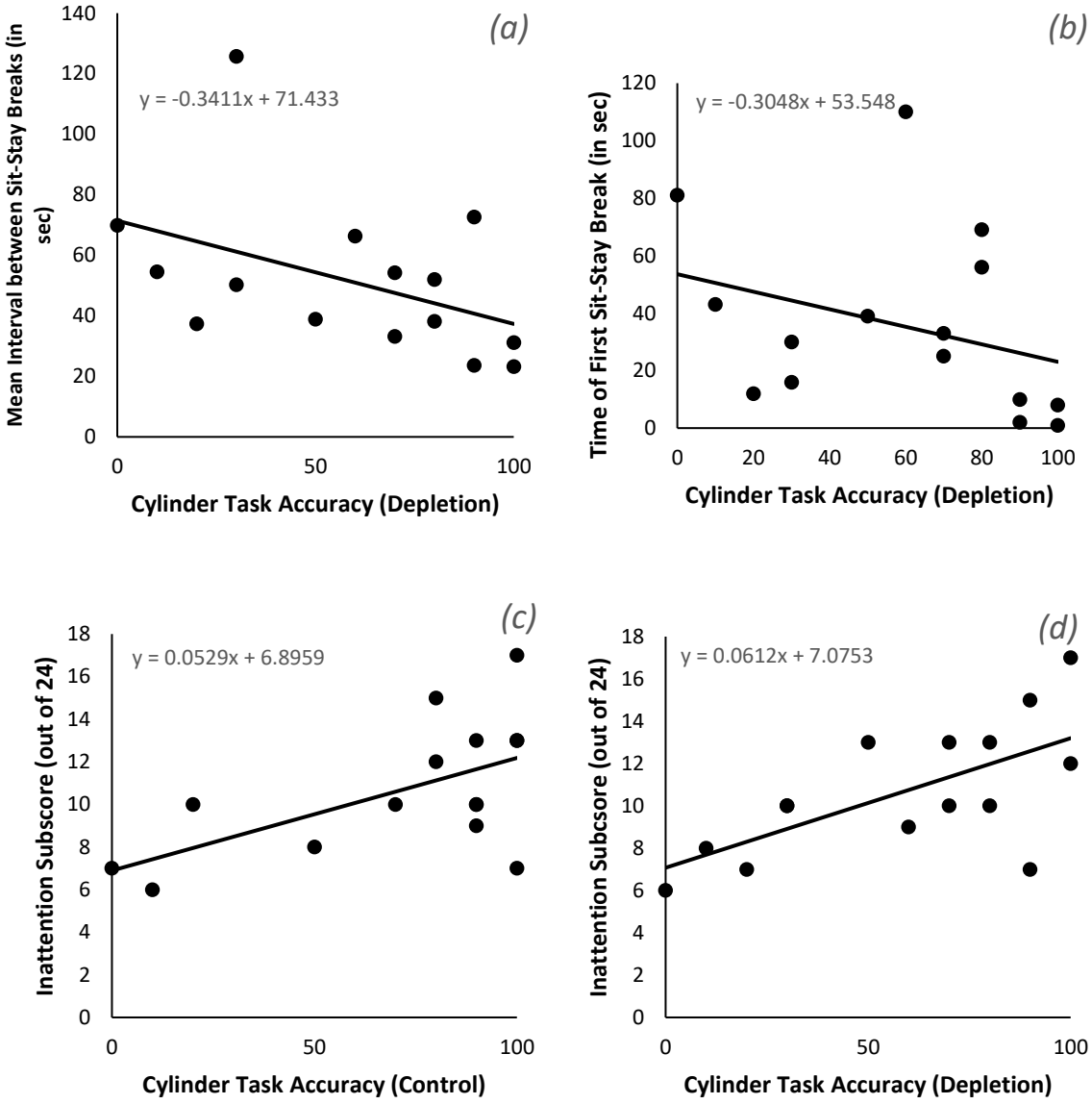


Figure 1.3. Correlations between executive function measures in Experiment 1.

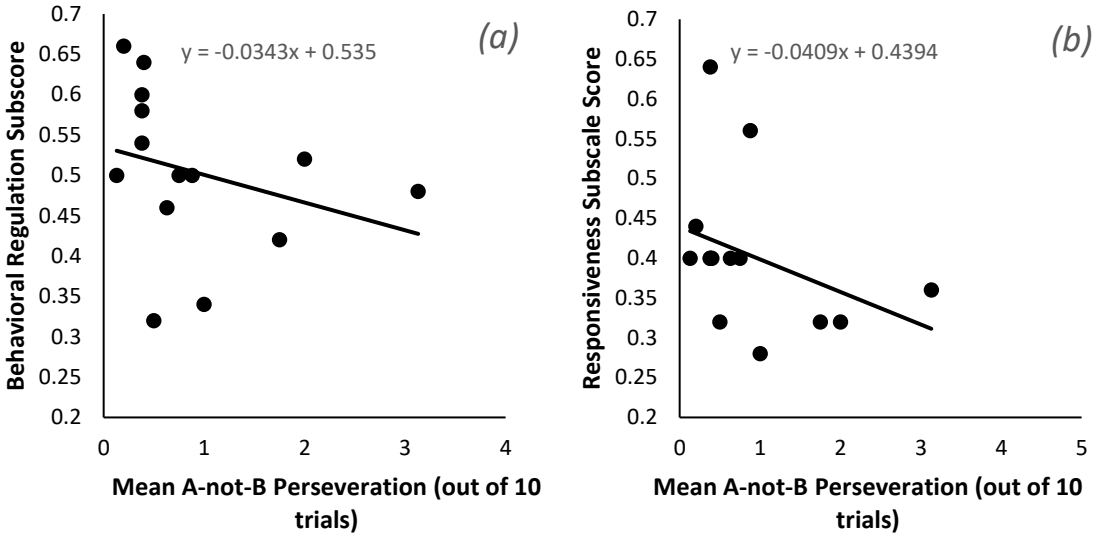


Figure 1.4. Correlations between A-not-B perseveration and Behavioral Regulation (*a*), and Responsiveness (*b*).

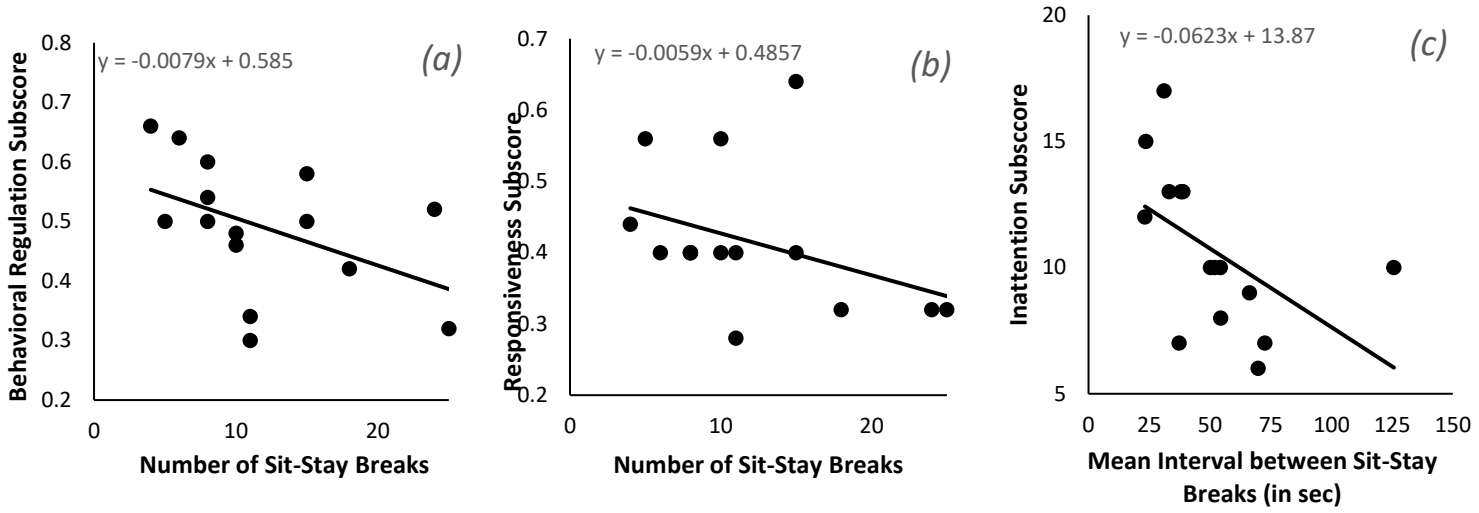


Figure 1.5. Correlations between number of sit-stay breaks and Behavioral Regulation (*a*) and Responsiveness (*b*), and between mean interval between breaks and Inattention (*c*).

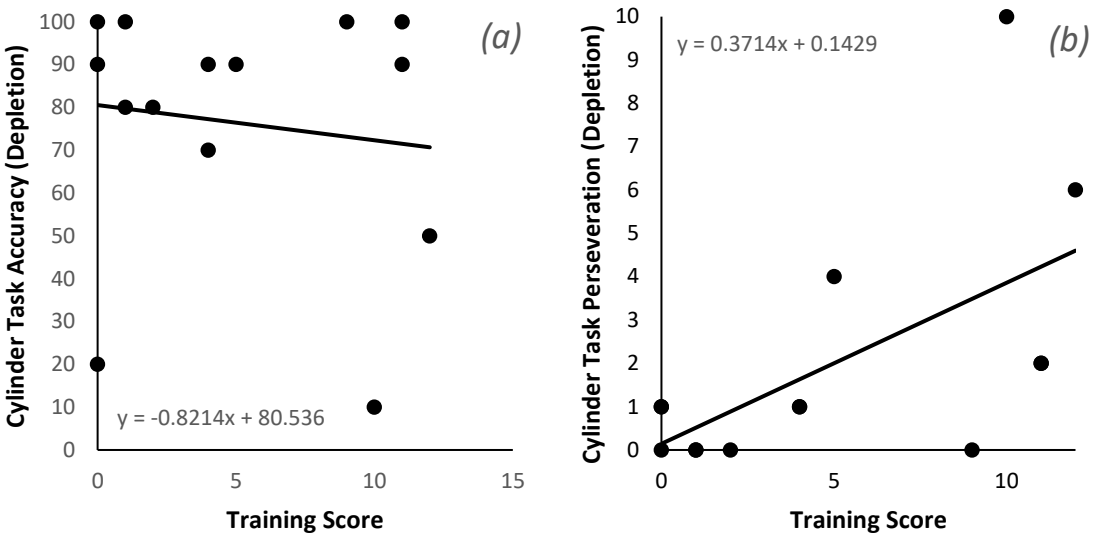


Figure 1.6. Cylinder task accuracy (*a*) and perseveration (*b*) in the depletion condition as a function of training score.

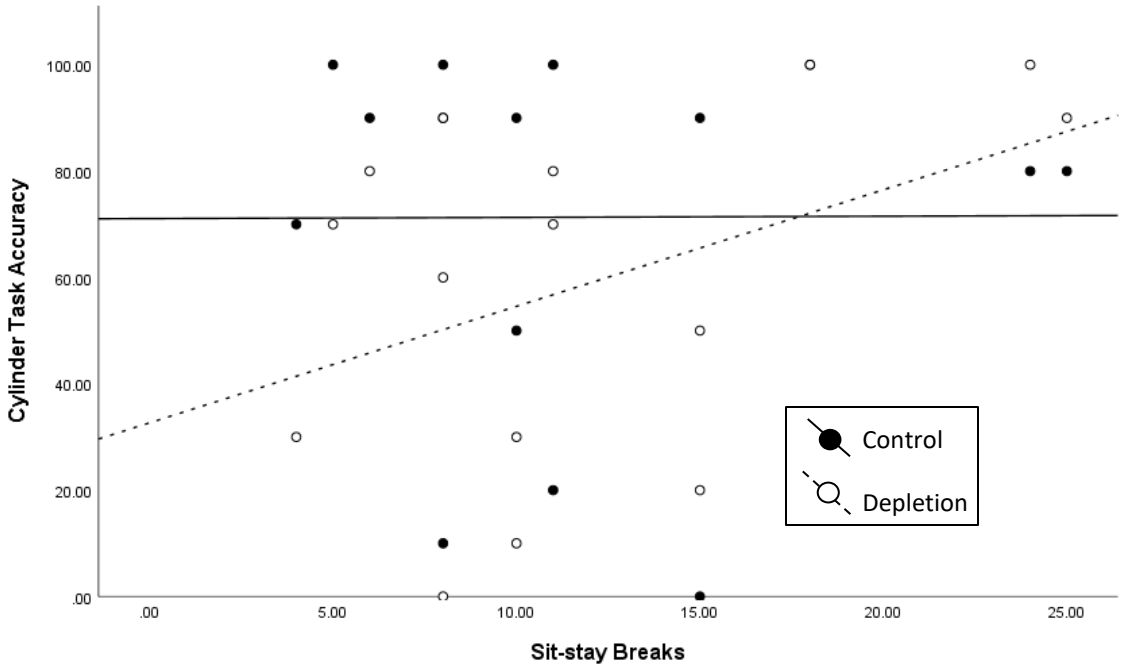


Figure 1.7. Cylinder task accuracy as a function of Condition and Number of Sit-Stay breaks.

CHAPTER SEVEN

EXPERIMENT 2: OMISSION OF FAMILIARIZATION TRIALS

In a previous investigation, Marshall-Pescini and colleagues (2015) showed that dogs attain near-ceiling performance on the cylinder task, even when familiarization (or "training") trials are omitted. Subjects who had exposure to familiarization trials showed a mean accuracy of 96%, whereas those with no exposure showed a mean accuracy of 86%. The authors suggested that the consistently high level of performance observed during the task is independent of prior experience retrieving food from a cylinder apparatus. However, this null finding has not yet been replicated. Additionally, the group receiving no familiarization trials was underrepresented compared to dogs that had (*N*s = 13 and 24, respectively). No power analysis was reported by the authors to justify the sample sizes.

The primary purpose of Experiment 2 was to learn whether omission of familiarization trials would increase the novelty of the cylinder task, making it more challenging and thus a more valid reflection of inhibitory control. I predicted that subjects exposed to familiarization trials would outperform subjects who were not. As in Experiment 1, I examined whether performance on the cylinder task was related to performance on the A-not-B task and owner-reported variables from the Dog ADHD-RS and DIAS questionnaires, and tested for the influence of age and training on task performance. Finally, I estimated the reliabilities of both tasks.

Method

Subjects

To determine the effect size of familiarization trials on cylinder task performance, I first obtained the mean accuracies and standard errors of three of the groups tested by Marshall-Pescini et al. (2015): Trained pet dogs (M = 9.8, SE = 0.1), untrained pet dogs (M = 9.4, SE = 0.3), and pet dogs tested without familiarization trials (M = 8.6, SE = 0.6). Next, I converted all SEs to SDs using the equation SD = SE ($\sqrt{n}$). This calculation yielded the following values: Trained dogs: 9.8 ± .35, Untrained dogs: 9.4 ± 1.04, No familiarization: 8.6 ± 2.17 (Mean ± SD). Because the authors' omnibus test indicated no significant differences in performance between the groups, I collapsed across training status to create one group of 24 pet dogs that had experienced the familiarization trials (9.6 ± 0.7) to compare to the 13 pet dogs of unknown training status who had not. Using Gpower, I found an effect size of .89 for the familiarization trials. A sample of 34 dogs, split between familiarization and no familiarization groups, was determined necessary to detect this sized effect with .8 power and an alpha level of .05 (one-tailed). Owners of prospective subjects completed the online pre-screening questionnaire as described in Experiment 1, and the same omission criteria were used to ensure subject comfort and human safety.

Procedure

Following acceptance to the study, subjects were randomly assigned to either the "familiarization" group or "no-familiarization" group using a random number generator. Subjects completed the cylinder task in the same manner described in Experiment 1 with two exceptions: (1) the depletion manipulation that preceded the cylinder task was omitted and (2) subjects in the no-familiarization group completed a filler activity (inplace of the familiarization phase) prior to the testing trials. In this filler task, the owner held the subject in place approximately 2 m from me as I assumed a kneeling position facing the subject. I got the subject's attention by calling its name, showed it a treat, and placed the treat on the floor. I then made eye contact with the owner and said "okay," at which point the owner released the subject, allowing it to obtain and consume the treat. This sequence was repeated for five "trials." After the filler task, the subject had a rest break to interact with its owner for approximately one minute before beginning the test trials.

On a separate visit, subjects completed the A-not-B task as described in Experiment 1. Task order was counterbalanced across subjects, such that approximately half completed the A-not-B task first and half completed the cylinder task first. On the final visit, owners completed the questionnaire described in Experiment 1.

Design

The effect of experience (familiarization vs no familiarization) with the cylinder apparatus was measured between-subjects. As in Experiment 1, the main dependent variables were cylinder task accuracy and the number of test trials preceding the first

correct response (perseveration). Relationships were examined between behavioral (cylinder and A-not-B performance) and owner-reported measures (inattention, activity impulsivity from the ADHD questionnaire and overall impulsivity, behavioral regulation, responsiveness, and aggression/response to novelty from the DIAS). Finally, I examined the associations of age and training history with measures of executive function.

Ethical Note

All procedures were approved by the Montana State University's Institutional Animal Care and Use Committee (Protocol # 2017-13).

Coding and Analyses

All data were analyzed using SPSS Statistics 25 (IBM Corporation). Prior to data analysis, I used the Kolmogorov-Smirnov test to assess the normality of both cylinder task accuracy and perseveration. The distribution for cylinder task accuracy was normal for both no familiarization [D (18) = .12, $p > .05$] and familiarization groups [D (16) = .18, $p > .05$]; however, perseveration was non-normal for both groups [D (18) = .32, $p < .001$ and D (16) = .27, $p < .01$, respectively]. Therefore, I tested the effect of familiarization trials by using an independent-samples *t*-test for accuracy, and a Mann-Whitney U test for perseveration. I also tested for within-session learning effects in both tasks. I compared accuracy (cylinder task) and perseveration (A-not-B task) from the first half of the test trials to the last half of the test trials using paired-samples *t*-tests. Learning effects in the cylinder task were examined separately for the two groups.

Exploratory analyses examining relationships between behavioral and owner-reported measures of executive function were conducted using Spearman correlations. All dependent measures from the cylinder task, A-not-B task, and questionnaires were *z*-transformed prior to analysis. I assessed the possible influence of both age and training on executive function by running linear models using age and formal training score as predictors and variables from the cylinder task and A-not-B task as outcomes. Finally, I assessed reliability of the cylinder task and the A-not-B task using Cronbach's alpha for both tasks.

Results

I recruited 36 subjects for Experiment 2. One subject refused to approach me or the apparatus upon arrival to the home and another contracted giardiasis before all three visits were completed. These subjects were omitted and analyses were performed on 34 subjects of various breeds, ages (*range* = 12 weeks – 14 years, *M* = 54.2 years), and formal training score (*range* = 0 – 28, *M* = 9.1). Demographic information of subjects used in Experiment 2 are displayed in Table 2.1. Descriptive statistics for behavioral and owner-reported variables are displayed in Table 2.2.

Effect of Familiarization Trials on Cylinder Task Performance

As predicted, subjects in the no familiarization group were less accurate during the cylinder task (*M* = 42%, *SE* = 7%) than subjects that had experienced familiarization trials (*M* = 63%, *SE* = 7%), $t(32) = -2.14$, $p < .05$ (one-tailed). There was also a trend toward greater perseveration in the no familiarization group (*Mdn* = 1.5) than the

familiarization group (*Mdn* = .5), but this tendency was only marginally significant, Mann-Whitney $U = 100$, $n^1 = 18$, $n^2 = 16$, $p = .06$. Patterns of accuracy and perseveration are shown in Figure 2.1.

Relationships Between Behavioral and Owner-Reported Variables

No Familiarization Group. No correlations were observed between cylinder task performance and A-not-B task performance (*p*s > .31), or between behavioral task performance and owner-reported measures (*p*s > .10). Correlations between behavioral and owner-reported measures in the No Familiarization group are shown in Table 2.3.

Familiarization Group. Consistent with Experiment 1, no correlation was observed between cylinder task performance and A-not-B task performance (*p*s > .21). Performance on these tasks did not correlate with any of the owner-reported variables (*p*s > .09). The correlations for behavioral and owner-reported variables in the familiarization group is shown in Table 2.4.

Influence of Age and Training History on Executive Function

Neither Age nor Training significantly influenced performance during the cylinder and A-not-B tasks. This was true for subjects in both the Familiarization group (*p*s > .11) and No Familiarization group (*p*s > .17).

Reliability of Cylinder and A-not-B Tasks

Reliability of task performance was acceptable for subjects in both No Familiarization and Familiarization groups (Cronbach's α =.79 and .70, respectively). The A-not-B task demonstrated questionable reliability (Cronbach's α = .54).

Discussion

My second experiment examined whether removing familiarization trials from the classic cylinder task paradigm would increase its difficulty. I predicted that subjects deprived of familiarization trials would show lower accuracy and greater perseveration relative to subjects experiencing familiarization trials. My secondary prediction was that, relative to subjects in the "familiarization" group, cylinder task performance for subjects in the "no familiarization" group should correlate more strongly with A-not-B task performance.

My first prediction was partially confirmed, with omission of familiarization trials leading to lower accuracy; however, perseveration did not differ between the groups. These results conflict with those of Marshall-Pescini et al. (2015), who showed high cylinder task performance across all groups, even when subjects did not have practice retrieving treats from the cylinder apparatus. My data indicate that cylinder task accuracy partially reflects previous experience with the apparatus. Specifically, in learning to retrieve treats from the opaque apparatus, dogs appear to learn the rules of the task that are subsequently transferred to their interaction with the transparent apparatus.

Therefore, cylinder task performance at least partly reflects the ability to transfer rules between two similar apparatus.

I found no evidence supporting my secondary hypothesis. Regardless of group, cylinder task performance did not correlate with A-not-B task performance. This replicates the finding in Experiment 1 and is consistent with results from previous investigations of canine inhibitory control (Bray et al., 2014; Fagnani et al., 2016). However, I was not able to replicate relationships observed between behavioral and owner-reported variables. Correlations found in Experiment 1 might have been due to demographic or performance differences between the samples. In particular, working breeds (e.g., collies, retrievers, and huskies) were more highly represented in Experiment 1 than Experiment 2. Thus, observed patterns in Experiment 1 might pertain only to certain types of dogs and, whether intuitive or not, should be interpreted with caution.

Finally, despite having a wider age range than in Experiment 1, I observed no effects of age on executive function. Again, this might be due to testing for a linear trend rather than a quadratic trend. I was also unable to replicate the negative influence of training on cylinder task performance found in Experiment 1.

Table 2.1
Demographic characteristics of subjects in Experiment 2 at the time of data collection.

Dog	Age	Sex	Breed (if known)
Althea	1 ½ y	SF	Old English bull dog
Bailey	7 y	SF	Red heeler X
Boomer	4 mo	NM	Labrador retriever
Cash	3 y	NM	German shepherd/Husky X
Colton	1 y	IM	Swiss mountain dog
Disket	10 y	SF	German shepherd/Husky X
Dixie	3 y	SF	Labradoodle
Dottie	4 y	SF	Dalmatian/Blue heeler X
Gypsy	1 ½ y	SF	Australian shepherd
Harley	4 y	SF	Blue heeler X
Huxley	3 ½ y	NM	Old English sheep dog
Indy	13 y	SF	Bichon fries
Jarvis	4 y	NM	Border collie X
Juno	2 y	NM	Golden retriever
Kasey	6 y	SF	Border terrier
Loki	4 y	NM	Doberman pincher
Luna	3 y	SF	German shepherd/Husky X
Maddie	6 y	SF	Border collie X
Moose	3 y	NM	Shi Tzu/Chihuahua X
Odin	1 y	IM	Great Dane
Otis	2 y	NM	Miniature Schnauzer/poodle X
Pepper	2 y	SF	French bulldog
Petunia	3 mo	IF	Corgi
Peyton	3 y	SF	PBT X
Raisin	1 ½ y	IM	American Staffordshire terrier
Rani	8 y	SF	Brussels griffon
Roscoe	2 y	NM	Shi Tzu
Sancho	14 y	NM	Poodle X
Stella	2 y	SF	Shiba inu X
Teddy	2 y	NM	Norwegian elkhound/Shepherd X
Yupik	3 mo	IM	Newfoundland
Zee Top	11 y	SF	Australian shepherd
Zoe	3 ½ y	SF	German shorthair pointer

Note. NM = neutered male, IM = intact male, SF = spayed female, IF = intact female.

PBT = pit bull type.

Table 2.2
Descriptive statistics for dependent measures in Experiment 2.

Measure	Minimum	Maximum	Mean (SE)	Std. Dev
Cylinder Task				
% Accuracy (No Familiarization)	0	100	42.2 (7.2)	30.4
Perseveration (No Familiarization)	0	10	2.3 (0.7)	3.2
% Accuracy (Familiarization)	20	90	63.1 (6.5)	26
Perseveration (Familiarization)	0	4	0.8 (0.3)	1.1
A-not-B Task				
Familiarization trials	1	2	1.1 (0.1)	0.3
Perseveration	0	5	1.1 (0.2)	1.3
Dog ADHD-RS				
Inattention	2	21	10.6 (0.7)	4.3
Activity-Impulsivity	5	20	12.1 (0.6)	3.5
DIAS				
Impulsivity (OQS)	0.34	0.61	0.51 (0.01)	0.07
Behavioral Regulation	0.30	0.74	0.50 (0.02)	0.12
Responsiveness	0.44	0.72	0.55 (0.01)	0.07
Aggression/Response to Novelty	0.28	0.64	0.41 (0.01)	0.08

Note. Items on the Behavioral Regulation and Responsiveness subscales of the DIAS were reverse-scored. Thus, higher scores on these subscales indicate lower levels of the measured construct.

Table 2.3

Spearman correlations between behavioral (cylinder task and A-not-B task) and owner-reported (Inattention, Activity-Impulsivity, OQS, Behavioral Regulation, Responsiveness, Aggression/Response to Novelty) measures for subjects in the No Familiarization group.

	1	2	3	4	5	6	7	8	9
1. Cylinder Acc.	1								
2. Cylinder Persev.	-.69**	1							
3. A-not-B	-.25	-.08	1						
4. Inattention	.14	-.04	.20	1					
5. Act-Imp	-.15	.32	.25	.50*	1				
6. OQS	.01	.05	.40	.81**	.70**	1			
7. Beh. Reg.	.01	.08	.39	.81**	.74**	.99**	1		
8. Respons.	.30	-.30	.24	.45	-.10	.29	.29	1	
9. Agg/Novelty	.16	-.13	.11	-.08	.23	.12	.07	-.25	1

Note. * p = .05 or less; ** p = .01 or less.

Table 2.4

Spearman correlations between behavioral (cylinder task and A-not-B task) and owner-reported (Inattention, Activity-Impulsivity, OQS, Behavioral Regulation, Responsiveness, Aggression/Response to Novelty) measures for subjects in the Familiarization group.

	1	2	3	4	5	6	7	8	9
1. Cylinder Acc.	1								
2. Cylinder Persev.	-.53*	1							
3. A-not-B	-.33	-.07	1						
4. Inattention	.14	.11	.36	1					
5. Act-Imp	.05	-.13	.25	.65**	1				
6. OQS	.27	-.21	-.15	.43	.44	1			
7. Beh. Reg.	.09	-.07	-.14	.60*	.56*	.92**	1		
8. Respons.	.32	-.23	.37	.07	.10	-.01	-.22	1	
9. Agg/Novelty	.38	-.43	.06	-.19	.02	.26	-.01	.17	1

Note. * p = .05 or less; ** p = .01 or less.

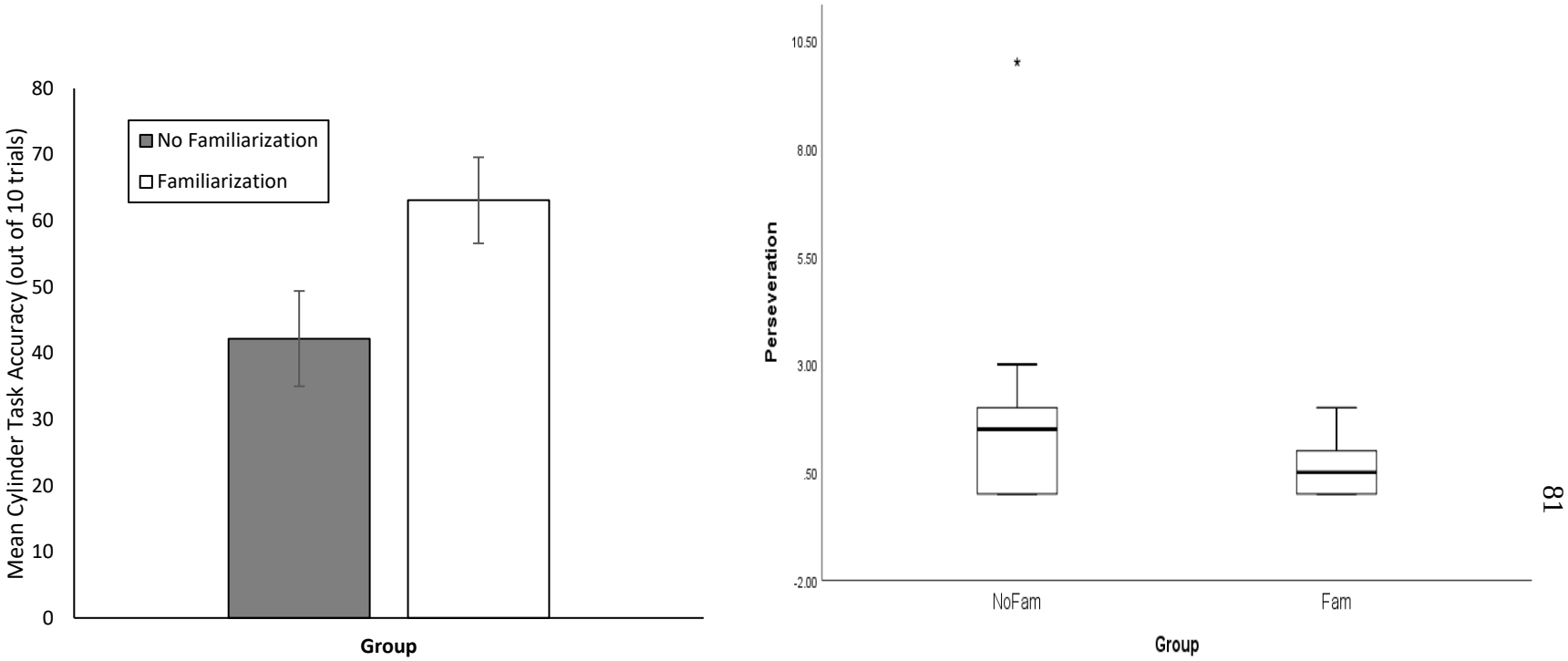


Figure 2.1. Patterns of mean Accuracy (left) and Perseveration (right) as a function of Group. Error bars (left) represent standard error of the mean.

CHAPTER EIGHT

POOLED ANALYSIS

Given the procedural similarity between the control condition in Experiment 1 and the familiarization group in Experiment 2, I conducted one final analysis to increase statistical power and conduct exploratory analyses. Cylinder task accuracy did not differ between the control condition in Experiment 1 and the familiarization group in Experiment 2, (t (29) = .75, p = .50). Thus, data were pooled resulting in a sample of 31 subjects.

Cylinder and A-Not-B Task Performance

Cylinder task accuracy was negatively skewed and ranged from 0 to 100%. The mean accuracy for the pooled sample was 67% (*SE* = 5%), which is similar to performance in Bray et al.'s (2014) experiment. Perseveration for both the cylinder task was positively skewed, ranging from zero to ten trials. Finally, A-not-B task performance was positively skewed, ranging from zero to five trials.

Relationships Between Behavioral and Owner-Reported Measures

As with Experiments 1 and 2, I found no correlation between the cylinder task and the A-not-B task. Cylinder task accuracy was significantly correlated with

Inattention (r_s = .37) and Responsiveness (r_s = -.39). A-not-B perseveration was correlated with Responsiveness (r_s = -.40).[7]

Task Reliability

I estimated the reliability of both cylinder and A-not-B tasks using Cronbach's alpha. Again, I utilized the method suggested by Weaver and Maxwell (2014) to estimate reliability of the A-not-B task with missing data. The cylinder task demonstrated high reliability (α = .83), whereas the A-not-B task demonstrated questionable reliability (α = .65).

Influence of Age and Training History

Finally, I examined the influence of age and training on cylinder task and A-not-B task performance. Age did not influence task performance (*p*s > .20), but training had a negative influence on cylinder task performance. The more training a subject had received, the lower its accuracy (LM: β = -1.8, *SE* = 0.6, *t* = -2.8, *p* < .05, unstandardized) and the greater its perseveration (LM: β = 0.1, *SE* = 0.04, *t* = 2.2, *p* < .05, unstandardized).

[7] Removing the subject previously omitted as an outlier in Experiment 1 from A-not-B correlation analyses did not significantly change the data; A-not-B perseveration remained correlated with only Responsiveness, r_s = -.41.

CHAPTER NINE

GENERAL DISCUSSION

The overarching purpose of this study was to better understand canine executive function by assessing the reliability and construct validity of two popular canine inhibitory control tasks. Overall, the data indicated that the cylinder task holds more promise as a measure of canine executive function than the A-not-B task. Consistent with previous research, I was unable to find any correlation between the two tasks, likely due to low reliability and construct validity of the A-not-B task. However, the sit-stay manipulation might be a useful addition to future task batteries. Taken together, results from these experiments can inform future explorations into canine executive function.

The Cylinder Task

In previous studies, dogs have performed exceptionally high during the cylinder task, with mean accuracy ranging from 70% to 98% (Bray et al., 2014; MacLean et al., 2014; Marshall-Pescini et al., 2015; Fagnani et al., 2016). The primary purpose of both my experiments was to test whether modified forms of the task would attenuate these ceiling effects. However, no ceiling effects emerged, even in the control conditions with mean accuracy ranging from 63% (Experiment 2) to 71% (Experiment 1).

Why was performance so low in the current study relative to previous investigations? One explanation could be that the cylinder task measures a characteristic that can vary drastically across individuals. Previous researchers have shown evidence

for such individual differences in inhibitory control (Cook et al., 2016, Riemer et al., 2014; Wright et al., 2012). An even more likely explanation relates to the qualities of my cylinder apparatus. Although my procedure was identical to those used in previous studies, the apparatus itself was smaller in terms of both length and diameter. The smaller diameter in particular likely made the task more challenging by increasing the effort needed to retrieve the treat from either side of the apparatus. Importantly, this modification did not prevent successful performance; dogs as small as Shi Tzus and as large as Great Danes were able to retrieve treats from the cylinder. Fagnani et al. (2016) proposed apparatus modification as a means of addressing ceiling effects, and the overall reduced performance in the current study is supportive of their idea.

Results from Experiment 1 suggest that the cylinder task indeed measures an effortful process, as accuracy suffered following self-control exertion. Importantly, the reduction in inhibitory control performance was related to the amount of self-control exerted during the sit-stay manipulation. This is conceptually consistent with classic limited-resource accounts of self-regulation (Gilbert, Krull, & Pelham, 1988; Hagger, Wood, Stiff, & Chatzisarantis, 2010; Muraven, Tice, & Baumeister, 1998, but see also Inzlicht & Schmeichel, 2012). Although there was no evidence of learning across the ten test trials in either experiment, data from Experiment 2 indicate that accuracy relies partly on having learned to properly retrieve treats from the apparatus. That is, dogs are able to transfer the treat acquisition strategy learned during familiarization to subsequent test trials, which are more difficult given the new visual salience of the treat. Importantly, the

cylinder task demonstrated high reliability across both experiments suggesting that it measures, at least partly, a stable ability in dogs.

In future studies researchers should consider modifying criteria for "correct" and "incorrect" responses. Generally, an incorrect response is recorded if a dog touches the front or top of the cylinder with a paw or snout. However, I observed some dogs in my study using their paws to manipulate the apparatus, making the open ends easier to access. Previous researchers have noticed similar behaviors, and modified coding criteria to accommodate such exploration styles. For example, Kabadayi et al. (2017) only marked touching the barrier as incorrect if the touch was oriented toward the treat. This allows for differentiation between barrier touches reflecting a direct approach, and those geared toward exploring or manipulating the apparatus.

The A-Not-B Task

In both experiments, dogs were tested on multiple switch trials in absence of human cues. Compared to the cylinder task, A-not-B task reliability was poor (Tavakol & Dennick, 2011). From both observational and statistical standpoints, performance seemed especially vulnerable to factors outside of the experimental context. Overall, my results suggest that this task has limited capability to capture individual differences in executive function, at least in dogs.

In particular, some subjects exhibited asymmetrical perseveration during the task. That is, they responded correctly on switch trials when the treat went from the left-most cup to the right-most cup, but perseverated on the right-most cup even when they had

watched as the treat was moved to the left-most cup. For example, one subject in Experiment 1 perseverated on the left-most cup for two sequences before losing motivation. This subject lived in a two-dog household, and the owner reported that, during feeding, the subject ate exclusively from a food bowl to the left of a shared water dish while the other dog ate exclusively from a bowl to the right of the water dish. The repeatedly reinforced behavior of veering to the left to receive food might conceivably have led to the observed perseveration on the left-most cup.

Although this form of perseveration only occurred in a subset of subjects, it warrants caution in future investigations, as it suggests that factors outside the experimental context can powerfully influence task performance. Smith and colleagues (1999, p. 258) leveled a similar criticism of the task, stating that A-not-B task performance is "far too fluid, too context dependent, too easily derailed by even seemingly minor changes in conditions to be a reliable indicator of some enduring structure of mind." Overall, I recommend that this task be omitted from future task batteries and replaced with a more reliable and valid assessment of canine executive function. Even if the cylinder task and the A-not-B task draw upon a similar process, it is apparent that using them in combination is not useful in assessing executive function, namely inhibitory control.

The Sit-Stay Task

Although the sit-stay manipulation has primarily been used to induce fatigue (Miller et al., 2010; 2012; 2015), it might be useful as a measure of executive function in

its own right. In line with Miller et al.'s results, I found in Experiment 1 that attempting to hold a sit-stay for ten minutes was challenging for dogs, and reduced subsequent performance on an inhibitory control task. There was also considerable variability in my subjects' ability (or willingness) to remain in a sit stay, providing evidence for individual differences in task performance. Correlational analyses showed that performance was related to owner-reported measures of behavioral regulation, inattention, and responsiveness. Specifically, dogs rated as higher in behavioral regulation and responsiveness were better able to hold the sit-stay, and dogs rated as high in inattention took frequent breaks from the sit-stay. These patterns suggest validity of the sit-stay task in measuring these constructs. However, the sample size for this experiment was small, and resulting correlations should be treated with caution. Further, I provided preliminary evidence of this task's reliability, suggesting that this task measures a stable construct that varies between dogs.

Future research could attempt to replicate the current findings with a larger sample, and further evaluate the task's reliability and validity. Additionally, I recommend modifying the dependent measures to more accurately reflect self-control exertion. Some owners had difficulty putting their dogs back into a sit-stay, taking up to a minute to get their dog back into position. This directly impacts a subject's reported performance by limiting number of sit-stay breaks and exaggerating the mean interval between breaks. Instead, researchers could report the total amount of time the dog was in the sit-stay over the ten-minute interval. Reporting the maximum amount of time

between breaks could also be used to assess impulsivity, similar to the measure reported by Reimer and colleagues (2014) in a delay-of-gratification paradigm.

Limitations

The current study contributes new insight into the cylinder and A-not-B tasks with respect to canine cognition by empirically demonstrating the strength of the former and the weaknesses of the latter. While the samples for both experiments were adequate for testing the modified cylinder paradigms, they have limited power to properly assess correlations between behavioral and owner-reported variables. Researchers should consider validating other behavioral measures using owner-report with larger samples.

Another issue that might have impacted the data was occasional owner confusion during completion of the Dog ADHD-RS. Some of the items seemed to include two different characteristics (e.g, items 1, 2, 10, and 11), and owners were uncertain in responding when one part of the statement was true to their dog (e.g., "It's easy to get my dog's attention…"), but the other wasn't ("…but my dog loses interest quickly"). Future studies using this scale should modify these items for clarity.

Future Directions

In addition to extensions already mentioned, research going forward should continue assessing the reliability and construct validity of tasks used to measure canine executive function. Rigorous task development and assessment, combined with adequately-powered samples, will enhance the sensitivity of experimental designs and

permit more definitive conclusions regarding the effects of genetics, training, and environment on canine cognition. Such conclusions have practical implications for training, breeding programs, dog-specific legislation, and welfare of dogs residing in shelters (Hennessey et al., 2001; Mornement et al., 2010; 2014; Salman et al., 2000; van Rooy et al., 2014).

In particular, I propose using task batteries and latent variable analysis to test the influences of human-driven selection, types of training, and owner characteristics on canine executive function. For example, Udell et al. (2014) showed that performance on human-guided tasks is influenced by breeding, namely the intactness of the predatory sequence. The full canid predatory sequence, outlined by Coppinger and colleagues (Coppinger & Coppinger, 2001; Coppinger & Schneider, 1995), is triggered by moving prey and progresses through the following steps: (1) orientation, (2) visual tracking, (3) stalking, (4) chasing, (5) grabbing with the teeth, (6) delivering the "kill" bite, (7) dissecting, and (8) consuming. In working lines, dogs are selected for exaggerated (e.g., terriers bred to chase and kill pests) or inhibited sequences (e.g., collies trained to track and move flocks without harming them) to appropriately perform a given task. Such selection might impact executive function as well, namely inhibitory control. Based on previous research, I would predict that dogs bred for inhibited sequences, such as border collies, would perform better on inhibitory control tasks than dogs bred for the full, wild-type sequence, such as terriers.

In line with Marshall-Pescini et al. (2009), I would also expect specific forms of training to influence performance on executive function tasks. Specifically, I would

expect dogs trained for independent tasks to exhibit better inhibitory control and working memory than dogs trained to collaborate with humans. For example, dogs trained in agility likely rely more on human direction than dogs trained for search and rescue, and might rely more on exogenous, human-provided control than internally-driven control. In the context of the sit-stay task, this could manifest in more frequent breaking of the sit-stay in agility dogs than search and rescue dogs.

Finally, researchers have demonstrated the relevance of owner behavior and characteristics on dog behavior. For example, owners who use more punishment-based methods and are less consistent in administering discipline tend to have dogs that are more impulsive and aggressive than more consistent owners who use positive training methods (Arhant et al., 2010). Further, owner perceptions and characteristics shape the quality of the owner-dog relationship more than dog characteristics (Meyer & Forkman, 2014). These findings, along with many others suggest that owners play a larger role in their dogs' behavior than typically considered (Bennett & Rohlf, 2007; Jagoe & Serpell, 1996; Kubinyi, Turcsán, & Miklósi, 2009; Marinelli, Adamelli, Normando, & Bono, 2007). Future research could examine how specific owner characteristics (e.g., training methods, executive function, consistency) influence executive function in dogs.

Conclusion

The current findings indicate that the cylinder task is a reliable measure, reflecting an effortful process that can be negatively impacted by previous self-control exertion and failure of rule transfer and, therefore, that dogs display stable individual differences in

inhibitory control. The A-not-B task, in contrast, seems polluted by learning, side bias, low reliability, and previous experience outside of the experimental context. Future research on canine executive function would do well to eliminate the A-not-B task from batteries, include dependent measures from the cylinder task besides just accuracy (e.g., direction of approach, approach latency), and assess reliability and construct validity of tasks prior to inclusion in task batteries. The sit-stay task seems like a promising contender for inclusion. Such increased diligence regarding task quality can allow researchers form better theories, collect more accurate data, and help the field progress in practical endeavors such as behavioral assessment, breeding, and training.

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APPENDICES

APPENDIX A

OWNER PARTICIPATION PRE-SCREENING QUESTIONNAIRE

Study Participation

Thank you for your interest in our research! Please complete this form in its entirety and a researcher will be in contact with you shortly.

First, tell us a little about your dog.

Dog's Name: _____
Dog's Age: _____
Dog's Breed (if known): _____
How did you acquire your dog?
- Shelter/Rescue agency
- Purchased from breeder
- Other

What type of training has your dog received?
- Obedience
- Agility
- Herding
- Scent detection
- Service/therapy work
- Trained at home/no formal training
- Other

On which of the following vaccinations is your dog up-to-date?
- Parvovirus
- Canine hepatitis
- Rabies
- Distemper
- Kennel cough

Fear, Aggression, and Trainability

Please answer the following questions honestly, based on your dog's typical behavior. Less-than-perfect behavior will not disqualify your dog from the study. Your answers to these questions will help us ensure everyone's safety, as well as your dog's comfort, during the study.

For reference: 0 = never true for my dog, 1 = rarely true for my dog, 2 = sometimes true for my dog, 3 = often true for my dog, 4 = always true for my dog.

My dog acts aggressively when an unfamiliar person approaches its owner or member of the owner's family at home.

0 1 2 3 4

My dog acts aggressively when an unfamiliar person approaches its owner or member of the owner's family AWAY from the home.

0 1 2 3 4

My dog acts aggressively toward unfamiliar people visiting the home.

0 1 2 3 4

My dog acts aggressively when verbally corrected/punished by a member of the household.

0 1 2 3 4

My dog acts aggressively when a member of the household retrieves food or objects stolen by the dog.

0 1 2 3 4

My dog acts aggressively when approached by a member of the household while he or she is eating.

0 1 2 3 4

My dog acts anxious or fearful when approached directly by an unfamiliar adult male at home.

0 1 2 3 4

My dog acts anxious or fearful when approached directly by an unfamiliar adult female at home.

0 1 2 3 4

My dog acts anxious or fearful when unfamiliar people visit our home.

0 1 2 3 4

My dog acts anxious or fearful when first exposed to unfamiliar situations.

0 1 2 3 4

My dog acts anxious or fearful in response to strange or unfamiliar objects on or near the sidewalk.

0 1 2 3 4

Has your dog ever bitten a person?

Yes
No

If you answered "yes" to the previous question, please (briefly) describe the incident(s).

_____

_____

My dog can obey the "sit" command immediately.

0 1 2 3 4

My dog can obey the "stay" command immediately.

0 1 2 3 4

My dog can hold a "sit-stay" for at least two minutes.

0 1 2 3 4

My dog is motivated by food during training.

0 1 2 3 4

Owner (Your) Name: _____
Email: _____
Address: _____
Phone number: _____
Additional information or questions for the researcher:

_____

_____

APPENDIX B

CANINE BEHAVIORAL QUESTIONNAIRE

Respondent's Name: _____
Date: _____
Dog's Name: _____
Dog's Breed: _____
Dog's Age: _____ Dog's Sex: M/F Spayed/Neutered? Yes/No

Please indicate how often each statement is true for your dog. If you would like to add short notes, do so in the provided space on the last page, indicating the statement to which you are referring next to each note. **(* indicates items that are reverse-scored)**

1. My dog has difficulty learning because it is careless or can be easily distracted by other things.

Never	Rarely	Occasionally	Often	Always
0	1	2	3	4

2. It's easy to get my dog's attention, but my dog loses interest quickly.

Never	Rarely	Occasionally	Often	Always
0	1	2	3	4

3. It's difficult for my dog to concentrate on a task or play.

Never	Rarely	Occasionally	Often	Always
0	1	2	3	4

4. My dog leaves from its place when told to "stay."

Never	Rarely	Occasionally	Often	Always
0	1	2	3	4

5. My dog cannot be quiet or easily calmed.

Never	Rarely	Occasionally	Often	Always
0	1	2	3	4

6. My dog fidgets all the time.

Never	Rarely	Occasionally	Often	Always
0	1	2	3	4

7. My dog doesn't listen even if he/she knows someone is speaking to him/her.

Never	Rarely	Occasionally	Often	Always
0	1	2	3	4

8. My dog is excessive and difficult to control.

Never	Rarely	Occasionally	Often	Always
0	1	2	3	4

9. My dog loves to play and run.

Never	Rarely	Occasionally	Often	Always
0	1	2	3	4

10. My dog solves simple tasks easily, but has difficulties with complicated tasks, even if he/she knows them and has practiced them often.

Never	Rarely	Occasionally	Often	Always
0	1	2	3	4

11. My dog reacts hastily and that is why he/she cannot perform tasks.

Never	Rarely	Occasionally	Often	Always
0	1	2	3	4

12. My dog's attention can be easily distracted.

Never	Rarely	Occasionally	Often	Always
0	1	2	3	4

13. My dog cannot wait; he/she has no self-control.

Never	Rarely	Occasionally	Often	Always
0	1	2	3	4

14. My dog shows extreme physical signs when excited (e.g., drooling, panting, raising hackles, urination, licking lips, widening of eyes).

Never	Rarely	Occasionally	Often	Always
0	1	2	3	4

15. When my dog gets very excited, it can lead to fixed repetitive behavior (i.e., an action that is repeated in the same way over and over again), such as tail chasing or spinning around in circles.

Never	Rarely	Occasionally	Often	Always
0	1	2	3	4

16. I would consider my dog to be very impulsive (i.e., has sudden, strong urges to act; acts without forethought; acts without considering effects of actions).

Never	Rarely	Occasionally	Often	Always
0	1	2	3	4

17. My dog appears to be 'sorry' after it has done something wrong.

Never	Rarely	Occasionally	Often	Always
0	1	2	3	4

18. My dog does not think before it acts (e.g., would steal food without first looking to see if someone is watching).

Never	Rarely	Occasionally	Often	Always
0	1	2	3	4

19. My dog can be very persistent (e.g., will continue to do something even if it knowns it will get punished or told off).

Never	Rarely	Occasionally	Often	Always
0	1	2	3	4

20. My dog is easy to train.*

Never	Rarely	Occasionally	Often	Always
0	1	2	3	4

21. My dog is very cautious when meeting unknown dogs. (DISTRACTER)

Never	Rarely	Occasionally	Often	Always
0	1	2	3	4

22. My dog is very friendly towards strangers. (DISTRACTER)

Never	Rarely	Occasionally	Often	Always
0	1	2	3	4

23. My dog is constantly demanding attention or social interaction from people when in the home. (DISTRACTER)

Never	Rarely	Occasionally	Often	Always
0	1	2	3	4

24. My dog takes a long time to lose interest in new things.*

Never	Rarely	Occasionally	Often	Always
0	1	2	3	4

25. My dog calms down very quickly after being excited.*

Never	Rarely	Occasionally	Often	Always
0	1	2	3	4

26. My dog appears to have a lot of control over how it responds.*

Never	Rarely	Occasionally	Often	Always
0	1	2	3	4

27. My dog is very interested in new things and new places.*

Never	Rarely	Occasionally	Often	Always
0	1	2	3	4

28. My dog reacts very quickly.

Never	Rarely	Occasionally	Often	Always
0	1	2	3	4

29. My dog is not very patient (e.g., gets agitated waiting for its food or waiting to go out for a walk).

Never	Rarely	Occasionally	Often	Always
0	1	2	3	4

30. My dog often steals objects in the house (e.g., shoes, socks, remote control). (DISTRACTER)

Never	Rarely	Occasionally	Often	Always
0	1	2	3	4

31. My dog likes to play with toys. (DISTRACTER)

Never	Rarely	Occasionally	Often	Always
0	1	2	3	4

32. My dog seems to get excited for no reason.

Never	Rarely	Occasionally	Often	Always
0	1	2	3	4

33. My dog doesn't like to be approached or hugged.

Never	Rarely	Occasionally	Often	Always
0	1	2	3	4

34. My dog becomes aggressive (e.g., growl, snarl, snap, bite) when excited.

Never	Rarely	Occasionally	Often	Always
0	1	2	3	4

35. My dog may become aggressive (e.g., growl, snarl, snap, bite) if frustrated with something.

Never	Rarely	Occasionally	Often	Always
0	1	2	3	4

APPENDIX C

FORMAL TRAINING QUESTIONNAIRE

Training History

Please indicate by circling the amount of experience your dog has in each type of formal training, and ask the experimenter if you need any clarification.

0 = No experience
1 = Sporadic training
2 = Once or twice a month
3 = Once or twice a week
4 = Completed (with or without an exam)

1. Puppy school	0	1	2	3	4
2. Basic obedience	0	1	2	3	4
3. High-level obedience	0	1	2	3	4
4. Protection	0	1	2	3	4
5. Agility	0	1	2	3	4
6. Search and rescue	0	1	2	3	4
7. Companion dog training	0	1	2	3	4
8. Nose work	0	1	2	3	4
9. Sheep dog training	0	1	2	3	4
10. Dog dancing/tricks	0	1	2	3	4
11. Hunting/retrieving	0	1	2	3	4
12. Therapy dog	0	1	2	3	4
13. Other	0	1	2	3	4