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Self-Directed Learning in Nonhuman Primates

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Self-Directed Learning in Nonhuman Primates

by

Joseph McKeon

Under the Direction of Michael J. Beran, Ph.D.

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of

Master of Arts

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ABSTRACT

Self-directed learning (SDL) is a form of learning wherein individuals have primary control over much or all of the learning process. Little research has been done to investigate this topic in nonhuman animals. The current study involved testing rhesus monkeys and tufted capuchin monkeys on a chained sequential learning task to assess whether they could engage in SDL. Monkeys were either forced to sequence a randomly assigned number of unfamiliar items, allowed to choose the number of unfamiliar items they wanted to sequence, or allowed to choose the number of items they wanted to sequence in a set of familiar items. Species differences in choice behavior emerged, with rhesus monkeys choosing long sequences and capuchins choosing medium-length sequences. However, neither of these strategies proved efficient. The results did not support the idea that nonhuman primates can engage in SDL, and potential causes for the species' different strategies are discussed.

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by

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DEDICATION

I would like to dedicate this thesis to my wife Sarah, who has always supported me through my hardest times, my mother, who made sure I was set up for success all my life, and my father, who would have been proud of all I have done.

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I would like to acknowledge my amazing advisor Mike, my incredibly supportive and helpful thesis committee members Sarah and Dr. Perdue, my fellow students in the COMIC and SUCCESS Labs, and the staff at the Language Research Center for their nonstop support and care for our animals, for their invaluable contributions to this project.

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1 INTRODUCTION

Learning (the relatively stable change in behavior as a result of experience, feedback, and cognitive processing of information) is a major topic of study in the field of psychology. It comprises a wide range of phenomena that involve the acquisition of knowledge or skills through experience, independent study, or instruction (i.e., children learning to speak, doctors learning medical procedures, animals learning which individuals in their social group are safe to interact with; Bruner, 2004). There is, however, much discourse in the field about how learning occurs – is it intrinsically or extrinsically motivated? Is it the same across different learning situations? Is it an active or passive process? What role does reinforcement or punishment play in the speed of learning? The current study will add to this literature dedicated to better describing and understanding learning processes, specifically in the realm of animal learning.

Nonhuman animals (hereafter referred to as animals) have always been involved in the study of learning – Kohler's chimpanzees taught the world about insight learning (Kohler, 1925), Pavlov's dogs about conditioning (Pavlov, 1906), and countless studies have looked at the behavior of rats, guinea pigs, cats, dogs, birds, and primates using mazes, puzzle boxes, Skinner boxes, and many other apparatus and methodologies (Skinner, 1963; see also Bruner, 2004). The formal discussion of animal learning and intelligence in psychology dates as far back as 1882 with the publication of George Romanes's *Animal Intelligence*, a book describing in detail the mental capacity of animals (Romanes, 1882). Romanes' mentor, Charles Darwin, also saw the value of studying animal minds in relation to human minds. Darwin argued against human exceptionalism and asserted that the differences between human and animal intelligence are a matter of degree, not kind, and that it follows that an understanding of animal minds can lead to a better understanding of our own (Darwin, 1871).

Morgan's (1894) work, *An Introduction to Comparative Psychology*, described direct ties between animal learning and the field of comparative cognition (as Morgan puts it, "the psychology of man and the higher animals compared"; pg. 362). Margaret Washburn's (1908) *The Animal Mind* was an incredibly detailed account of phenomena like tool use, sensory perception, and learning across a variety of animal species. It was another influential piece of literature (though it is sometimes underappreciated compared to the work of her male colleagues in this period). Following these foundational works, the field of comparative cognition and the study of animal learning grew in popularity and developed in complexity throughout the twentieth century (see Beran et al., 2014; Domjan, 1987).

1.1   What is Learning?

The definition of "learning" has varied across history. Following the foundation of scientific psychology, a highly influential theory of human behavior emerged from the work of psychologists (or, as they often preferred to identify themselves at this time, physiologists) such as Ivan Pavlov, John Watson, B. F. Skinner, and others (Lefrancois, 2000). Pavlov (1927) demonstrated the idea of classical conditioning, wherein behavioral responses are elicited by stimulus substitution. A dog's handler provides a dog with food, which makes the dog salivate, and eventually the handler's presence alone causes the dog to salivate, a behavior originally only seen in response to the food itself; this idea became popular and serves as the foundation for many psychological theories of behavior even today (Lefrancois, 2000).

Watson studied Little Albert, an 11-month-old boy, to understand emotional conditioning and response transfer (spread of responses to stimuli which are similar to the conditioned stimulus; Watson & Rayner, 1920). Specifically, Watson's work demonstrated how emotional responses, not just physiological ones, could be conditioned using Pavlov's classical

conditioning procedures. He then found that Little Albert, without any intentional conditioning from the experimenters, generalized his conditioned fear of a white rat to anything small, white, and furred. This interesting observation is now commonly known as stimulus generalization. He argued that all learning was the result of chained sequences of conditioned responses, something he eventually called *habits* (Watson, 1930). It should be noted that Watson and Rayner's study has since been criticized for not accounting for confounding variables such as the normal development of fear responses to previously nonfrightening stimuli, the weakness of the conditioned responses, and numerous inconsistencies between Watson and Rayner's written accounts of the study and the events seen in study footage (Powell & Schmaltz, 2021). Nonetheless, studies sparked by the popularity of Watson and Rayner's (1920) work have successfully demonstrated the concept of conditioned fear responses in humans and animals (e.g., Brown et al., 1951; Kalin et al., 1996; Lissek et al., 2008)

Skinner, who studied animals in special cages often called "Skinner boxes," developed the theory of operant conditioning wherein responses can be gradually shaped (learned) through positive and negative reinforcement and punishment (Skinner, 1963). Similarly to Watson, Skinner believed that learning (and other behaviors) could only be explained by external phenomena, and that psychology should refrain from speculating about internal processes that cannot be observed. Learning, he argued, could be classified into two types: classical (Pavlovian) learning, and operant learning. He agreed with Watson and Pavlov that classical conditioning could explain some learned behaviors, namely those that result from directly observed phenomena.

For instance, a dog approaches the oven door when the oven is on, singes a few whiskers on the hot surface, and jerks away in fear and pain. Given enough experiences with this (one may

even be enough), the fear response to the oven door will be conditioned and the dog will begin to fear the oven door itself, regardless of whether the appliance is on. However, what about a dog (who has never singed a whisker) that has learned to walk across the room voluntarily when its owner opens the oven? Skinner argued that these types of behaviors, wherein organisms are acting *on* the environment, not reacting *to* it, are explained by operant conditioning (read: learning; Skinner, 1963). In operant learning, an organism changes its behavior based on reinforcement and punishment – if one reinforces "correct" behaviors in response to a stimulus or environment, the organism will eventually behave "correctly" without the need for reinforcement (note: behaviors can also be weakened or extinguished using punishment as opposed to reinforcement). For instance, a dog that happens to roll over while stretching on the floor will likely receive reinforcement from their owners via praise and affection. The "rolling over" behavior, now reinforced, will likely be repeated again. Skinner's operant conditioning work was primarily done with rats and pigeons (Skinner, 1948, 1957), but the idea for Skinner and many behaviorists who followed is the same when applied to humans or other animal species: our environment plays the major role in our learning, and there is little difference in human and animal learning because of this.

These were just a few of the influential figures in the history of learning research. The most important aspect of their argument was that, as mentioned, internal processes could not be inferred by psychological research, and all explanations for learning and behavior should be based on external factors – this theory became known as *behaviorism* and was a dominant perspective through the mid-1900s (Lefrancois, 2000). However, beginning in the mid-1900s, another theory of behavior (and learning) began to gain popularity in the field of psychology.

Cognitivism, spearheaded by psychologists such as Edward Tolman, Wolfgang Koehler, and others, took a more Gestalt approach to human behavior and posited that the influence of internal processes such as attention, perception, information-processing, and more could not be ignored (Lefrancois, 2000). In general, learning under early cognitivism was much more internal than external – learning was achieved through experiencing, analyzing, storing, and organizing the world around us (Mayer, 2011). Additionally, as organisms develop, they have differential learning abilities depending on the thought structures (or cognitions) they currently possess, such as information processing, representation, perception, and attentional abilities (Piaget, 1971).

Tolman developed *purposive behaviorism* – the idea that we are driven towards goals by cognitions (in his words, *intervening variables*; Tolman, 1928). He was unconvinced that any organism operated solely based on stimulus-response associations, but instead operated (behaved) based on some sort of internal purpose or drive that was crucial to the learning process. To behaviorists who took issue with the non-observable nature of internal processes, he noted that the scientific community has no issue inferring other invisible concepts such as space, time, energy, gravity, etc., based on their effects on the observable environment. Thus, he argued, while scientists should be cautious in their inferences about internal mental processes, it can nonetheless be done, and that these inferences are not human-exclusive. One of his most influential works was in fact based on the cognition of rats and its similarity to that of humans (Tolman, 1948).

Kohler also promoted the idea of internal processes using the behavior of animals. By demonstrating insight learning in chimpanzees (*Pan troglodytes*), he suggested that they must have some sort of mental representation and cognitive processes, at least in this form of learning. He based this on the observation that chimpanzees in his study spontaneously created unique

solutions to a novel problem without shaping or prior experience (although they did have experience with the use of sticks and the testing environment). Kohler (1925) argued that this was an advantage that Thorndike's experiments denying animal intelligence did not have.

Comparative psychologists were instrumental to our understanding of cognition as a concept – the aforementioned works by Tolman and Kohler sparked a whole new discussion of internal processes in animals and humans, including the demonstration of inference in monkeys (Grether & Maslow, 1937), tool use in rats and monkeys (Fritz, 1930; Kluver, 1933, respectively), hypothesis-based learning in rats (Krechevsky, 1932), and much more (see Roitblat et al., 1984).

Comparative psychologists later in the century such as Bitterman (1960), Shettleworth (1998), and Dewsbury (1987) began refining our understanding of human and animal cognition by discussing the difference in cognitive performance of animals such as fish and invertebrates to that of mammals and birds and further then to humans, ultimately positing that while invertebrates mostly use association-learning processes, most of the differences in animal and human learning and cognitive abilities are more of quality, not of quantity. It would not be accurate to say that only humans have cognitive abilities, and that animal research allows us to see what we have that they do not and declare ourselves the smartest animal. Instead, animals are simply different in their abilities to learn based on their sensory structures, ecological abilities, and evolved environmental niches, making those abilities rich for human-animal comparison, not competition.

Although there are debates within cognitive psychology about many of the aspects of learning through cognition based on history, theory, species, and more, the general idea today is that learning is attributable to a change in a learner's knowledge due to experience (Mayer,

2011). "Knowledge" in the area of cognitive learning is stored information that can be factual (understanding the factual characteristics of things), conceptual (understanding models, schemas, principles, etc.), procedural (understanding how to complete an action), strategic (understanding how to achieve a goal), or belief-based (understanding how one learns or what one knows). Mayer's (2009) framework of cognitive learning is one that reflects well the current idea of how individuals learn, namely consisting of stimulus selection, organization, and integration. Selection is the attendance of the learner to items in sensory memory and the movement of those items to working memory. Organization is the arrangement of the aspects of the items (e.g., color, sound, volume, distance, etc.) into coherent models of those aspects, and integration occurs when we compare our prior knowledge with the stimuli presented to us and potentially adjust our knowledge, storing this information into long-term memory. Mayer's (2009) model, while certainly not the only one (see Atkinson & Shiffrin, 1968; Sweller, 1994), is characteristic of the generally accepted constructivist learning theory. According to this theory, learners take an active role in constructing mental representations, filtering important information, organizing that information into coherent structures, and integrating it with existing knowledge. This process is different from response and knowledge acquisition, neither of which involve the learner's active control in the learning process (Mayer, 1992).

Mayer's (2009) model of cognitive learning included the idea of belief knowledge, the understanding of one's own knowledge and abilities. This knowledge can also be understood as metacognition – colloquially defined as *thinking about thinking* (Georghiades, 2004). John Flavell, who first proposed the idea of metacognition in the mid-1970s (though discussions of how we view our own thinking processes have been around for centuries), described it as "knowledge and cognition about cognitive phenomena" (Flavell, 1979, p. 906). He posited that

metacognition involved two sub-processes: metacognitive knowledge and metacognitive regulation. Metacognitive knowledge is devoted to understandings or beliefs about what influences our (and others') cognition and can be broken down into declarative knowledge (knowledge about one's own thoughts and abilities), procedural knowledge (knowledge about the contingencies and requirements about a given task, problem, etc.), and strategy knowledge (knowledge about strategies that can be used in a given situation and when/how to modify these strategies; Flavell, 1976). This metacognitive knowledge influences and is influenced by metacognitive regulation, the strategies we use to regulate our thinking and behavior, such as seeking more information when we are unsure or opting out of responding to questions that we know we cannot answer.

Metacognition is a very popular topic for learning theories, as it contains aspects of both self-monitoring and behavioral change, both of which aid learners in acquiring more knowledge and achieving goals. As mentioned, a large part of the learning process involves a change in *belief knowledge*, or metacognition. Any researcher interested in either learning or metacognition has a vested interest in understanding the other – if learning can alter one's metacognitive knowledge, one would be interested in just how learning comes about, and how exactly it interacts with long-term memory to change our knowledge and behavior. If previously held metacognitive beliefs are integrated into new experiences during the learning episode, one would be interested in how our understanding of our own knowledge and abilities changes and how we decide to focus on and integrate new information. This last point, the influence of our metacognitive monitoring on learning, has the potential to play a big role in a form of learning that explicitly involves learner control: self-directed learning.

1.2   Self-Directed Learning

Self-directed learning (SDL) is any form of learning in which individuals take primary control over planning, implementing, and even evaluation of their learning (Hiemstra, 1994). Theories of human SDL posit that individual learners become empowered to take more responsibility for their learning, that self-direction is a continuum or trait present in all learners and learning situations, and that SDL requires a concept of the self as self-directing. It involves the ability to diagnose one's learning needs realistically, and the ability to select and perform effective strategies skillfully and with initiative. In this framework, learners are motivated by internal incentives like self-esteem, curiosity, achievement, and the like (Hiemstra, 1994; Knowles, 1975).

This topic emerged in the 1960s, sparked by a study conducted by Houle (1961) wherein he interviewed adults engaged in some form of continuing education. From this, he was able to categorize them into three groups; the goal-oriented (learning in order to complete a task), the activity-oriented (learning for the sake of the process), and the learning-oriented (learning in order to gain knowledge). This demonstrated that there exist different motivations for individuals to seek out learning and learning experiences. Tough (1971), a psychologist who specialized in adult education, took interest in Houle's study, was one of the first to specifically use the term SDL in his work. Tough wrote about the processes learners go through in planning and implementing their learning episodes. These processes include deciding what knowledge or skill the individual would like to learn, determining what resources are necessary, deciding when, where, and how quickly to learn, deciding how to estimate their progress, implementing the learning, and dealing with motivational blocks.

Following that work, Knowles (1975) published his book *Self-Directed Learning: A Guide for Learners and Teachers*, often considered one of the seminal works in the field of SDL (Hiemstra, 1994). In it, he outlines the foundational assumptions of SDL, which are summarized as follows:

- Humans grow in their capacity and need to be self-directed

- Learners' experiences are rich resources for learning

- Individuals learn what is required for evolving life tasks

- Adults' natural inclination is task- or problem-centered learning

- Self-directed learners are motivated by internal incentives like self-esteem, curiosity, achievement, etc.

Knowles (1975) also outlined some of the requirements of SDL, namely that a learner needs to have a concept of the self as self-directing, the ability to realistically diagnose their learning needs, and the ability to choose effective strategies for making use of learning resources. While Knowles did not specifically discuss the role of cognition in his book, it is important to note how similar these requirements are to aspects of metacognition – they require monitoring one's own knowledge and regulating that knowledge and subsequent strategies. The relationship between these two concepts was undeniable from the very beginnings of the study of SDL, and this relationship will be discussed in detail later in this paper.

Following Knowles's book, there was an increase in empirical research on SDL (Hiemstra, 1994). Guglielmino (1978) developed a Self-Directed Learning Readiness Scale (SDLRS) that is still used today and that is often called the Learning Preference Assessment (LPA). The scale contains Likert-style responses to questions about the learner's feelings about the learning process, their own motivations and learning abilities, and their beliefs surrounding

learning. Pilling (1996) created the Self-Directed Learning Perception Scale (SDLPS), which allows students to express their thoughts surrounding the SDL learning process and their thought processes therein.

1.2.1 Experimental Evidence of SDL

Since the development of SDL as an area of study in psychology, three major areas of research have emerged, as defined by Brockett and Hiemstra (1991). These areas are learning projects, qualitative studies, and quantitative measures. Studying learning projects, one of the original avenues to investigate SDL, allows researchers to assess naturally occurring SDL efforts without experimenter intervention. Such studies have demonstrated that roughly 50-70% of the learning projects of adults are self-directed (e.g., Coolican, 1975; Hiemstra, 1975; Peters & Gordon, 1974; Tough, 1979). However, studies that use this method are often criticized for being methodologically and statistically inconsistent (Brockett & Hiemstra, 1991). Qualitative studies allow researchers to conduct in-depth interviews that help outline the sociological aspects of SDL, but because of the lack of experimental manipulation and data collection, they are not as useful at determining the personality traits that go into and outcomes of SDL. Quantitative research, which all of the research below falls into, is not flawless, but is the most applicable to the investigation of SDL from a cognitive perspective.

Torrance and Mourad (1978) found significant positive correlations between SDL and originality and creative achievements in Education graduate students. Corbeil (2003) demonstrated a significant positive correlation between SDL readiness and student success and academic performance. Corbeil also found that a set of three predictor variables that included SDL readiness, online technologies self-efficacy, and locus of control, accounted for a significant 55% of the variance in academic performance. Shaine (2015) found that self-

regulation, cognitive strategy, and self-efficacy accounted for 44.8% of the variance in academic performance. Zhou and Li (2020) investigated the effect of an autonomous learning intervention in middle school students and found that those who learned to self-direct their own learning showed higher classroom participation, interactive activity, and academic performance (particularly in their language classes).

In a study using the Resource Associates Self-Directed Learning scale (shown to be positively correlated to the SDLRS; Lounsbury & Gibson, 2006), Lounsbury et al. (2009) found that SDL was positively related to GPA and to measures such as verbal, numerical, and abstract reasoning, life satisfaction, and academic satisfaction in middle school, high school, and college-aged students. Zhoc et al. (2018) found that students across disciplines at Hong Kong-area universities who had high emotional intelligence and control also had a high propensity for SDL, and that those students also had higher learning outcomes such as GPA and perceived self-growth.

Chou (2012) demonstrated a positive correlation between pre-tested SDL abilities and online learning performance in nursing students on an in-lab exam. However, there was no direct effect when the students were split into high- and low-SDL ability groups (based on the same scale) on interaction with class material or exam performance after an 8-week programming class, although Chou highlighted a number of potential sources of this inconsistency. All in all, while there are a few contradictory results, the literature generally seems to agree that the ability to self-direct one's learning has a positive effect on both perceived and actual learning outcomes. The next step, logically, for both the field and this paper, was to look at the possible underlying mechanisms of SDL that allow it to be such an effective learning style.

1.2.2   The Role of Cognition in SDL

One of the common trends in SDL research and theory is the strong role of cognition in the SDL process. Gureckis and Markant (2012) described a cognitive perspective on SDL. They argued that because learners have control over how they sample their information, they can ignore redundant information and allocate more encoding effort to that which is unknown, making each bout of learning more efficient. Self-directed learners could also be using inductive inferences about how their information was sampled (instructor-led or self-directed) to inform their generalizations of that information. It could be that the planning and active control over how learning is conducted could enhance learning performance, regardless of how the learning is planned. It could be that the inclusion of individual choice may increase metacognitive monitoring of the student's learning and provide them with continuous internal feedback as they go through the learning process. This would be promising for education interventions – if there truly is an innate effect of learner control on learning performance, regardless of how the learner organizes their materials, study schedule, etc., then simply providing them with that control would help increase performance outcomes.

Garrison's (1997) comprehensive model of SDL explicitly criticizes the historical focus of SDL research and theory on the learner's ability to take control over the external aspects of the learning process. In his model of SDL, metacognition and cognitive responsibility (the management of the learning process) play a much larger role in the learning process than control over the materials or assessment of learning. These two skills help learners assess information, construct learning plans, and compare external feedback with their own internal assessments of the information, still providing them with the ability to control *how* they learn, if not *what* they learn. Thus, as in Gureckis and Markant's (2012) model, it is the act of controlling the learning

that helps increase performance. The literature has shown that students with higher feelings of self-efficacy and control over their lives perform better academically and feel more confident in their learning abilities across age groups, further supporting this idea (primary school: Shaine, 2015; high school: Hwang et al., 2016; higher education: Hayat et al., 2020).

In Frazer et al.'s (2021) MAPS (metacognition, agency, and personal selves) model, metacognition is explicitly stated to be one of the four interacting components of self-regulated learning (a term often used synonymously or as a facet of SDL; Loyens et al., 2008), and Metcalfe (2009) argued that metacognitive judgements are crucial to enhanced learning. In general, nearly every modern model (and some older models) include metacognition as a part of the SDL process, and this makes logical sense – for a learner to plan their learning goals, they need to have an understanding of their own learning so that they can ignore (or skim) information they already know and focus their learning efforts on that which they do not.

Experimental literature supports the idea that metacognition and SDL may be linked. Jin and Cheng (2020) found significant positive correlations between metacognitive ability and SDL ability in nursing students. Similarly, Kincannon et al. (1999) found that providing college students with metacognitive training on subjects such as reflection, planning, and evaluation, helped not only their objective performance in an SDL environment, but helped increase their confidence in their performance as well. Örs and Titrek (2018) found a significant correlation between measures of SDL readiness (Fisher's Self-Directed Learning Readiness Scale) and metacognitive awareness (Metacognitive Awareness Inventory) in undergraduate students. Even in kindergarten children, a metacognitive training intervention was shown to increase SDL, even more so than an intervention based on active processing theory (the idea that asking many questions about a text will eventually raise the quality of the questions and promote

comprehension; Glaubman et al., 2012). Much more research has been conducted on the relationship between cognition (specifically metacognition) and SDL, most of it finding a significant positive relationship between the two, but a major literature gap exists in the fact that little research has been done on this topic in nonhuman animals, despite their historical involvement in the study of human learning (Bruner, 2004).

Based on the information presented so far, it is clear that cognition (and specifically metacognition) plays a role in SDL. Thus, it follows that any organism, human or otherwise, who demonstrates metacognitive abilities may also possess the ability to self-direct their own learning. This is the primary assumption prompting the current study, but first it is necessary to show evidence that metacognitive abilities do exist outside of our species.

1.3 Animal Cognition and Metacognition

The question of whether animals can engage in metacognition is one that has been heavily debated across the years. The first empirical demonstration was Smith et al.'s (1995) paper on uncertainty responses in a bottlenosed dolphin (*Tursiops truncates*). Given easy and hard trials to complete in a discrimination task, the dolphin performed similarly to humans in using an escape option more often on the objectively most difficult trials. Soon after, Smith et al. (1997) showed similar results in rhesus monkeys (i.e., more escape responses to hardest trial discriminations). Since then, metacognitive abilities such as cognitive control, uncertainty monitoring, and information seeking have been demonstrated in a variety of species such as rats (Foote & Crystal, 2007), pigeons (Adams & Santi, 2011), and many nonhuman primate species (see Beran et al., 2012). Outside of the great apes, rhesus monkeys in particular seem to be metacognitive, showing evidence for useful information seeking (Beran et al., 2006; Beran & Smith, 2011), metamemory (Hampton, 2001; Templer et al., 2018) and uncertainty

monitoring/responding (Shields et al., 1997; Washburn et al., 2006), as well as in numerous other paradigms that are beyond the scope of this paper, but that reflect the extensive evidence for metacognition in that species.

However, not all animals perform like macaques. There are many species differences in the degree and type of metacognitive abilities demonstrated. For example, brown tufted capuchin monkeys (*Cebus s. apella*) demonstrate advanced cognitive abilities such as tool use, social reasoning, conceptual learning and transitivity, self-control, and basic causality (D'Amato, Salmon, & Columbo, 1985; D'Amato, Salmon, & Loukas et al., 1985; Falótico, 2022; Fujita et al., 2002, 2003; Perdue et al., 2015), but there is mixed evidence thus far as to whether capuchins display some of the key aspects of metacognition such as information seeking and uncertainty responding (Beran et al., 2016; Kishimoto et al., 2019; Smith et al., 2018; Vining & Marsh, 2015). Capuchin monkeys sometimes show evidence of information seeking behavior (Beran & Smith, 2011), but not all monkeys show this behavior and they do not tend to use inferences when information seeking (Beran & Smith, 2011; Paukner et al., 2006; Vining & Marsh, 2015).

Capuchins also tend to not show strong evidence for uncertainty responding (Beran et al., 2009, 2014; Perdue et al., 2015). Beran et al. (2016) hypothesized (and supported) that this responding depended on risk tolerance, and found that when risk was higher, capuchin monkeys tended to use uncertainty responses more often. This higher risk tolerance may be due to their natural propensity for foraging and object manipulation, as this species may have evolved to accept higher risk options to fit in better with their environment (Smith et al., 2018). Capuchin monkeys also seem to show evidence for metamemory, but in a more basic form and only in less difficult conditions compared to rhesus monkeys (Basile et al., 2009; Fujita, 2009). Overall, it

seems that evidence for capuchin metacognition is mixed, and positive results mostly support a more rudimentary form of metacognition than that shown by rhesus monkeys.

1.4   SDL in Animals

As of now, very few studies have looked at SDL in animals, and most have been done with learning paradigms that may not be ideal for charting SDL. Silasi et al. (2018) conducted one of the first studies specifically assessing SDL in rodents, the main goal of which was to find a way to reduce researcher effort and time when training mice on motor tasks. To do this, the authors created a lever-pressing apparatus that could be placed in the mouse home cages that produced a water reward, and the apparatus incrementally trained them to press the lever at a specific angle for a specific amount of time. RFID tags were used to identify which mouse had entered the training chamber and change their response requirements accordingly, as the mice were socially housed. They found that the mice willingly learned to correctly respond to the lever in their home cage. While this experiment did not directly investigate SDL, it did show that mice were willing to train on a task autonomously (Bernhard et al., 2020).

Mun at al. (2015) more closely approached SDL in their study on spatial learning in mice. They found that when mice were placed in a dimly lit environment, they showed higher exploratory behaviors and enhanced spatial learning. This dimly lit environment was less threatening and thus allowed for more exploratory behaviors, as is seen in a higher instance of rearing within the testing chamber, as opposed to the escape-oriented exploration prompted by a more brightly lit environment. These results were compared to those in a human experiment wherein volitional exploration prompted higher recognition in a spatial memory test (Voss et al., 2011). These two studies provide only rudimentary evidence for SDL in animals, but the results are nonetheless promising and excellent motivation to delve deeper into the topic.

Despite the lack of literature directly investigating SDL in animals, there are promising findings in related phenomena. For instance, Harlow (1949) showed that naïve monkeys showed improved abilities to learn an object-quality discrimination problem over time, in essence confirming that they could "learn how to learn." The monkeys also showed the ability over time to become more effective in reversing their responses when a discrimination rule was suddenly made opposite to what it was on previous trials. Harlow also tested monkeys' responses to alternating antagonistic response rules, between object quality and position cues. He found that an increase in learning of the new position discrimination negatively influenced the previously mastered object quality discrimination, but that both discriminations leveled out above chance levels of responding. Other studies have shown that animals such as rats (Murphy et al., 2008), jays (Wilson et al., 1985), and zebra finches (van Heijningen et al., 2013) are also able to learn generalizable rules and extract those rules to novel situations. Although all of these examples are related to *aspects* of SDL such as the ability to flexibly apply concepts to new situations, none of the learning involved in them is explicitly self-directed, further emphasizing a large gap in the literature. Thus, the current study seeks to investigate the topic of SDL in two nonhuman primate species, different in their metacognitive abilities, to see if this form of learning can be identified in a nonhuman animal.

In order to evaluate this idea that metacognitive abilities should relate to SDL proficiency, rhesus macaques (*Macaca mulatta*) and capuchins were trained on a chained two-to-four item sequential learning task. They were taught how to complete the task and familiarized with three unique sequence length indicator symbols (hereafter referred to as sequence symbols) that controlled the number of items they had to sequence on a given trial. After training, they completed trials wherein they were either forced to sequence a randomly assigned number of

items, or they were allowed to choose the number of items they wanted to sequence on that trial. It was hypothesized that evidence of SDL would come from monkeys adjusting the number of stimuli they chose to sequence based on relative expertise (i.e., they should have chosen fewer stimuli when new sequences were presented, and then adjusted to choosing longer and longer sequences). It was predicted that rhesus monkeys, but not capuchin monkeys, would show this evidence because rhesus monkeys show stronger evidence for metacognition than capuchin monkeys. If this prediction was correct, I would be providing a direct measure of SDL in a nonhuman animal, the first of its kind. Not only would this fill a major gap in both the SDL and comparative literatures, but it will also provide evidence about the degree to which control over one's own learning is a highly innate, evolutionarily advantageous strategy, at least in some primate species. Should this be true, it has strong implications not only for human learning interventions, in children and adults, but it also will prompt further investigation into the learning traits and abilities of many other nonhuman animals across taxa. Any species differences (or similarities) may also allow us to track the evolutionary track of SDL.

2   METHODS

2.1   Subjects

Six adult male rhesus monkeys and eighteen adult capuchin monkeys (males = 7, females = 16) at the Language Research Center (LRC) of Georgia State University participated in the study. Final data includes three rhesus monkeys and ten capuchins (M = 3, F = 7), and exclusion criteria are discussed in Section 2.4.

At the beginning of the study all rhesus monkeys were singly housed with visual and auditory access to other monkeys, and four monkeys had access to a compatible partner that they shared time with each day (they did not complete testing during that time). During the study period one rhesus monkey died, leaving only two rhesus monkeys paired with a compatible partner and three rhesus monkeys singly housed. All capuchin monkeys were group-housed in groups of two or more animals. All monkeys had access to indoor and outdoor enclosures with a variety of enrichment items including toys, climbing structures, and foraging puzzles. They were given a full diet of fresh fruits and vegetables daily along with monkey chow and were not food- or water-restricted for the purposes of testing.

Monkeys routinely participate in a variety of computerized cognitive tests throughout their day, and all are experienced with cognitive and learning tasks akin to what was presented within the current study (e.g., Beran et al., 2006; Parrish et al., 2018; Smith et al., 2020). All experimental procedures were approved by the Institutional Animal Care and Use Committee of Georgia State University. Georgia State University is accredited by the Association for Assessment and Accreditation of Laboratory Animal Care International.

2.2   Apparatus

The monkeys were tested using the LRC's Computerized Test System which is comprised of a personal computer, digital joystick, 17-inch color monitor (800 x 600p), and pellet dispenser (Evans et al., 2008; Richardson et al., 1990). They manipulated the joystick with their hands to produce isomorphic movements of a small cursor on the computer. Correct responses to the computer program led to the delivery of a food reward (a 45-mg banana-flavored chow pellet; Bio-Serv, Frenchtown, NJ) via a pellet dispenser. Monkeys were not restrained during testing and viewed the monitor from approximately 30 to 40 cm. The computer program was written in Visual Basic 6.0. Test sessions ranged from five hours (capuchin monkeys) to 24 hours of continuous access (rhesus monkeys), but monkeys could work or rest as they chose.

2.3   Procedure

After a training phase (described below), monkeys completed a set of twenty-five sequential learning sessions with four unique sets of stimuli (randomly selected clipart images). The overall task involved sequencing two items, three items, or four items within the set in a specific order. Previous research has shown that rhesus monkeys and capuchin monkeys are able to learn to sequence at least this many items (e.g., Beran & Parrish, 2012; Terrace, 2003).

2.3.1   Training Phase

To familiarize the monkeys with the task contingencies, monkeys completed a training phase that gradually increased the number of items being sequenced while simultaneously introducing the monkeys to the sequence symbols, a set of four different stimuli that represent the number of items to be sequenced in a given trial (pictured in Figure 2.1). The items to be

sequenced were pulled from the same four-image set for the entire training phase. These symbols (and the stimuli to be sequenced) were 100 x 100 pixels.
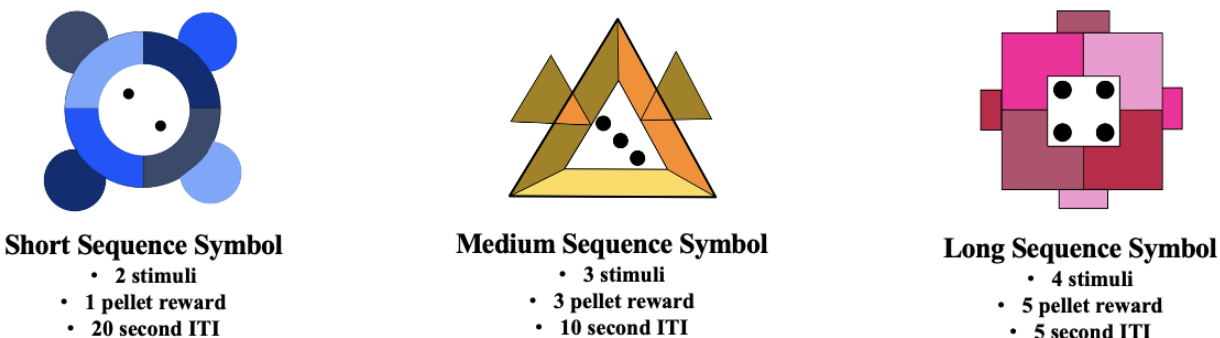
Short Sequence Symbol
- 2 stimuli
- 1 pellet reward
- 20 second ITI

Medium Sequence Symbol
- 3 stimuli
- 3 pellet reward
- 10 second ITI

Long Sequence Symbol
- 4 stimuli
- 5 pellet reward
- 5 second ITI

Figure 2.1 Sequence Length Indicator Stimuli (Sequence Symbols)

After moving the cursor to touch a trial initiation stimulus on the center of the screen, the two-item sequence symbol appeared in one of five set locations that made a semi-circular arrangement across the center and lower part of the screen, with the cursor appearing centered onscreen and equidistant from each of those five possible locations. Monkeys had to move the cursor to select the sequence symbol, at which point two clipart images appeared in one of five locations that also made a semi-circular arrangement across the center and upper part of the screen, with the cursor also appearing centered onscreen and equidistant from each of those five possible locations. Monkeys then moved the cursor to select the first stimulus – if they chose the incorrect stimulus all stimuli were removed, a buzz sound played, and the task entered a 30 second timeout period before monkeys were allowed to complete another trial. If they chose the correct stimulus first that stimulus was removed, and the cursor was reset back to the center of the screen. Monkeys then had to choose the second stimulus in the sequence, at which point a chime sound played and one pellet was dispensed as food reward. After a 20 second inter-trial interval, monkeys were allowed to complete the next trial. Across the entire study, the number of pellets dispensed at the end of a correctly completed trial increased based on the number of items

sequenced in that trial (one pellet for two items, three pellets for three items, and five pellets for four items). The inter-trial interval decreased based on the number of items sequenced in that trial (twenty seconds for two items, ten seconds for three items, and five seconds for four items), and the punishments remained the same (buzz sound, no pellets, thirty second timeout).

Monkeys completed two-item sequence trials until they reach a performance criterion (22 of the last 25 trials sequenced correctly), and then they progressed to sequencing three items. At the start of the three-item sequence trials the three-item sequence symbol, three clipart images, and the cursor appeared under the same conditions as the two-item sequence trials. Once they reached a performance criterion of 19 of the most recent 25 trials correct, they moved to sequencing four items with a new sequence symbol and with the performance criterion then set to 17 of the last 25 trials answered correctly. After reaching criterion on sequencing four items, they should have familiarized themselves with the task and they had experience with the sequencing symbols that preceded each of the trial sequence lengths. The decreasing criterion recognized that as the number of stimuli increased, chance levels of performance decreased (i.e., with two stimuli, chance is 50%, with three stimuli chance is 16.5%, with four stimuli chance is 4%).

Note that throughout this training, the same stimuli were used as the sequence got longer. Using the English alphabet as an example, after learning to sequence A-B the monkeys then had to sequence A-B-C, and then A-B-C-D. With this addition of only one new stimulus per criterion shift, and removal of correctly selected items, the monkeys were expected to train quickly. This was important for the testing phase where it was crucial that they could anticipate easier training based on the number of items they initially choose to sequence when a new set of stimuli was introduced.

Monkeys then completed 400 trials in which each block of 4 trials presented them with the 2-item, 3-item, and 4-item icon one time in randomized order (and required that they sequence the associated number of items). This was designed to familiarize them with trial-by-trial changes in the possible number of stimuli they could encounter onscreen and further helped with the association of the sequence symbols and the number of items they were associated with. They then moved to the testing phase provided that overall performance still exceeded 85% correct for 2-item sequences, 75% correct for 3-item sequences, and 66% correct for 4-item sequences. The program repeated these 400 trial blocks until they met this performance criterion.

2.3.2 Testing Phase

Stimuli to be sequenced and their placement onscreen in this phase was identical to the training phase. In this phase, however, monkeys completed either 'Forced' (Control) sessions, 'Choice' (Experimental) sessions, and 'Repeat' sessions in which each session used four novel clipart stimuli (with the exception of Repeat sessions, described below). At the start of each testing day, the program assigned the monkeys to either the Forced, Choice, or Repeat conditions based on a predetermined, pseudo-randomized session order to ensure equal numbers of each session type. Monkeys had to complete at least 60 trials in the day or a maximum of 160 trials (except for one rhesus monkey who completed a maximum of 80 trials per session due to low task motivation). If they did not complete the minimum number of trials the condition was repeated with new stimuli in the next testing session to prevent carry-over learning. Over the course of the study, monkeys completed 10 Control sessions, 10 Experimental sessions, and 5 Repeat sessions.

Trials in the Forced condition were presented in the same way as the final training phase, and the number of items to be sequenced was randomized across trials. During trials in the

Choice condition, all three sequence symbols appeared in a semi-circle in three of five

predetermined (but randomized) positions on the bottom half of the screen. The monkeys chose

whether to sequence two, three, or four stimuli on each trial by selecting the respective sequence

symbol with their cursor. After selecting the number of items to be sequenced, trials proceeded

as described in the training phase. Trials in the Repeat condition followed the format of the

experimental sessions, but the stimuli to be sequenced were the same as those in the previous

session they completed (regardless of the condition of that session). Figure 2 includes a visual

depiction of the trial format in all conditions.
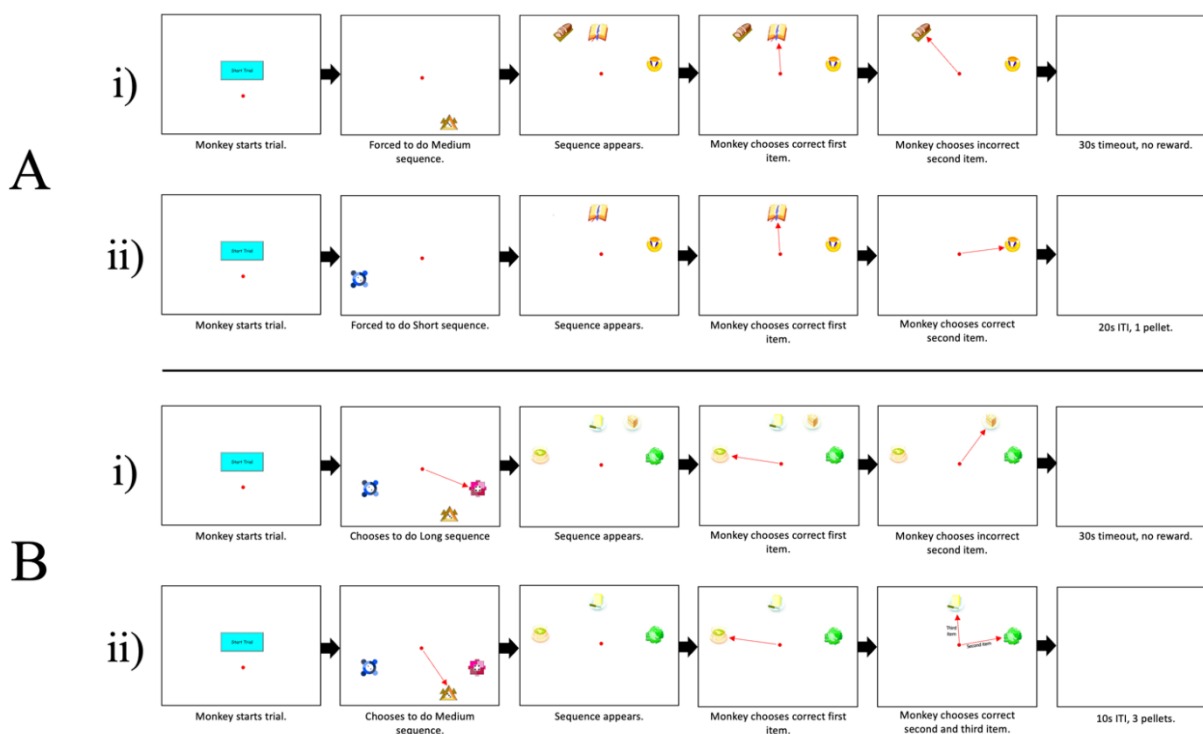
Note. Each row depicts an example trial for monkey performance on Training/Forced (A) and
Choice/Repeat (B) trials, and for incorrect (i) and correct (ii) responses.

Figure 2.2 Trial Setup in the Training and Testing Phases

During each trial, the program recorded the monkey's name, the date and time of the

completed trial, the phase (train or test), the trial number, the condition (Forced, Choice, or

Repeat) in the testing phase, the number of items that were forced to be sequenced (always

labeled as '4' in Choice and Repeat sessions), how many items they chose to sequence, where the sequence symbol appeared on the screen, the order in which they chose the stimuli, the number of items selected in a trial (regardless of accuracy), the sequence symbol response latency (in ms), the sequence duration (time from sequence symbol selection to trial completion, in ms), and the trial outcome (correct or incorrect).

2.4   Exclusion Criteria

A set of exclusion criteria were developed in order to have actionable guidelines for including or excluding monkeys from the task. First, any monkey who completed less than 100 trials per day for five days in a row in the training phase was dropped from the program. Second, any monkey who failed to pass training on two-, three-, or four-item sequences after 3,000 trials or who failed to pass the final training phase after 3,600 trials was dropped.

Third, to address low motivation in the testing phase, a "jumpstart" (capuchin) and "continuous" (rhesus) protocol were created. In the jumpstart protocol, which started after 10 sessions of completing < 60 trials, the capuchin was set up on a different computerized task for 5-15 minutes, and then put back on the testing program. In the continuous protocol, monkeys were left on the task for 2-3 continuous days without closing the program. If monkeys failed to complete > 60 trials in six of the next ten testing sessions (jumpstart) or six of the next ten days (continuous), they were removed from the study. If they did meet the criteria, they resumed testing as normal. Lastly, monkeys were removed from the study if they did not chose to work on the task for more than two months. Two rhesus monkeys and eight capuchins were removed from the study based on these criteria. Table 2.1 shows descriptive statistics for each monkey in the training phase, as well as monkeys that were removed from the study and the reason why.

2.5   Data Analysis

All statistical analyses were conducted using IBM SPSS Statistics and VassarStats (© Richard Lowry 1998-2023).

3   RESULTS

3.1   Training Phase

Training data (the number of trials it took each monkey to pass each training phase) were assessed for normality using the Shapiro-Wilk test and violations of normality were found for the two-item phase, $W(13) = 0.84$, $p = .037$, the four-item phase, $W(13) = 0.86$, $p = .041$, the final training phase, $W(13) = 0.85$, $p = .030$, and the total number of training trials, $W(13) = 0.86$, $p = .041$. Because of this, nonparametric analyses were used to determine any significant effects in the training data.

I conducted an independent-samples Mann-Whitney U Test on species for each training phase individually and found that there were no species differences in the number of trials it took to pass the two-item phase, $U = 9.00$, $p = .37$, the three-item phase, $U = 6.00$, $p = .16$, the four-item phase, $U = 14.00$, $p = .94$, the final training phase, $U = 9.00$, $p = .37$, or the total number of training trials, $U = 11.00$, $p = .57$. I also ran a Friedman's test on number of training trials by training phase and found a significant effect of training phase, $\chi^2(4) = 29.59$, $p < .001$.

Pairwise comparisons using Wilcoxon signed-rank tests with a Bonferroni correction of alpha to .008 to account for repeated tests showed that there was no difference in how long it took monkeys to pass the two-item phase ($M = 92.00$) compared to the three-item phase ($M = 141.54$), $Z = -0.39$, $p = .45$, or the four-item phase ($M = 274.92$), $Z = -1.23$, $p = .015$, but they required more trials to pass the final training phase ($M = 1507.69$) than the two-item phase, $Z = -2.54$, $p < .001$. There was no difference in how long it took them to pass the three-item phase compared to the four-item phase, $Z = -0.85$, $p = .095$, but they took longer to pass the final training phase than the three-item phase, $Z = -2.15$, $p < .001$. There was no difference in how

long it took monkeys to pass the four-item phase compared to the final training phase, $Z = -1.31$, $p = .01$.

3.2 Testing Phase

3.2.1 Accuracy

Statistical assumptions such as skewness, kurtosis, and normality (via the Shapiro-Wilk test) were assessed for the chosen outcome variables across all statistical tests in order to determine the appropriate statistical tests for the predictions. Parametric analyses were used when violations were not found, and equivalent nonparametric tests were used when violations were found.

I conducted a 4-way General Linear Model (GLM) on accuracy (percent correct) using species (between-subjects), condition (within-subjects), block (within-subjects), and sequence length (within-subjects) as factors. The block variable was created by dividing each session into four quartiles of 40 trials each in order to assess performance across trials within a session. A GLM was used instead of an ANOVA to account for multiple missing cases. The analysis showed no 4-way interaction, $F(10, 340) = 0.21$, $p = .995$, $\eta p^2 = 0.006$. None of the three-way interactions were significant (all $p > .05$). There was a significant interaction between species and sequence length, $F(2, 340) = 5.43$, $p = .005$, $\eta p^2 = 0.03$, between condition and block, $F(6, 340) = 2.21$, $p = .041$, $\eta p^2 = 0.04$, and between condition and sequence length, $F(4, 340) = 2.66$, $p = .033$, $\eta p^2 = 0.03$.

To investigate the species and sequence length interaction, I conducted a 2-way GLM on accuracy using species and sequence length as factors, and found no significant interaction, $F(2, 33) = 0.45$, $p = .64$, $\eta p^2 = 0.027$. There was no main effect of species, $F(1, 33) = 0.008$, $p = .93$, $\eta p^2 < .001$. There was a main effect of sequence length, and post-hoc analyses using Bonferroni

tests and a correction of alpha to .017 to account for repeated tests found that monkeys were more accurate on Short sequences ($M = 82.75$) than on Medium sequences ($M = 56.03$) and Long sequences ($M = 25.57$), and more accurate on Medium sequences than on Long sequences (all $p < .001$).

To investigate the interaction between condition and block, I conducted a 2-way GLM on accuracy using condition and block as factors, and the analysis found a marginally significant interaction, $F(6, 142) = 2.09$, $p = .058$, $\eta p^2 = 0.081$. To further investigate this interaction, I first conducted a 1-way GLM on accuracy using block as a factor separately for each condition. In the Forced condition, I found a significant effect of block, $F(3, 47) = 10.33$, $p < .001$, $\eta p^2 = 0.40$, and pairwise comparisons using Tukey HSD tests and a Bonferroni alpha correction to .017 found an increase in performance between Block 1 ($M = 42.29$) and Block 2 ($M = 54.36$), no change in performance between Block 2 and Block 3 ($M = 58.96$), no change in performance between Block 3 and Block 4 ($M = 62.19$), but higher performance in Block 4 than in Block 1. In the Choice condition, there was a main effect of block, $F(3, 48) = 12.65$, $p < .001$, $\eta p^2 = 0.44$, and pairwise comparisons found an increase in performance from Block 1 ($M = 34.51$) to Block 2 ($M = 53.08$), no change in performance from Block 2 to Block 3 ($M = 60.54$), and no change in performance from Block 3 to Block 4 ($M = 65.79$), but higher performance in Block 4 than in Block 1. In the Repeat condition, there was no main effect of block, $F(3, 47) = 0.50$, $p = .68$, $\eta p^2 = 0.031$.

Next, I conducted a 1-way GLM on accuracy using condition as a factor separately for each block. In Block 1, condition had a significant main effect, $F(2, 36) = 22.24$, $p < .001$, $\eta p^2 = 0.55$, and post-hoc paired comparisons using Bonferroni tests and an alpha correction to .017 found no difference in performance between the Forced ($M = 42.29$) and Choice ($M = 34.51$)

conditions, but that monkeys did better in the Repeat ($M = 66.28$) condition than both other conditions. In Block 2, condition had a significant main effect, $F(2, 36) = 4.64$, $p = .016$, $\eta p^2 = 0.21$, but post-hoc paired comparisons found no differences in performance between any of the conditions. In Block 3, condition had a significant main effect, $F(2, 36) = 3.42$, $p = .044$, $\eta p^2 = 0.16$, but post-hoc paired comparisons again found no differences in performance between any of the conditions. In Block 4, condition did not have a significant main effect, $F(2, 34) = 2.42$, $p = .10$, $\eta p^2 = 0.13$.

I also ran a 1-way GLM on accuracy with condition as a factor, specifically looking at the performance in the last block of the Forced and Choice condition compared to the performance in the first block of the Repeat condition, and found no main effect of condition, $F(2, 35) = 0.30$, $p = .74$, $\eta p^2 = 0.02$.

Lastly, to investigate the interaction between condition and sequence length, I conducted a 2-way GLM on accuracy using condition and sequence length as factors. There was not a significant interaction between the factors, $F(4, 106) = 0.91$, $p = .46$, $\eta p^2 = 0.03$, but both condition, $F(2, 106) = 13.52$, $p < .001$, $\eta p^2 = 0.20$, and sequence length, $F(2, 106) = 174.82$, $p < .001$, $\eta p^2 = 0.77$ showed significant main effects. Post-hoc paired comparisons using Bonferroni tests and an alpha correction to .017 on both factors revealed that monkeys performed significantly better in the Repeat ($M = 64.18$) condition than the Forced ($M = 53.40$) and Choice ($M = 51.25$) conditions (all $p < .01$), and that monkeys performed better on Short ($M = 82.65$) than on Medium ($M = 58.68$) and Long ($M = 28.45$) sequences, and better on Medium sequences than on Long sequences (all $p < .001$).

3.2.2   *Sequence Length Choice Behavior*

For each monkey, I conducted a Chi-Square Goodness of Fit test using the number of times they chose each sequence length in the choice condition compared to a hypothetical null model wherein they chose each sequence symbol an equal number of times. The differences between sequence length choice were assessed using the adjusted residual values, which provide information on whether a specific cell (e.g., number of times Short sequence was chosen) differs from what is predicted in the null model (directionality of that difference also is given), and the results of these tests are in Table 3.2.

Table 3.1 Individual Monkeys' Sequence Length Bias in the Choice Condition

Monkey	χ^2	Short	Medium	Long
Rhesus				
Luke	31.32	21.32%[*]	39.28%	39.40%
Mac	893.73	6.45%[*]	6.45%[*]	86.71%[*]
Murph	928.60	4.75%[*]	9.38%[*]	85.88%[*]
Capuchins				
Attila	1678.16	1.04%[*]	83.54%[*]	15.42%[*]
Bailey	73.56	24.10%[*]	44.90%[*]	31.00%
Gambit	66.73	46.61%[*]	30.88%	22.51%[*]
Gretel	607.62	31.20%	61.20%[*]	7.50%[*]
Ingrid	39.15	23.34%[*]	39.97%[*]	36.69%[*]
Liam	508.59	19.25%[*]	71.78%[*]	8.97%[*]
Lily	297.91	10.07%[*]	56.88%[*]	33.06%
Logan	1242.38	1.31%[*]	97.38%[*]	1.31%[*]
Paddy	1163.86	10.04%[*]	74.25%[*]	15.71%[*]
Wren	301.98	24.73%[*]	62.24%[*]	13.02%[*]

Note. [*] Indicates a significant difference from random choice behavior (33.3%). For all χ^2, p < .001.

Results showed that all monkeys except one capuchin chose to do the Short sequences at a rate below chance. Two out of three rhesus monkeys showed a significant bias towards the Long sequences and away from the Medium sequences, nine out of ten capuchins showed a significant bias towards the Medium sequences and eight out of ten capuchins showed a

significant bias away from the Long sequences. Figure 3.2 shows an overall description of each species' sequence length bias.
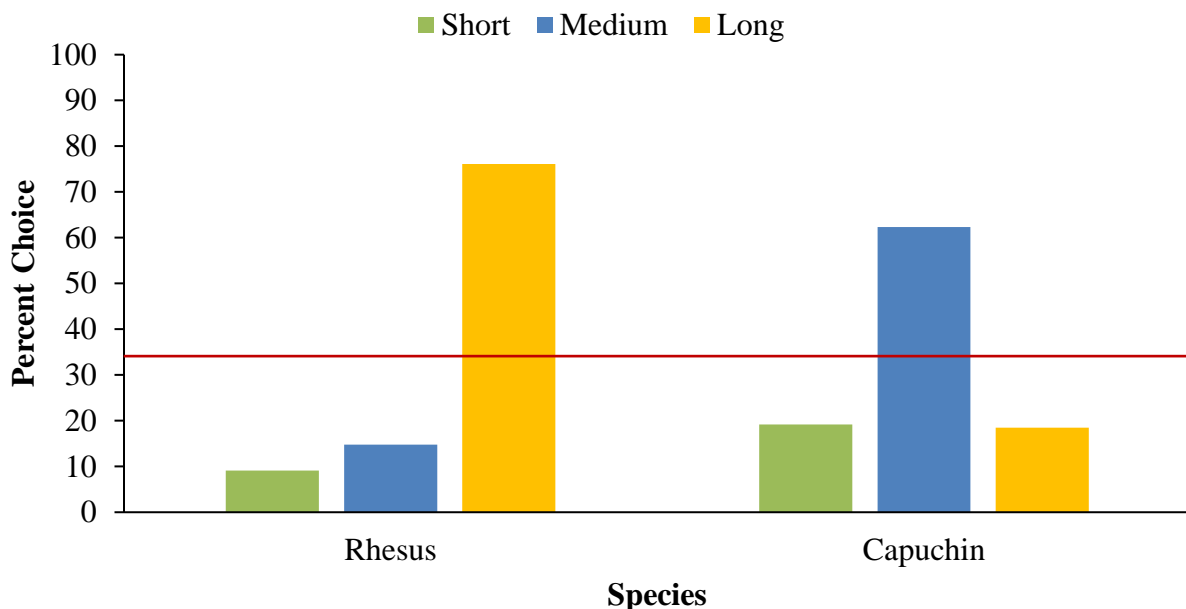
Note. This graph displays the percent choice collapsed across all monkeys within each species. Red line represents random choice percentage (33.3%).

Figure 3.1 Species Bias in Sequence Length Choice in the Choice Condition

I tested whether the two species' sequence length preference changed across a session by calculating the average sequence length across all trials within each block in the choice condition. Multiple violations of normality were found, specifically in Block 1, $W(12) = 0.86$, $p = .046$, Block 3, $W(12) = 0.83$, $p = .023$, and in the overall average sequence length, $W(12) = 0.83$, $p = .023$. Thus, nonparametric analyses had to be used. I conducted an independent-samples Mann-Whitney U test on species for each trial block individually as well as on the overall average sequence length and found that rhesus were choosing longer sequences than capuchins in Block 1, $U = 1.00$, $p = .014$, Block 3, $U = 1.00$, $p = .014$, Block 4, $U = 2.00$, $p = .028$, and overall, $U = 1.00$, $p = .014$, but not in Block 2, $U = 4.00$, $p = .077$. I also ran a

Friedman's test on average sequence length across blocks individually for each species and found no main effect of block for either the rhesus $\chi^2(3) = 5.79$, $p = .12$, or the capuchins, $\chi^2(3) = 1.72$, $p = .63$.

Lastly, I reran the Chi-Square Goodness of Fit test using the number of times they chose each sequence length but this time in the repeat condition, and I found that every subject retained the same bias pattern they showed in the Choice condition.

3.2.3   Reward Efficiency

To determine whether the monkeys' choices in the Choice condition were advantageous in terms of food rewards, I calculated for each monkey with the species-specific bias (any monkey who did not show this bias was excluded) the average number of pellets obtained per trial in the Forced and Choice conditions. I conducted a 2 x 3 mixed model repeated measures ANOVA on pellets per trial with species (rhesus and capuchin) as the between-subjects variable and condition as the within-subjects variable. There was not a significant interaction between the factors, $F(1, 9) = 0.067$, $p = .80$, $\eta p^2 = 0.007$, nor was there a main effect of species, $F(1, 9) = 1.53$, $p = .25$, $\eta p^2 = 0.15$, but there was a main effect of condition, $F(1, 9) = 7.09$, $p = .026$, $\eta p^2 = 0.44$. To investigate this main effect further, I ran post-hoc comparisons using a paired samples t-test and found that monkeys' reward efficiency was significantly higher in the Choice ($M = 1.60$) than the Forced ($M = 1.27$) condition, $t(10) = -3.40$, $p = .007$, $d = -1.03$.

To investigate this further, I calculated the monkeys' cumulative pellets earned every 10 trials (totaling 16 "session checkpoints") in the choice condition and ran a 2-way GLM on cumulative pellets using species and session checkpoint as factors. The interaction was not significant, $F(15, 138) = 0.27$, $p = .997$, $\eta p^2 = 0.03$, but species had a significant main effect, $F(1, 138) = 4.50$, $p = .036$, $\eta p^2 = 0.03$, as did session checkpoint, $F(15, 138) = 22.39$, $p < .001$,

$\eta p^2 = 0.71$, which is to be expected considering the nature of the analyses and the fact that monkeys had learned the sequences, resulting in consistent (though not constant) pellet rewards. I conducted an independent-samples t-test on the effect of species on average number of pellets accumulated, and found no significant difference, $t(9) = 0.90$, $p = .39$, $d = 0.70$.

3.2.4   Post-Hoc Explorations

Several interesting patterns appeared in the data, prompting explorations that were not originally planned. The first was to assess the potential cause of the species difference in sequence length bias.

The exploration into reward efficiency did not offer an explanation, but one explanation could be a difference in the animals' testing conditions, with rhesus monkeys having more time and physical space with their computers than capuchins (see Section 4.3 for more details). To test whether rhesus monkeys were potentially coping with the more frequent timeouts by taking a break from testing, I looked at their session duration data and calculated the average number of trials per minute for each monkey in their first and last session in each condition. I ran a 2 x 2 x 3 mixed models repeated measures ANOVA on trials per minute using species (between-subjects), session (first vs. last, within-subjects), and condition (within-subjects) as factors, excluding monkeys who did not show the species-specific sequence length bias. None of the interactions (3-way or 2-way) were significant, nor were any of the main effects significant (all $p > .05$). This suggests that the monkeys were not completing their trials at different rates, and thus that rhesus monkeys were not likely taking breaks from the program to cope with increased timeouts associated with the higher risk of the difficult sequences. This also suggests that these monkeys did not become more or less efficient with their time across the duration of the study, nor was their rate of trial completion different between the conditions.

The next exploration arose from visual inspection of each monkeys' average pellet efficiency across the sessions (Figure 3.2), which revealed different reward efficiency groups. Specifically, there seemed to be two "high-efficiency" monkeys, five "mid-efficiency" monkeys, and four "low-efficiency" monkeys (specific groups defined in Table 3.2).
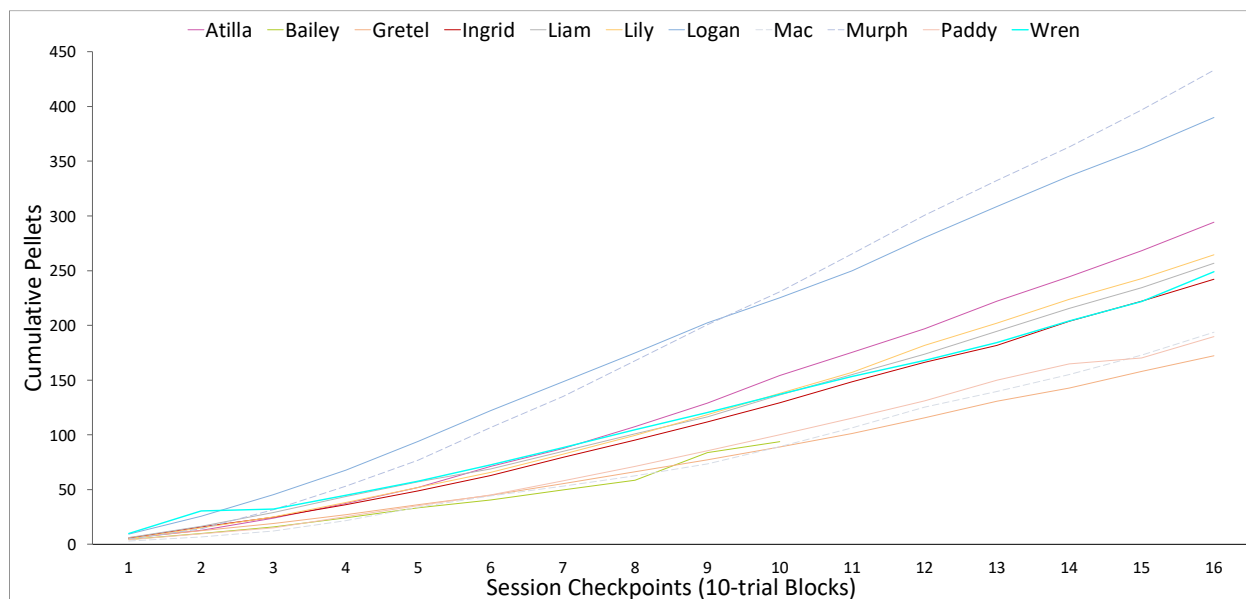
Note. Data for rhesus monkeys is depicted using dotted lines, data for capuchins using solid lines. The number of pellets at each checkpoint was the average cumulative number of pellets they had received on the last trial in the checkpoint (e.g., trial 10 in checkpoint 1).

Figure 3.2 Individual Monkeys' Pellet Efficiency Across Choice Sessions

Table 3.2 Efficiency Groupings

Monkey Name	Age (Y)	Species	Average Pellets Accumulated
High-Efficiency			
Murph	31	Rhesus	433.10
Logan	18	Capuchin	390.00
Mid-Efficiency			
Attila	11	Capuchin	294.33
Ingrid	11	Capuchin	242.22
Liam	20	Capuchin	256.89
Lily	26	Capuchin	264.50
Wren	21	Capuchin	248.89
Low-Efficiency			
Mac	8	Rhesus	193.67

Bailey[*]	24	Capuchin	93.8
Paddy	13	Capuchin	189.63
Gretel	20	Capuchin	172.13

Note. * = Monkey consistently did not complete all 160 trials in a session.

To test whether these groups were significantly different from each other, I conducted a 2-way GLM on accumulated pellets using efficiency group (between-subjects) and session checkpoints (within-subjects) as factors. The interaction between group and session checkpoint was significant, $F(30, 122) = 35.29$, $p < .001$, $\eta p^2 = 0.90$. To investigate this interaction, I conducted a 1-way GLM on accumulated pellets using group as a factor separately for each session checkpoint and ran post-hoc paired comparison tests with a Bonferroni correction of alpha to .017 and found no effect of group after the first ten trials (checkpoint 1), $F(2, 8) = 1.45$, $p = .29$, $\eta p^2 = 0.27$, after the second checkpoint, $F(2, 8) = 3.00$, $p = .11$, $\eta p^2 = 0.43$, but a significant main effect of group at the third checkpoint, $F(2, 8) = 17.11$, $p = .001$, $\eta p^2 = 0.81$, with the low-efficiency group ($M = 15.58$) having accumulated fewer pellets than the mid-efficiency ($M = 27.04$) and high-efficiency groups ($M = 38.5$), but no difference between the latter two. From the fourth checkpoint onwards, there was always a significant main effect of group (all $p < .001$), with the high-efficiency group having accumulated more pellets than both the mid-efficiency and low-efficiency group, and the mid-efficiency group always having accumulated more pellets than the low-efficiency group (all $p < .01$) (see Figure 3.3). Lastly, to attempt to determine what caused these different efficiency levels, I reran the original 2-way GLM using age as a covariant, and found no significant main effect of age, $F(1, 121) = 0.21$, $p = .65$, $\eta p^2 = 0.002$.
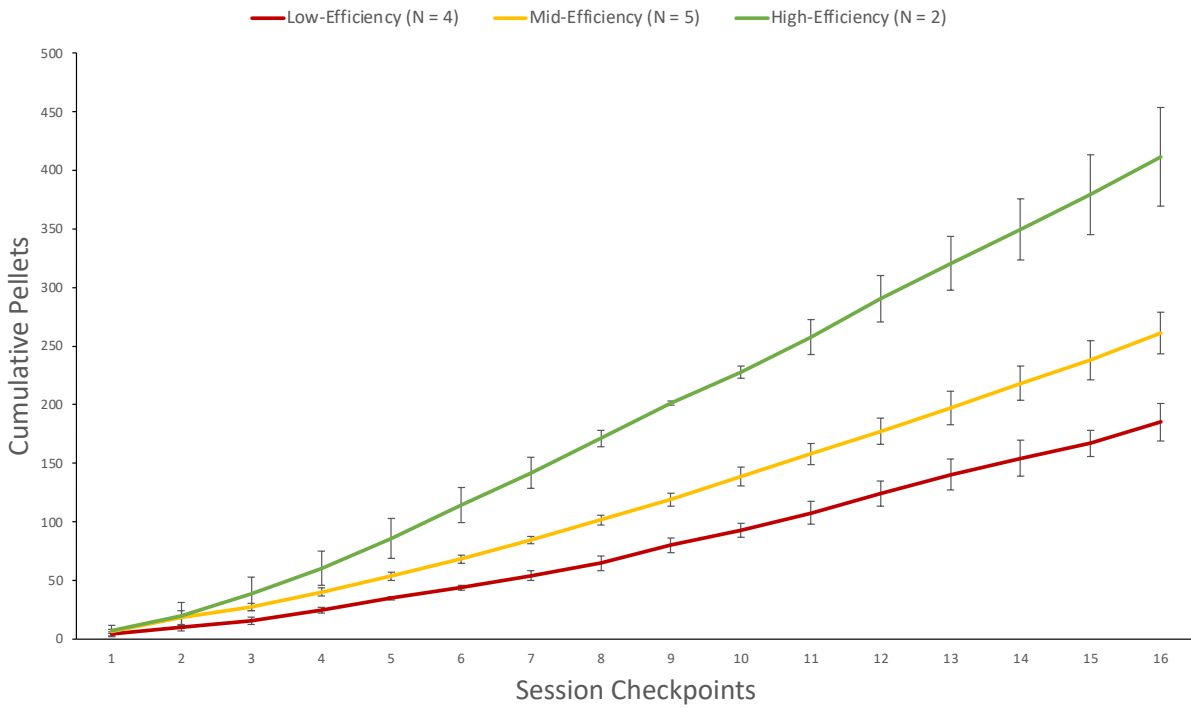
Note: Error bars represent 95% C.I.s

Figure 3.3 Cumulated Pellets Across Choice Sessions for Each Efficiency Group

4   CONCLUSION

The results from the training phase indicated that the rhesus monkeys and capuchins were no different in how long it took them to train on the task, and that there were no differences in how long it took for monkeys to train in each of the different phases, other than a significantly higher number of trials required in the final training phase than in the two-item training phase and the three-item training phase. This result was in line with expectations and indicated that both species learned to do a task, and that the objectively easier and harder version of the task were, in fact, easier and harder to complete.

The results in regard to accuracy demonstrated that Short sequences were sufficiently easier than Medium and Long sequences, and that Medium sequences were sufficiently easier than Long sequences, which is a pattern I expected to see. I also found a complicated effect of block, such that in the Forced and Choice conditions, monkeys demonstrated learning between Blocks 1 and 2, but no change between Blocks 2 and 3 or between Blocks 3 and 4. In the Repeat condition, there was no effect of block. Overall, monkeys performed better in the Repeat condition than in the other two conditions, but only in Block 1. This seems to suggest, overall, that the greatest rate of learning occurred within the first 80 trials of each session, and that increases in accuracy generally plateaued after that. Additionally, the fact that monkeys were familiar with the sequence and had already achieved that maximum level of learning boosted Repeat condition performance over and above the other two conditions, but that further learning did not occur with more experience in this condition. Supporting this idea is the finding that performance in the final block of Forced and Choice sessions matched that of the first block of Repeat sessions. Overall, it seems that learning did occur, but that 80 trials was sufficient enough experience time to reach peak performance on these sequences.

In the Choice condition, there emerged a significant trend in choice behavior, with most rhesus monkeys choosing to complete Hard sequences and avoiding the Medium sequences, and capuchins overwhelmingly choosing the Medium sequences and avoiding the Hard sequences. Most monkeys seemed to show low preference for the Short sequences regardless of species. The monkeys did not change their sequence choice within or across sessions. These findings are compelling when taking into consideration the respective cost/benefit relationship of each of the sequences. Short sequences were by far the easiest for the monkeys to complete and their performance matched this in all three conditions, but the small reward and the large cost stemming from the longest ITI of all the sequences meant that monkeys may have perceived these sequences as not worthwhile and avoided them altogether. Medium sequences had a higher level of risk, with chance performance changing from 50% (Short sequences) to 16.7%, but there was a larger reward, both in terms of number of pellets and decreased ITI. Long sequences had the highest level of risk, with chance performance being 4.2%, but the highest reward, again in terms of pellets and a decreased ITI. These biases contradict my prediction about the pattern of their choice behavior – if these animals were engaging in SDL, I expected them to choose Short sequences early in the task, then move to Medium sequences when they felt confident enough in their understanding of the first two items, then move to Long sequences when they felt confident in the first three, assuming metacognitive monitoring was taking place.

A question arises from this; was there an advantage to these strategies, even if SDL was not being used? The results suggest not: when investigating only the monkeys that showed their species-specific bias, no significant species (or, strategy) trends emerged when looking at average reward efficiency or reward efficiency over time within sessions.

Overall, the results from this experiment did not support the main hypotheses focused on self-directed learning – these monkeys, regardless of species, did not adjust the number of stimuli they chose to sequence based on experience or confidence, and rhesus monkeys did not outperform capuchins in the Choice condition. Thus, I cannot conclude that these data show any evidence of non-human primates' ability to self-direct their own learning. However, I did find interesting species differences in choice behavior, although these differing choice strategies did not appear to be advantageous. Despite that fact, there must be some reason for this species difference to emerge.

4.1   Conditioned Associations

One reason could be that the monkeys were reacting to their experience in the training phase. They could have developed a positive association with one of the sequence lengths and a negative association with the others. Research has shown that rhesus monkeys can learn negative and positive associations of stimuli and exhibit anticipatory behaviors depending on whether the association was positive or negative (Paton et al., 2006). In Rimpley and Buchanan-Smith (2013), capuchin monkeys learned to associate a predictable signal with aversive events (in this case, zookeepers entering their enclosure) and this predictable signal decreased anxiety-related behavior. It could be argued that these species use of uncertainty responses is a conscious avoidance of difficult trials, which carry with them a negative association (rhesus monkeys: Smith et al., 1997; capuchins: Beran et al., 2016). However, based on the analysis of their training data, and the fact that there were distinct species patterns in bias patterns, I believe this is unlikely in the present study. First, there were no species differences in overall training performance, which means that there should be no reason, based on training experience, for

rhesus monkeys to show a bias for the Long sequences and for capuchins to show a bias towards Medium sequences.

Second, there was no difference in the number of training trials that it took for monkeys to pass each training phase, other than a higher number of trials required for the final training phase compared to the two-item phase and the three-item phase. However, this was confounded by the fact that they only needed to complete a minimum of 22 trials to pass the two-item phase and 19 trials to pass the three-item phase (assuming 100% accuracy), and they were required to complete a minimum of 400 trials to pass the final training phase.

4.2   Species' Sequencing Abilities

Another possibility is that rhesus monkeys were simply better at the task and able to complete the Long sequences, while capuchins struggled with the Long sequences and defaulted to the most difficult discrimination that still yielded reward. This theory would predict an interaction between species and sequence length in the Forced condition, with rhesus monkeys showing higher performance than capuchins on Longer sequences, but I did not find this, nor were there any species differences in the other two conditions.

4.3   Testing Environment

Another reason could be the physical testing conditions of the monkeys. Two of the three rhesus monkeys (Luke and Murph) had access to their computers for 20 hours a day and the other rhesus monkey (Mac) had 24-hour access to his computer. Luke lost his social partner over the course of the study, at which point he also had 24-hour access to his computer. In contrast, while the main capuchin enclosures are large and allow for outdoor access overnight, the monkeys are separated from their social groups for testing. They have approximately 4 hours of computer access each day in a 35 cm x 60 cm x 46 cm testing box.

Part of the reason for this difference in caging size is that adult male rhesus monkeys are on average 7.7 kg and 47-53 cm long (Lewis & Prongay, 2015), while adult male capuchins are on average 3.65kg and 44.4 cm long, and females are on average 2.52 kg and 39 cm long (Gron, 2009). Additionally, rhesus monkeys live full-time in their testing cage, while capuchins are only separated into the testing boxes for computerized testing purposes.

Based on these differences, rhesus monkeys may have been motivated to take the riskier option for the higher payout because if they answered incorrectly, they had more space to move and distract themselves while they waited for the 30 second timeout. They also had more time with their testing system each day, giving them more time to complete the 160 (maximum) trials of the task. Capuchins may have been motivated to take the less risky option because they a) did not have as much room to distract themselves during timeouts and b) had less time with the testing system. The results from the Repeat condition suggest that monkeys of both species do retain memory of the sequence in previous sessions, so they may have been pressured to maximize reward within a session given that they had an 80% chance of having to learn a new sequence the next time they participated in the task.

This potential cause, while interesting, does not seem to be supported by the data (as there was no difference in the amount of time it took animals to complete the sessions) and would need additional testing. For instance, I would need to assess whether the rhesus monkeys engaged in movement in their testing enclosure during timeouts. No observational data were conducted during the task, so the monkeys' gross motor behavior while completing the task is unknown. The same goes for the capuchins – if they were motivated to do as many trials as possible, it would be important to assess whether they were working continuously throughout the testing session.

A more direct issue with this interpretation is that, if physical testing conditions affected these monkeys' respective strategies why do our two species behave similarly on some tasks but not others (such as the current one)? For instance, Watzek et al. (2018) tested these rhesus monkeys and capuchins on a "pursuit" task in their usual testing boxes to investigate sunk cost effects. The monkeys had to track a target with their cursor for varying periods of time (1, 5, or 7 seconds). They either completed trials in an unsignaled condition wherein they received no cue about the required duration of tracking, or signaled trials wherein the screen's color changed to different shades of gray to indicate how many required seconds of tracking remained. There was no timeout between trials, so failure to track the target for the required duration incurred no punishment other than the lack of rewards. If monkeys were performing optimally in the signaled condition, they would abandon the target based on the appropriate signal. In the unsignaled condition, optimal performance would involve abandoning the target after 1 s and either a) met the minimum tracking duration and received their reward, or b) failed to meet the minimum duration, but were able to move immediately to the next trial to try again. If they demonstrated the sunk cost effect, they would be more likely to track the target longer in the unsignaled condition due to uncertainty about the required tracking duration.

Watzek et al. (2018) found that both species were more likely to opt out of a trial when the remaining duration was signaled. When it was not signaled, they tracked the target for longer than 1s and they were more likely to continue based on how long they had already been tracking it. While there was a species difference in the extent of the sunk cost effect, with rhesus monkeys being more likely to continue than capuchins, both species nonetheless performed suboptimally. If differences in testing conditions were part of the reason for this sunk cost effect (which the authors do mention), one could expect that rhesus monkeys but not capuchins would fall victim

to it. The rhesus had more time with their computers and could afford to pursue the target for longer. The capuchins, however, because of the limited time in the testing box, should have completely abandoned every (unsignaled) trial after 1 s. The fact that they did not do may suggest that their behavior was not motivated by their testing conditions.

4.4   Risk Assessment and Uncertainty

There are two potential reasons that these monkeys chose and maintained a sequence length bias that are more rooted in cognition. These are risk assessment and uncertainty, both of which have been assessed in our animals. Both of these ideas center around the personal conceptualization of the unknown. Knight (1921) wrote that *risk* was involved in situations where we do not know the exact outcome, but strong predictions can be made about the odds of certain outcomes. *Uncertainty* refers to situations in which we do not have all the information necessary to predict any outcomes. The literature on uncertainty monitoring in our animals has been discussed, with our rhesus monkeys showing strong evidence that they monitor their uncertainty in discrimination tasks, and capuchins showing more rudimentary, context-dependent evidence (but evidence nonetheless; rhesus monkeys: Smith et al., 1997; capuchins: Beran et al., 2016).

If these animals were relying solely on uncertainty, I also would expect their choices to be different. A pure-uncertainty strategy would be my predicted one – that in Choice sessions monkeys would start with Short sequences when they were unfamiliar with any of the items, move to Medium sequences when they understood the order of the first two items, and then move to Long sequences when they understood the order of the first three items. Additionally, in the Repeat condition, because they were already familiar with the sequence, they should have started with the Medium or Long sequences to maximize their rewards. This would be the most

effective strategy for a self-directed learner, which these animals have not demonstrated themselves to be here.

Regarding risk, both of these nonhuman primate species have demonstrated a preference for risky choices, especially when the outcome of their decision was signaled to them (Smith & Beran, 2020), and after a high payout in the previous trial (rhesus: Smith et al., 2017; capuchins: Ciacci et al., 2023). Capuchins in general show a great tolerance for risk (Broihanne et al., 2019; De Petrillo et al., 2015, 2023), and rhesus monkeys show mixed evidence, with most computerized studies demonstrating risk-seeking behavior (Hayden et al., 2023; Stauffer et al., 2015) and a more naturalistic study using foraging behavior found that rhesus were risk-averse (Eisenreich, 2019). In fact, as discussed, increasing risk was the only way to compel capuchins' use of an uncertainty response, something that rhesus monkeys did at the original level of risk (Beran et al., 2016). Our capuchins even demonstrated a higher preference for risk than capuchins from the Unit of Cognitive Primatology and Primate Center in Italy in Ciacci et al. (2023)'s study. The capuchins in my study, curiously, showed the opposite trend compared to what is seen in the literature – they defaulted to a less (but not the least) risky option than the rhesus.

Our rhesus monkeys and capuchins have also shown suboptimal choice behavior in relation to risk. Notably, Smith and Beran (2020) found that monkeys' risky behavior did not reflect their reward efficiency. In fact, a significant negative correlation revealed that the more risk-prone the monkey was, the fewer pellets they received on average. Assuming that the monkeys in the current study were relying purely on the risks inherent in the task, they also showed suboptimal strategies here, as their reward efficiency was not different between the Forced and Choice conditions. Their overall accuracy also did not change when they were

allowed to choose the sequence length – the only time they saw any benefit in their performance across conditions was in the Repeat condition, when they were already familiar with the sequence. If they were relying on risk assessment, the optimal strategy would involve both species starting by choosing Medium sequences in the Choice condition and Long sequences in the Repeat condition (and avoiding Short sequences, as almost all of them seemed to do), but this did not occur. Each monkey had a specific bias, and they maintained this bias regardless of their familiarity with the stimuli. However, a suboptimal strategy does not rule out the possibility that they were relying on risk assessment. In fact, both humans and animals show suboptimal strategies when engaging in risk-based decision making (Cunningham & Shahan, 2019; Molet et al., 2012; Zentall, 2019).

4.5   Efficiency Groupings

While not a focus of the study, I did find through post-hoc investigations of reward efficiency three distinct groups of reward efficiency levels, with two monkeys being highly efficient, five being moderately efficient, and four being low in reward efficiency. However, it is unclear what factors may play a role in this grouping. Age did not appear to covary with grouping, but it is possible that testing experience could play a role. Leinwand and Brosnan (2019) found that change detection in a computerized cognitive task was different between two groups of capuchins based on relative computerized testing experience, with more experienced monkeys more able to detect change than those with less experience using the LRC's computerized testing system. However, at the time of this study, the difference between experience was substantial – the more experienced monkeys had lived at the LRC for nine years (though they may not have been fully trained on computerized testing that whole time), while the less experienced monkeys had been at the LRC for only one year at the time of the study. As of

the date of the current study, the less experienced monkeys have had roughly five years of experience with our systems, which is what Leinwand and Brosnan (2019) called "extensive experience." However, it should be noted that one of the low-efficiency monkeys (in fact, one of the lowest within that group, even), was the monkey with the least experience, so it is not out of the question that testing experience could play some (if not a definitive) role in these groupings. It would be appropriate to find data on and analyze the relationship between LRC computer testing experience and reward efficiency to rule this out officially.

Alternative factors that could play a role include dominance (though our rhesus monkeys do not experience social hierarchy to the extent that our group-housed capuchins do) or various executive functioning abilities such as working memory span, inhibitory control, cognitive flexibility, etc. It would be interesting to test these animals on measures of these abilities and examine any relationships between them and the reward efficiency groupings.

4.6   Conclusion

Although I did not demonstrate the SDL abilities of animals in this study, it is not out of the question that they do have these abilities. The methodology I used here was the first of its kind, as to date SDL has not been investigated in animals. In this design, subjects who engaged in SDL would have had to gauge their performance on a trial-to-trial performance via metacognitive monitoring, the assessment of one's own cognitions and knowledge (Son & Schwartz, 2002). Metacognitive monitoring, despite potentially improving performance, can be cognitively exhausting (Gog et al., 2011; Seufert, 2018; Wang & Lajoie, 2023). It is likely that animals (and humans) are much more likely to choose a less demanding strategy when it is readily available, even if the metacognitive (or SDL) strategy would be more rewarding.

The data collected so far have prompted several possible avenues for future research. The first involves collecting additional data. As mentioned, I have no way of knowing what the monkeys were physically doing while they completed the task. To assess whether rhesus monkeys used self-distraction during the task, whether that be through engaging with something else in their enclosure, additional sessions could be run while filming the monkeys, and behavioral observations could be compared to their task performance.

A second option would be to present this task to humans to see if they use the optimal SDL strategy. If they do, I will know that the task generates SDL, but the monkeys just chose to not engage in it. If humans do not show SDL, it may mean that there were flaws in the methodology that discouraged or did not allow SDL to occur. I could also present this to a species such as chimpanzees or bonobos, who show advanced cognitive abilities more akin to our own. If these species (or other great apes) demonstrate SDL in this task, I would have evidence for SDL in a nonhuman animal and it could be argued that the ability to self-direct one's own learning evolved after we diverged from our most common ancestor with monkeys, or that monkeys are less motivated to engage in SDL than are great apes.

A new task to assess SDL could be developed, one that does not allow (or discourages) the use of simpler strategies. For instance, rather than being able to choose, on a given trial, whether you would like to test yourself on an "Easy," "Medium," or "Hard" discrimination, the task could just offer two difficulty levels. Alternatively, rather than allowing subjects to choose how hard they test themselves on a trial-to-trial basis, the task could involve a number of trials at a given difficulty level, and then allow the animals to either graduate to a higher difficulty for a better reward or stay at their current level. This model closely resembles the Keller Plan, a method of instruction designed to personalize the learning process for the learner (Keller, 1968).

This method, which predates Knowles' (1975) publication on SDL, includes five key features, two of which are applicable to nonhuman learning. The first is the "go-at-your-own-pace feature," by which students are allowed to progress to new units in the classroom when they desire, and the "unit-perfection requirement for advance," which only allows students to progress to new materials when they demonstrate mastery of the current materials (Keller, 1968, p. 83).

In practice, this could involve a standard cognitive task, such as sequencing. The animals would need to be trained to understand some icon that represents moving to a higher difficulty for a higher reward, and another that represents staying at the same difficulty level. Monkeys would learn to sequence a set of stimuli, and then once reaching a performance criterion, be prompted to choose between staying or moving on. This way, rather than making a decision in every trial, monkeys would only make a decision once they have mastered a given sequence. This is just one example of a new task that could probe at the SDL abilities of animals.

Lastly, the species differences I found in task strategy offer numerous avenues for potential future work. For instance, it could be that the relative ITIs in the task played a role in the monkeys' choice behavior. The low ITI of the Long sequences could have motivated rhesus monkeys to prefer these sequences while the high difficulty deterred capuchins, or the 5-second difference in ITI between the Medium and Long sequences might not have been sufficient motivation to attempt these sequences, compared to the 10-second difference between the Short and Medium sequences. I intentionally structured these ITIs the way I did to offer additional motivation for monkeys to want to graduate their performance from the Short to the Long sequences (as I assumed monkeys, given no motivation other than reward, would not go beyond Short sequences) and to change the risk level of the sequences, but many configurations of the ITI and timeout structure exist. For instance, I could alter the task so that the ITIs remain the

same between sequence lengths, but the timeouts could increase with increasing sequence length. I could also alter the ITIs as they are, making the differences in their values more extreme. Lastly, an adjustment procedure similar to that used by Evans et al. (2014) could be employed in which the task would track the delay tolerance for each monkey and adjust the program to increase (or decrease) the delay until a change in behavior was seen.

In conclusion, while this study did not support the ability of rhesus monkeys or capuchins to self-direct their own learning, it did demonstrate an interesting species difference in task strategy, with rhesus monkeys choosing the riskiest sequence lengths and capuchins choosing those with a lower level of risk (but still not the lowest-risk option available to them). I also found distinct groupings in reward efficiency, with three significantly different levels of efficiency emerging. It remains to be seen what might account for the differences in learning strategy and reward efficiency, and whether other variations of this task, or development of new tasks, can generate more positive evidence that nonhuman primates can engage in SDL.

REFERENCES

Adams, A., & Santi, A. (2011). Pigeons exhibit higher accuracy for chosen memory tests than for forced memory tests in duration matching-to-sample. *Learning & Behavior*, *39*, 1-11.

Atkinson, R., & Shiffrin, R. (1968). Human memory: A proposed system and its control processes. In K. Spence & J. Spence (Eds.). *The psychology of learning and motivation: Advances in research and theory* (Vol. 2). Academic Press.

Basile, B. M., Hampton, R. R., Suomi, S. J., & Murray, E. A. (2009). An assessment of memory awareness in tufted capuchin monkeys (*Cebus apella*). *Animal Cognition*, *12*(1), 169-180.

Beran, M. J., Brandl, J., Perner, J., & Proust, J. (2012). *Foundations of metacognition*. Oxford University Press.

Beran, M. J., Klein, E. D., Evans, T. A., Chan, B., Flemming, T. M., Harris, E. H., Washburn, D. A., & Rumbaugh, D. M. (2008). Discrimination reversal learning in capuchin monkeys (*Cebus apella*). *The Psychological Record*, *58*, 3-14.

Beran, M. J., & Smith, J. D. (2011). Information seeking by rhesus monkeys (*Macaca mulatta*) and capuchin monkeys (*Cebus apella*). *Cognition*, *120*(1), 90-105.

Beran, M. J., Smith, J. D., Redford, J., Washburn, D. (2006). Rhesus macaques (*Macaca mulatta*) monitor uncertainty during numerosity judgments. *Journal of Experimental Psychology Animal Behavior Processes, 32(2),* 111-119.

Beran, M. J., & Parrish, A. E. (2012). Sequential responding and planning in capuchin monkeys (*Cebus apella*). *Animal Cognition*, *15*, 1085-1094.

Beran, M. J., Parrish, A. E., Perdue, B. M., & Washburn, D. A. (2014). Comparative cognition: Past, present, and future. *International Journal of Comparative Psychology*, *27*, 3-30.

Beran, M. J., Perdue, B. M., Church, B. A., & Smith, J. D. (2016). Capuchin monkeys (*Cebus apella*) modulate their use of an uncertainty response depending on risk. *Journal of Experimental Psychology: Animal Learning and Cognition*, *42*(1), 32-43.

Bernhard, S. M., Lee, J., Zhu, M., Hsu, A., Erskine, A., Hires, S. A., & Barth, A. L. (2020). An automated homecage system for multiwhisker detection and discrimination learning in mice. *PLoS ONE*, *15*(12), e0232916.

Bethell, E. J., Holmes, A., MacLarnon, A., & Semple, S. (2012). Cognitive bias in a non-human primate: Husbandry procedures influence cognitive indicators of psychological well-being in captive rhesus macaques. *Animal Welfare*, *21*(2), 185-195.

Bitterman, M. E. (1960). Toward a comparative psychology of learning. *American Psychologist, 15*(11), 704–712.

Brockett, R. G., & Hiemstra, R. (1991). *Self-direction in adult learning: Perspectives on theory, research, and practice*. Routledge.

Broihanne, M.-H., Romain, A., Call, J., Thierry, B., Wascher, C. A. F., De Marco, A., Verrier, D., & Dufour, V. (2019). Monkeys (*Sapajus apella* and *Macaca tonkeana*) and great apes (*Gorilla gorilla, Pongo abelii, Pan paniscus,* and *Pan troglodytes*) play for the highest bid. *Journal of Comparative Psychology*, *133*(3), 301-312.

Brown, J. S., Kalish, H. I., & Farber, I. E. (1951). Conditioned fear as revealed by magnitude of startle response to an auditory stimulus. *Journal of Experimental Psychology*, *41*(5), 317-328.

Bruner, J. (2004). A short history of psychological theories of learning. *Daedalus*, *133*(1), 13–20.

Bruner, J. S., Goodnow, J. J., & Austin, G. A. (1956). *A study of thinking*. Wiley.

Chou, P.-N. (2012). Effect of students' self-directed learning abilities on online learning outcomes: Two exploratory experiments in electronic engineering. *International Journal of Humanities and Social Science*, *2*(6), 172-179.

Ciacci, F., Mayerhoff, S., De Petrillo, F., Gastaldi, S., Brosnan, S. F., & Addessi, E. (2023). State-dependent risky choices in primates: Variation in energy budget does not affect tufted capuchin monkeys' (*Sapajus* spp.) risky choices. *American Journal of Primatology*, *85*(10), e23542.

Coolican, P. M. (1975). *The learning styles of mothers of young children* (Doctoral dissertation). Syracuse University.

Corbeil, J. R. (2003). *Online technologies self-efficacy, self-directed learning readiness, and locus of control of learners in a graduate-level web-based distance education program.* Unpublished doctoral dissertation. The University of Houston, Houston, TX.

Cunningham, P. J., & Shahan, T. A. (2012). Rats engage in suboptimal choice when the delay to food is sufficiently long. *Journal of Experimental Psychology: Animal Learning and Cognition*, *45*(3), 301-310.

D'Amato, M. R., Salmon, D. P., Columbo, M. (1985). Extent and limits of the matching concept in monkeys (*Cebus apella*). *Journal of Experimental Psychology: Animal Behavior Processes*, *11*(1), 35-51.

D'Amato, M. R., Salmon, D. P., Loukas, E., & Tomie, A. (1985). Symmetry and transitivity of conditional relations in monkeys (*Cebus apella*) and pigeons (*Columba livia*). *Journal of the Experimental Analysis of Behavior*, *44*(1), 35-47.

Darwin, C. (1871). *The descent of man, and selection in relation to sex*. John Murray.

De Petrillo, F., Rossi, F., Gastaldi, S., & Addessi, E. (2023). Do tufted capuchin monkeys, *Sapajus* spp., experience regret in decision making under risk? *Animal Behaviour*, *202*, 73-86.

De Petrillo, F., Ventricelli, M., Ponsi, G., & Addessi, E. (2014). Do tufted capuchin monkeys play the odds? Flexible risk preferences in *Sapajus* spp. *Animal Cognition*, *18*, 119-130.

Dewsbury, D. A. (1987). Animal intelligence: A construct neither defined nor measured. *Behavioral and Brain Sciences, 10*(4), 661.

Domjan, M. (1987). Animal learning comes of age. *American Psychologist*, *42*(6), 556-564.

Eisenreich, B. R., Hayden, B. Y., & Zimmermann, J. (2019). Macaques are risk-averse in a freely moving foraging task. *Scientific Reports*, *9*, 15091.

Evans, T., Beran, M. J., Chan, B., Klein, E., & Menzel, C. R. (2008). An efficient computerized testing method for the capuchin monkey (*Cebus apella*): Adaptation of the LRC-CTS to a socially housed nonhuman primate species. *Behavior Research Methods*, *40*(2), 590-596.

Evans, T. A., Perdue, B. M., Parrish, A. E., & Beran, M. J. (2014). Working and waiting for better rewards: Self-control in two monkey species (*Cebus apella* and *Macaca mulatta*). *Behavioural Processes*, *103*, 236-242.

Falótico, T. (2022). Robust capuchin tool use cognition in the wild. *Current Opinion in Behavioral Sciences*, *46*, 101170.

Flavell, J. H. (1976). Metacognitive aspects of problem solving. In L. B. Resnick (Ed.), *The nature of intelligence* (pp. 231-236). Erlbaum.

Flavell, J. H. (1979). Metacognition and cognitive monitoring: A new area of cognitive-developmental inquiry. *American Psychologist*, *34*(10), 906–911.

Frazer, L. D., Schwartz, B. L., Metcalfe, J. (2021). The MAPS model of self-regulation: Integrating metacognition, agency, and possible selves. *Metacognition and Learning*, *16*, 297-318.

Fritz, M. F. (1930). A note on the use of tools by the white rat. *Journal of Genetic Psychology*, *37*, 330-331.

Follmer, D. J., & Sperling, R. A. (2016). The mediating role of metacognition in the relationship between executive function and self-directed learning. *British Journal of Educational Psychology*, *86*(4), 559-575.

Foote, A. L. & Crystal, J. D. (2007). Metacognition in the rat. *Current Biology, 17,* 551-555.

Fujita, K. (2009). Metamemory in tufted capuchin monkeys (*Cebus apella*). *Animal Cognition*, *12*, 575-585.

Fujita, K., Kuroshima, H., & Asai, S. (2003). How do tufted capuchin monkeys (*Cebus apella*) understand causality involved in tool use? *Journal of Experimental Psychology: Animal Behavior Processes*, *29*(3), 233–242.

Fujita, K., Kuroshima, H., & Matsuda, T. (2002). Do tufted capuchin monkeys (*Cebus apella*) spontaneously deceive opponents? A preliminary analysis of an experimental food-competition contest between monkeys. *Animal Cognition*, *5*, 19-25.

Garrison, D. R. (1997). Self-directed learning: Toward a comprehensive model. *Adult Education Quarterly*, *48*(1), 18-33.

Georghiades, P. (2004). From the general to the situated: Three decades of metacognition. *International Journal of Science Education*, 26(3), 365-383.

Glaubman, R., Glaubman, H., & Ofir, L. (1997). Effects of self-directed learning, story comprehension, and self-questioning in kindergarten. *The Journal of Educational Research*, *90*(6), 361-374.

Grether, W. E, & Maslow, A. H. (1937). An experimental study of insight in monkeys. *Journal of Comparative Psychology*, *24*, 127-134.

Gron, K. J. (2009, April 17). Primate factsheets: Tufted capuchin (*Cebus apella*) taxonomy, morphology, & ecology. *Wisconsin National Primate Research Center*. https://primate.wisc.edu/primate-info-net/pin-factsheets/pin-factsheet-tufted-capuchin/

Guglielmino, L. M. (1978). Development of the self-directed learning readiness scale (Doctoral dissertation, University of Georgia, 1977). *Dissertation Abstracts International Section A: Humanities and Social Sciences, 38*(11-A), 6467.

Gureckis, T. M., & Markant, D. B. (2012). Self-directed learning: A cognitive and computational perspective. *Perspectives on Psychology*, *7*(5), 464-481.

Hampton, R. R. (2001). Rhesus monkeys know when they remember. *Proceedings of the National Academy of Sciences*, *98*, 5359-5362.

Harlow, H. F. (1949). The formation of learning sets. *Psychological Review*, *56*(1), 51-65.

Hayat, A. A., Shateri, K., Amini, M., & Shokrpour, N. (2020). Relationships between academic self-efficacy, learning-related emotions, and metacognitive learning strategies with academic performance in medical students: A structural equation model. *BMC Medical Education*, *20*, 1-11.

Hayden, B. Y., Heilbronner, S. R., Nair, A. C., & Platt, M. L. (2023). Cognitive influences on risk-seeking by rhesus macaques. *Judgement and Decision Making*, *3*(5), 389-395.

Hiemstra, R. (1975). *The older adult and learning*. (ERIC Report No. ED 117 371). Syracuse University Press.

Hiemstra, R. (1994). Self-directed learning. In T. Husen & T. N. Postlethwaite (Eds.), *The international encyclopedia of education* (2nd ed.). Pergamon Press.

Houle, C. O. (1961). *The inquiring mind*. University of Wisconsin Press.

Hwang, M. H., Choi, H. C., Lee, A., Culver, J. D., & Hutchison, B. (2016). The relationship between self-efficacy and academic achievement: A 5-year panel analysis. *The Asia-Pacific Education Researcher*, *25*, 89-98.

Jin, M., & Cheng, J. (2020). The correlation of metacognitive ability, self-directed learning ability and critical thinking in nursing students: A cross-sectional study. *Nursing Open*, *8*(2), 936-945.

Kalin, N. H., Shelton, S. E., Davidson, R. J., & Lynn, D. E. (1996). A new method for aversive pavlovian conditioning of heart rate in rhesus monkeys. *Physiology & Behavior*, *60*(4), 1043-1046.

Kincannon, J., Gleber, C., & Kim, J. (1999, February 10-14). *The effects of metacognitive training on performance and use of metacognitive skills in self-directed learning situations* [Paper presentation], National Convention of the Association for Educational Communications and Technology, Houston, TX, USA.

Kishimoto, R., Iwasaki, S., & Fujita, K. (2019). Do capuchins (*Sapajus apella*) know how well they will remember? Analysis of delay length-dependency with memory strategies. *Journal of Comparative Psychology*, *133*(3), 340-350.

Kluver, H. (1933). *Behavior mechanisms in monkeys*. University of Chicago Press.

Knowles, M. (1975). *Self-directed learning: A guide for learners and teachers.* Association

    Press.

Kohler, W. (1925). *The mentality of apes*. Routledge.

Kolb, A. Y., & Kolb, D. A. (2009). The learning way: Meta-cognitive aspects of experiential

    learning. *Simulation & Gaming*, *40*(3), 297-327.

Krechevsky, I. (1932). "Hypotheses" in rats. *Psychological Review*, *39*, 516-532.

Lefrancois, G. R. (2000). *Theories of human learning: What the old woman said* (5th ed.).

    Thomson Learning.

Leinwand, J. G., & Brosnan, S. F. (2019). Capuchin (*Sapajus* [*Cebus*] *apella*) change detection.

    International Journal of Comparative Psychology, *32*, 43086.

Lewis, A. D., & Prongay, K. (2015). Chapter 6 – Basic physiology of *Macaca mulatta*. In J.

    Bluemel, S. Korte, E. Schenck, & G. F. Weinbauer (Eds.). *The nonhuman primate in*

    nonclinical drug development and safety assessment (pp. 87–113). Academic Press.

Lissek, S., Biggs, A. L., Rabin, S. J., Cornwell, B. R., Alvarez, R. P., Pine, D. S., & Grillon, C.

    (2008). Generalization of conditioned fear-potentiated startle in humans: Experimental

    validation and clinical relevance. *Behaviour Research & Therapy*, *46*(5), 678-687.

Lounsbury, J. W., & Gibson, L. W. (2006). *Personal Style Inventory: A personality measurement*

    system for work and school settings. Resource Associates, Inc.

Lounsbury, J. W., Levy, J. J., Park, S.-H., Gibson, L. W., & Smith, R. (2009). An investigation

    of the construct validity of the personality trait of self-directed learning. *Learning and*

    Individual Differences, *19*, 411-418.

Loyens, S. M. M., Magda, J., & Rikers, R. M. J. P. (2008). Self-directed learning in problem-based learning and its relationships with self-regulated learning. *Educational Psychology Review*, *20*, 411-427.

Maestripieri, D. (2003). *Primate psychology*. Harvard University Press.

Mayer, R. E. (1992). Cognition and instruction: Their historic meeting within educational psychology. *Journal of Educational Psychology, 84*(4), 405–412.

Mayer, R. E. (2009). *Multimedia learning* (2nd ed). Cambridge University Press.

Mayer, R. E. (2011). *Applying the science of learning*. Pearson Merrill Prentice Hall.

Molet, M., Miller, H. C., Laude, J. R., Kirk, C., Manning, B., & Zentall, T. R. (2012). Decision making by humans in a behavioral task: Do humans, like pigeons, show suboptimal choice? *Learning & Behavior*, *40*, 439-447.

Morgan, C. L. (1894). *An introduction to comparative psychology*. Walter Scott Publishing Co.

Mun, H., Saab, B. J., Ng, E., McGirr, A., Lipina, T. V., Gondo, Y., Georgiou, J., & Roder, J. C. (2015). Self-directed exploration provides a *Ncs1*-dependent learning bonus. *Scientific Reports*, *5*.

Murphy, R. A., Mondragon, E., & Murphy, V. A. (2008). Rule learning by rats. *Science*, *319*(5871), 1849-1851.

Örs, M., & Titrek, O. (2018). The correlation between metacognitive awareness level and self-directed learning readiness of undergraduate nursing and midwifery students. *Journal of Education and Training Studies*, *6*(11), 218-228.

Paton, J. J., Belova, M. A., Morrison, S. E., & Salzman, C. D. (2006). The primate amygdala represents the positive and negative value of visual stimuli during learning. *Nature, 439,* 865–870.

Paukner, A., Anderson, J. R., & Fujita, K. (2006). Redundant food searches by capuchin monkeys (*Cebus apella*): A failure of metacognition? *Animal Cognition*, *9*, 110–117.

Pavlov, I. P. (1906). The scientific investigation of the psychical faculties or processes in the higher animals. *Science*, *24*(620), 613-619.

Peters J. M., & Gordon, R. S. (1974). *Adult learning projects: A study of adult learning in urban and rural Tennessee.* (ERIC Report No. ED 102 431). University of Tennessee Press.

Pilling-Cormick, J. (1996). *Development of the self-directed learning perception scale* (Doctoral dissertation). University of Toronto.

Powell, R. A., & Schmaltz, R. M. (2021). Did Little Albert actually acquire a conditioned fear of furry animals? What the film evidence tells us. *History of Psychology*, *24*(2), 164-181.

Perdue, B. M., Bramlett, J. L., Evans, T. A., & Beran, M. J. (2015). Waiting for what comes later: Capuchin monkeys show self-control even for nonvisible delayed rewards. *Animal Cognition*, *18*, 1105-1112.

Perdue, B. M., Church, B. A., Smith, J. D., & Beran, M. J. (2015). Exploring potential mechanisms underlying the lack of uncertainty monitoring in capuchin monkeys. *International Journal of Comparative Psychology*, *28*, 1-18.

Piaget, J. (1971). The theory of stages in cognitive development. In D. R. Green, M. P. Ford, & G. B. Flamer (Eds.), *Measurement and Piaget,* 1-11. McGraw-Hill.

Richardson, W. K., Washburn, D. A., Hopkins, W. D., Savage-Rumbaugh, E. S., & Rumbaugh, D. M. (1990). The NASA/LRC computerized test system. *Behavior Research Methods, Instruments, & Computers*, *22*(2), 127-131.

Rimpley, K., & Buchanan-Smith, H. M. (2013). Reliably signaling a startling husbandry event improves welfare of zoo-housed capuchins (*Sapajus apella*). *Applied Animal Behaviour Science*, *147*(1-2), 205-213.

Roitblat, H. L., Terrace, H. S., & Bever, T. G. (1984). *Animal cognition*. Psychology Press.

Romanes, G. J. (1882). *Animal intelligence*. Hesperides Press.

Seufert, T. (2018). The interplay between self-regulation in learning and cognitive load. *Educational Research Review*, *24*, 116-129.

Shaine, M. H. (2015). The effect of self-regulated learning strategies and self-efficacy on academic achievement of primary school students. *Psychology and Behavioral Sciences*, *4*(3), 107-115.

Shettleworth, S. J. (1998). *Cognition, evolution, and behavior*. Oxford University Press.

Shields, W. E., Smith, J. D., & Washburn, D. A. (1997). Uncertain responses by humans and rhesus monkeys (*Macaca mulatta*) in a psychophysical same-different task. *Journal of Experimental Psychology: General*, *126*(2), 147-164.

Silasi, G., Boyd, J. D., Bolanos, F., LeDue, J. M., Scott, S. H., & Murphy, T. H. (2018). Individualized tracking of self-directed motor learning in group-housed mice performing a skilled lever positioning task in the home cage. *Journal of Neuropsychology*, *119*, 337-346.

Skinner, B. F. (1948). 'Superstition' in the pigeon. *Journal of Experimental Psychology*, *38*, 168-172.

Skinner, B. F. (1957). The experimental analysis of behavior. *American Scientist*, *45*(4), 343-371.

Skinner, B. F. (1963). Operant behavior. *American Psychologist*, *18*(8), 503-515.

Smith, J. D., Schull, J., Strote, J., McGee, K., Egnor, R., & Erb, L. (1995). The uncertain response in the bottlenosed dolphin (*Tursiops truncatus*). *Journal of Experimental Psychology: General*, *124*, 391-408.

Smith, J. D., Shields, W. E., Schull, J., & Washburn, D. A. (1997). The uncertain response in humans and animals. *Cognition*, *62*(1), 75-97.

Smith, T., Parrish, A. E., Creamer, C. L., Rossettie, M. S., & Beran, M. J. (2020). Capuchin monkeys (sometimes) go when they know: Confidence movements in *Sapajus apella*. *Cognition*, *199*, 104237.

Smith, T. R., Smith, J. D., & Beran, M. J. (2018). Not knowing what one knows: A meaningful failure of metacognition in capuchin monkeys. *Animal Behavior and Cognition*, *5*(1), 55-67.

Son, L. K., & Schwartz, B. L. (2002). The relation between metacognitive monitoring and control. In T. J. Perfect and B. L. Schwartz (Eds.), *Applied metacognition,* 15-38. Cambridge University Press.

Stauffer, W. R., Lak, A., Bossaerts, P., & Schultz, W. (2015). Economic choices reveal probability distortion in macaque monkeys. *Journal of Neuroscience*, *35*(7), 3146-3154.

Templer, V. L., Brown, E. K., & Hampton, R. R. (2018). Rhesus monkeys metacognitively monitor memories of the order of events. *Scientific Reports*, *8*, 11541.

Terrace, H. S., Son, L. K., & Brannon, E. M. (2003). Serial expertise of rhesus macaques. *Psychological Science*, *14*, 66-73.

Tolman, E. C. (1928). Purposive behavior. *Psychological Review*, *35*, 524-530.

Tolman, E. (1948). Cognitive maps in rats and men. *Psychological Review*, *55*, 189–208.

Tough, A. (1971). *The adult's learning projects: A fresh approach to theory and practice in adult learning*. Pfeiffer & Co.

Tough, A. (1979). *The adult's learning projects* (2nd ed.). Institute for Studies in Education.

Tourrance, E. P., & Mourad, S. (1978). Some creativity and style of learning and thinking correlates of Guglielmino's Self-Directed Learning Readiness Scale. *Psychological Reports*, *43*, 1167-1171.

United States Department of Agriculture. (1991). Animal welfare; Standards; Final rule. *Federal Register, 56*, 6426-6505.

van Gog, T., Kester, L., & Paas, F. (2011). Effects of concurrent monitoring on cognitive load and performance as a function of task complexity. *Applied Cognitive Psychology*, *25*(4), 584-587.

van Heijningen, C. A. A., Chen, J., van Laatum, I., van der Hulst, B., & ten Cate, C. (2013). Rule learning by zebra finches in an artificial grammar learning task: Which rule? *Animal Cognition*, *16*, 165-175.

Vining, A. Q., & Marsh, H. L. (2015). Information seeking in capuchins (*Cebus apella*): A rudimentary form of metacognition? *Animal Cognition*, *18*(3), 667-681.

Voss, J. L., Gonsalves, B. D., Federmeier, K. D., Tranel, D., & Cohen, N. J. (2011). Hippocampal brain-network coordination during volitional exploratory behavior enhances learning. *Nature Neuroscience*, *14*, 115-120.

Wang, T., & Lajoie, S. P. (2023). How does cognitive load interact with self-regulated learning? A dynamic and integrated model. *Educational Psychology Review*, *35*, 69.

Washburn, M. F. (1908). *The animal mind; a text-book of comparative psychology*. The Macmillan Company.

Washburn, D. A., Smith, J. D., & Shields, W. E. (2006). Rhesus monkeys (*Macaca mulatta*) immediately generalize the uncertain response. *Journal of Experimental Psychology: Animal Behavior Processes*, *32*, 85-89.

Watson, J. B., & Rayner, R. (1920). Conditioned emotional responses. *Journal of Experimental Psychology*, *3*(1), 1-14.

Watson, J. B. (1930). *Behaviorism*. University of Chicago Press.

Watzek, J., & Brosnan, S. F. (2020). Capuchins and rhesus monkeys show sunk cost effects in a psychomotor task. *Scientific Reports*, *10*, 20396.

Wilson, B., Mackintosh, N. J., & Boakes, R. A. (1985). Transfer of relational rules in matching and oddity learning by pigeons and corvids. *The Quarterly Journal of Experimental Psychology Section B: Comparative and Physiological Psychology*, *37*(4b), 313-332.

Zentall, T. R. (2019). What suboptimal choice tells us about the control of behavior. *Comparative Cognition Behavior Reviews*, *14*, 1-17.

Zhoc, K. C. H., Chung, T. S. H., & King, R. B. (2018). Emotional intelligence (EI) and self-directed learning: Examining their relation and contribution to better student learning outcomes in higher education. *British Educational Research Journal*, *44*(6), 982-1004.

Zhou, L., & Li, C. (2020). Can student self-directed learning improve their academic performance? Experimental evidence from the instruction of protocol-guided learning in China's elementary and middle schools. *Science Insights Education Frontiers*, *5*(1), 469-480.