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Elizabeth Haseltine

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For the Sake of Curiosity: Do Monkeys Choose to View Counterfactual Information?

by

Elizabeth L. Haseltine

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ABSTRACT

Counterfactuals are alternative outcomes to past events. Curiosity for the counterfactual acts as an important driver of learning under uncertainty and helps to improve on past behaviors. This experiment observed counterfactual information collection rates during times of uncertainty and also assessed the willingness of nonhuman primates to gain information when there was a cost or benefit associated. Humans (Experiment 1), capuchins, and rhesus macaques (Experiments 1 and 2) were presented with a three-choice gambling task that consisted of hidden and visible reward values. When choosing visible reward values, participants could view the counterfactual information associated with the gamble. Only humans collected counterfactual information at levels different than chance. Humans also collected counterfactual information significantly more than capuchins. When monkeys saw trials in which the counterfactual information had a greater or lesser reward value compared to the noninformative option, the difference between the reward values was the sole predictor of choice.

INDEX WORDS: Counterfactual, Curiosity, Monkeys, Gambling, Decision Making, Comparative Cognition

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by

Elizabeth L. Haseltine

Committee Chair: Michael Beran

Committee: Sarah Brosnan
Heather Kleider-Offutt

Electronic Version Approved:

Office of Graduate Services
College of Arts and Sciences
Georgia State University
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DEDICATION

This thesis is dedicated to the people that have supported me throughout my education, particularly my parents, Melanie and Ken Haseltine, and my husband, Ryan Van Oost. The outpour of love, encouragement, and support you have all given me has guided me through this process. Thank you for continually helping me to achieve my goals, I will always be grateful.

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1 INTRODUCTION

Have you ever wondered what your life could have been like if you had made alternative choices or acted differently? Where would you be now if you had taken a different job, did not have kids, or moved away from home? Do you imagine yourself to be happier under alternative circumstances? As humans we create numerous “what if” and “if only” thoughts in everyday life. Some of these thoughts are about choices so consequential they reroute your path of life, for example, “what if I had taken a job right out of college instead of going to graduate school?” Some are not as significant, for example, “if only I had remembered to wash my dishes earlier.” These thoughts are termed counterfactuals. Past research has suggested that counterfactuals aid in decision making and future problem solving and are contributors to levels of life satisfaction (Medvec et al., 1995). Some people experience these thoughts to a higher degree than others, but most people produce these reflections at least occasionally, especially following a failure (compared to a success; Epstude & Roese, 2008). In this thesis, I will investigate the earliest emerging form of counterfactual interaction, counterfactual curiosity (or counterfactual seeking), discuss its advantages, and explore the possibility that nonhuman primates share the human desire to collect this information.

1.1 What is Meant by Counterfactual?

The term ‘counterfactual’ refers to something that is counter to established facts. Counterfactual thoughts are produced by thinking about what would have happened (or what was likely to have occurred) if what actually happened did not take place. Humans encounter counterfactuals frequently, appearing as thoughts, reasonings, or information as a byproduct of curiosity. Our ability to think counterfactually and create these false scenarios likely comes from advanced cognitive processes such as the ability to create mental simulations, produce abstract thoughts, and the capacity for cognitive control (Van Hoeck et al., 2015). Gaining counterfactual information through observation is a much simpler task, as one does not have to use any imaginative thought to determine different outcomes. This type of counterfactual information is frequently gained when gambling after revealing the alternative outcome. Our tendencies to be curious about and actively seek out counterfactual information (i.e., counterfactual curiosity) likely contributes to the desire to construct false scenarios or seek out factual alternatives. This curiosity is frequently displayed by our actions and demonstrated by our questioning of the world.

Counterfactual conditionals derive from acknowledging what event or action could have been different (the antecedent), and usually alter some outcome (the consequent). If one produces the thought, “If I had studied more, I would have passed the test,” the antecedent is studying more, while the consequent is passing the test. However, not all counterfactual expressions require the use of a consequent. For instance, if you ordered the chicken at a restaurant and your dining partner ordered the steak, thinking, “I should have ordered the steak” is still a counterfactual thought. In this scenario, you are comparing the two outcomes (ordering the chicken and ordering the steak) even though you did not explicitly state this. In another variation of consequent utilization, a counterfactual behavior could also result in the same outcome as reality. This is termed semifactual. Here, an alternative path does not change the situational outcome (e.g., “If I had studied more, I still would not have passed the test.”).

1.2 Describing Counterfactuals

There are multiple descriptors that help define the nature or even emotional output of a counterfactual thought. These descriptions include episodic and semantic (De Brigard & Giovanello, 2012), additive and subtractive (Begeer et al., 2009), or self- and other-focused

(Roese, 1997). The most prominent categorizations are upward and downward thoughts (Roese & Morrison, 2009).

1.2.1 Downward Counterfactuals

Downward counterfactuals occur when the alternative outcome is believed to be a *worse* outcome than reality; there is a perceived situational "win." Imagine being on a game show and having to pick one of two prizes: $5,000 or a prize hidden behind a curtain. This mystery item could be anything from an item with no value to a brand new $30,000 car. Choosing the guaranteed money and thinking, "If I had picked the mystery box, I could have gone home with no prize" is a downward counterfactual. This is because you are experiencing a world in which reality is superior to an imagined alternative. People who tend to be more agreeable (Ardakani et al., 2014) and optimistic (Kasimatis & Wells, 1995) engage in greater levels of downward counterfactual thinking. Advantages include gaining insight into avoiding future difficulties and feelings of relief and satisfaction (Epstude & Roese, 2008). These emotions communicate that our behaviors match our goals and that no behavioral modifications are necessary. Downward counterfactuals can also be valuable for the continuation of the status quo and to serve as a preventative function to identify how to stay away from situations in which an outcome could be worse (Roese & Epstude, 2017).

1.2.2 Upward Counterfactuals

Upward counterfactuals occur when the imagined scenario ends with what the actor believes is a *better* outcome than reality; there is a realized or perceived loss of a more satisfying outcome. Using the previous example, thinking, "If I had taken the mystery box, I could have received a much better prize" is an upward counterfactual because in that moment, you are creating a false reality in which there is a more positive alternative outcome. Unsurprisingly, upward counterfactual production tends to increase following negative life events and decisions one may see as reversible (opposed to irreversible; Hafner et al., 2012). People who possess more openness (Ardakani et al., 2014) and have lower levels of self-esteem (Roese & Olson, 1993) typically produce more upward counterfactuals. Compared to downward counterfactuals, upward counterfactuals are more likely to be automatic thoughts and are perceived as more vivid and realistic. Upward counterfactuals are also more prevalent, with multiple studies demonstrating that unrestricted counterfactual thoughts concerning recent events were as much as 90 to 95% upward (Petrocelli et al., 2012; Roese, 1997).

The most common undesirable outcome of an upward counterfactual is negative affect (such as regret, disappointment, or guilt), which is a direct result of upward counterfactuals. This negative affect may facilitate depression and anxiety disorders, especially when produced in excess (De Brigard et al., 2013). So why, if upward counterfactuals are closely tied to negative feelings, would they comprise the vast majority of counterfactual thoughts produced? Ultimately, counterfactual thinking is a performance-enhancing tool, and humans use this tool to evaluate past scenarios and gain problem-solving insights (Epstude & Roese, 2008). This allows someone to determine a more appropriate behavior to exhibit in the future if that event was to happen again. Similarly, upward counterfactuals may be closely related to the enhancement of motivation and self-efficacy (compared to downward counterfactuals) and heightening perceived opportunity, which is a contributing factor to behavior regulation techniques (Roese, 1994; Tal-Or et al., 2004; Wong, 2007).

1.3 Counterfactual Theories

Multiple frameworks attempt to shed light on the purpose of counterfactual thoughts and reasoning. The theories continue to expand with the growing body of empirical literature and are not always mutually exclusive. Some theories, such as Norm Theory (Kahneman & Miller, 1986), have contributed to a conceptual understanding of counterfactual reasoning. On the other hand, Functional Theory of Counterfactual Thinking (Epstude & Roese, 2008) has provided an explanation as to why this phenomenon has emerged in humans. As this theory describes the evolutionary reasoning for counterfactuals, this will be the theory of focus.

1.3.1 Norm Theory

The development of Norm Theory by Kahneman and Miller (1986) largely introduced psychology to the study of counterfactual thought. This conceptual framework ties closely to the literature on regret, one of the emotions that results exclusively through interactions with counterfactuals and the ensuing situational comparisons (Beck et al., 2014; Epstude & Roese, 2008; Mandel & Dhami, 2005). Norm Theory states that the normality of an event is important to the formation of a counterfactual and the occurrence of an abnormal or unusual event is positively correlated with counterfactual thoughts and feelings of regret. Norm Theory also serves as a link between counterfactuals and the action-effect literature which rules inaction as normal and taking an action to be abnormal. Consequently, humans tend to associate more regret when actions lead to negative experiences opposed to inactions that lead to the same experiences (Feldman & Albarracín, 2017). Since counterfactuals increase with abnormality, this provides an explanation as to why actions produce more regret (and thus counterfactuals) than inaction, as shown extensively within the literature (Byrne, 1997).

1.3.2 Functional Theory of Counterfactual Thinking

Through Functional Theory of Counterfactual Thinking, Epstude and Roese (2008; see also Roese & Epstude, 2017) described the positive influence of counterfactual thought on behavior regulation and performance enhancement. In this theory, the main function of counterfactuals is to reflect the goals of an individual and implement necessary behavioral changes. This theory followed some of the earliest research on counterfactuals which claimed that these thoughts can produce error, bias, and may be dysfunctional (e.g., Gleicher et al., 1990; Macrae, 1992). Functional Theory does not dismiss any negative outputs of counterfactual thoughts but instead supports the idea that the benefits produced greatly outweigh the consequences.

Epstude and Roese (2008) propose through Functional Theory that counterfactuals may guide behavior through either a content-specific or content-neutral pathway. The content-specific pathway activates when information gained from a counterfactual directly results in modified future behaviors due to the perceived effectiveness of an event on an outcome. For example, the thought, “If I had watched the oven more closely, my cookies would not have burned” may lead directly to the behavior of setting a timer or checking the oven more frequently. Three steps are identified that ultimately results in a behavior change through the content-specific pathway: 1) a problem or negative affect is recognized, initiating counterfactual thinking, 2) the counterfactual produces a mental simulation that shows an alternative life path based on the behavior revision, activating an intention, and finally 3) the intention will modify existing behaviors or produce new behaviors during the same or similar situation in the future.

One the other hand, the content-neutral pathway results in a more generalized behavior. This stems from a broader desire for a behavior change and is not directly related to the information gained from the counterfactual (e.g., “I could have done better”). The causal inference about a potential behavior seen in the content-specific pathway is not present in the content-neutral pathway. Instead, the content-neutral pathway directs how to store the gained information and supports one’s mindset (e.g., through shifts in attention), motivation (e.g., through negative affect or regulatory focus), or self-inference (e.g., feelings of situational control or overconfidence).

Although evidence has largely supported Functional Theory, it has not gone without criticism. For instance, some studies found that of counterfactuals produced, the majority were modifying uncontrollable aspects of past events (opposed to the individual’s own modifiable behavioral output; Ferrante et al., 2013; Mercier et al., 2017). This directly impacts the claim that the main purpose of counterfactuals is to serve as preparation for future situations. Other studies have produced contradictory results, providing evidence that counterfactuals, specifically episodic counterfactuals, do tend to focus on controllable action (Markman & Miller, 2006; McEleney & Byrne, 2006). It has also been found that self-blame may be a direct result of counterfactuals when looking at self-controlled behaviors and actions (Davis et al., 1996; Mandel & Dhami, 2005). Additionally, producing many (as opposed to few) counterfactual thoughts about a single scenario increased the prevalence of hindsight bias, (one’s overestimation of knowledge about a situation’s outcome; Sanna et al., 2002). This bias has been linked to having a greater perceived control than what one actually has, producing issues of overconfidence and the failure to correctly adapt behaviors. Further evidence challenging Functional Theory comes from Petrocelli et al. (2013, 2016) who reported a link between counterfactuals and reduction in performance. Specifically, the frequency of counterfactuals negatively correlated with performance and learning. Considering this, counterfactuals in excess may lead to harmful consequences, but in moderation they largely provide favorable outcomes.

Overall, Functional Theory identifies multiple behavioral benefits that result from counterfactual thoughts and reasoning and lead to behavioral enhancements (Epstude & Roese, 2008, 2017). The alignment of current and future behaviors strengthens planning and insight, but also produces emotions such as regret, relief, satisfaction, and guilt to ensure we are on the pathway to our goals. Counterfactual curiosity also acts as a facilitator to learning processes during times of uncertainty as it influences an actor to seek out the results of rejected choices. Additional benefits of counterfactuals manifest in the form of perceived control (McMullen et al., 1995; Nasco & Marsh, 1999), motivation (Tal-Or et al., 2004; Wong, 2007), and performance influence (Landman et al., 1995; Markman et al., 2008; Roese, 1994). With these highly beneficial outputs, counterfactual thought could be considered a fundamental feature of intellect (Epstude & Roese, 2008).

1.4 Counterfactual Reasoning and Future Oriented Thinking

Counterfactual thoughts revolve around past events and scenarios that one cannot change. Although these thoughts do influence future behaviors, counterfactuals are not equivalent to future thinking and hypothetical thought. Future thinking focuses on outcomes that have the possibility of being true in the future, and counterfactual thinking strictly focuses on how past outcomes could have been different; they are concerned with events that will never be true nor possible. However, when it comes to reasoning about matters of fact, possibilities, and impossibilities, researchers have proposed that the same processes and mental representations are necessary (Byrne, 1998). Even so, there are multiple differences between past and future thinking tendencies and evidence suggests that future-centered thoughts and simulations may be easier to produce than counterfactual ones (Burns et al., 2019).

Despite these distinctions, there is interplay between counterfactual reasoning and future-oriented thought such as prospective memory (and prospection in general). To fully encompass the preparative function of counterfactual thinking, one must be able to use their past experiences to guide their future behaviors, and this often means storing and recalling the desired behavioral modifications. However, counterfactuals do not always work perfectly; sometimes we forget what we wanted to do in lieu of a more automatic reaction, or sometimes we recognize what we should do but lack the motivation to carry it out. Additionally, some of the counterfactual information we collect only loosely embodies its preparative function. For instance, when playing Blackjack, a person may “stay” with their hand of 16 out of caution, but realize when the next person “hit,” a 3 was dealt and they would have had a hand that was more likely to win. Having this counterfactual realization does not provide a strong future advantage since it is highly unlikely that the same hand and order of cards in the dealing deck will occur again (at least in any reasonable time period). And, more importantly, “hitting” on 16 is generally a bad decision probabilistically. This type of counterfactual reinforces your knowledge of the probabilistic (not always realistic) outcome that you are likely already aware of. However, the counterfactual may still fill a current emotional void (should you feel relief or regret?) and no matter how unlikely, it is still generalizable, guiding behavior through a content-neutral pathway during future gambling (or gambling-like) situations, potentially even through a more subconscious experience (such as presenting itself as a gut feeling).

1.5 Drive of Curiosity

The drive to learn about the world and objects within our environment starts at a young age, guiding us to perform certain behaviors. The high level of curiosity seen in humans might have played a major role in increasing our evolutionary fitness. When living in rapidly changing environments, curiosity enables one to investigate and learn about novelties through visual exploration or physical manipulation. Not only do humans have a desire to learn things that directly impact their lives, as in cases of survival, but they also have a desire to know trivial information. Humans have even shown sustained curiosity for information under circumstances such as the fear of being shocked (Lau et al. 2020), when the information provides no apparent benefit (Marvin & Shohamy, 2016), and when the information comes at a cost (Rodriguez-Cabrero et al., 2019). For example, Rodriguez-Cabrero et al. (2019) presented adult humans with a computerized task that "dealt" three randomized cards face-down on each trial. After a delay, all card images were revealed at no cost, and the number of matching cards indicated the magnitude of payout. When presented with the ability to reveal the outcome of some or all the cards before the end of the time delay, participants paid using points that corresponded to a cash payout to reveal the card images on up to 25% of trials.

Curiosity surrounding counterfactuals produces even greater levels of potentially critical information than general curiosity; it allows the actor to know not only what did happen, but any other alternatives that may have happened, providing the greatest future advantage. Utilizing counterfactual curiosity, humans may "stock up" on all available information to help learn and better prepare for any future circumstance, even when the desired information has little importance to one's current situation. For example, on a Balloon Analogue Risk Task, adults "pumped" a computerized balloon, attempting to make as many pumps as possible before the balloon burst (FitzGibbon et al., 2021). When the information came with no cost, participants collected the counterfactual about how many times they could have pumped the balloon on 67% of trials. Adults have also sought counterfactual information when they perceived it as useful for the future, under circumstances with greater uncertainty, when the participant felt responsible for the factual outcome, and when the fear of missing out was elevated (Shani et al., 2008; Shani & Zeelenberg, 2007). Other studies have demonstrated that even when participants anticipated feelings of regret that would result from uncovering information, they elected to view the counterfactual anyhow (Summerville, 2011; van Dijk & Zeelenberg, 2007). This indicates that the desire for knowledge under uncertainty has a stronger pull than the negative consequences of knowing. Adults have also shown a preference to reveal counterfactuals when there was a small monetary cost to do so (FitzGibbon et al., 2021). These results suggest a robust human desire (at least among modernized cultures) to possess this nonfactual information. While counterfactual thought appears to be a common occurrence in multiple modern cultures (Chen et al., 2006; Maitner & Summerville, 2022), no known studies have investigated counterfactual curiosity outside of traditionally WEIRD populations.

1.6 Animal Use of Counterfactuals and the Potential for Nonhuman Counterfactual Curiosity

Multiple species employ exploratory behaviors to learn about novel situations and objects, ultimately allowing for more chances to better adapt to the environment (Forss & Willems, 2022; Glickman & Sroges, 1966; Hall et al., 2018). Some nonhuman primate studies assessing curiosity have provided evidence that novelty may not be the sole driver of curiosity and investigatory behaviors in nonhuman animals. For instance, Blanchard et al. (2015) tested rhesus macaques on a gambling task that gave subjects the chance to view the outcome of their gamble 2.25 seconds in advance. Viewing this information did not allow the subjects to change their response or alter the outcome of their reward. However, choosing to view this information did come at a cost to the subjects. Even so, Blanchard et al. found that the monkeys preferred trials where they saw advanced information over receiving no information, matching reports with humans (Rodriguez-Cabrero et al., 2019). This indicates that rhesus macaques may have the same drive as humans to acquire information even when they are unable to alter their current outcome.

Like humans, animals could benefit from counterfactual information and thought in many circumstances. If time is considered economically, then animals need to optimize how they spend their time to gain resources and progress through the social hierarchy. Thinking counterfactually and seeking information about alternative food patches that could have been visited or how to improve on a social interaction could increase one's overall fitness. Only one known study has been conducted to observe whether monkeys may be counterfactually curious. Wang and Hayden (2019) tested two water-deprived rhesus macaques on a gambling task and gave them the chance to obtain information about what they could have received if they made a different choice. Each trial, the subjects saw two long rectangular bars, one on the left side of the screen and the other on the right. These bars used color to provide a visual representation of the probability of water reward. For instance, one bar colored as 1/3 green and 2/3 red represented a 33% chance of a large reward and a 66% chance of no reward while the second bar colored as 3/4 dark blue and 1/4 red indicated a 75% chance of a medium reward and a 25% chance of no reward. In some trials, one of the bars had a small blue dot placed in the center. If the monkeys chose the bar with the dot, they would receive their reward and view a visual representation of the outcome of both probability bars.

In Wang and Hayden's (2019) task, the subjects preferred to view counterfactual information over receiving no information. In fact, to receive this information, these water-deprived monkeys often sacrificed the probability of a greater water reward in lieu of the probability of a smaller water reward that produced information. Wang and Hayden (2019) claimed these results met their proposed criteria necessary for human-like curiosity in animals: 1) being willing to sacrifice a reward, 2) gaining information that provides no benefit, and 3) the payment amount being dependent upon the value of the provided information. However, while the researchers introduced randomized outcomes that would not help on future trials, it is unlikely the information truly provided no benefit. In general, previous task experience helps one to predict probable outcomes, and the monkeys could not have been aware that it was impossible to optimize their responses on this nested gambling task. Additionally, providing water through tasks to deprived subjects likely creates a stronger desire for task optimization, producing a greater need for information. The nature of the methods also manufactured situations where the monkeys not only had to choose between which proportion bar they wanted to gamble on, but whether they wanted the counterfactual information. These separate choices made in conjunction may have impacted response patterns as choosing or not choosing the counterfactual information led to very different results, instead of having one set outcome and asking whether they wanted the information or not. The methods also included a visual stimulus to obtain counterfactual information while the opposing choice remained unchanged, making gaining information more salient. This leads to the potential of increasing intrigue toward the counterfactual choice because it was visually different.

Using a modified rock-paper-scissors game, researchers observed the strategic gameplay of two rhesus macaques against a computerized opponent (Lee et al., 2005). In this task, eye trackers allowed subjects to indicate their decisions through their visual fixations. Three different stimuli represented the choices between rock, paper, and scissors. Each symbol won against one other symbol and lost to the third, just like a game of rock-paper-scissors. Lee et al. found that the monkeys’ subsequent moves had a bias based on the previous choice of the computer. The monkeys often displayed a strategy of 1) picking the same move after a win or 2) picking the move that would have resulted in a win after losing. The second was especially true for one of the two monkeys, who Lee and colleagues claimed was showing evidence of belief learning.

Belief learning is the tendency of a player to consider past actions of their opponent to predict the opposition's future move, enabling the player to use hypotheticals and plan accordingly. The authors attributed these results to the capability of the participating monkeys to apply their knowledge of counterfactual outcomes to future trials.

With the same rock-paper-scissors concept, Abe and Lee (2011) tested three rhesus macaques and found the monkeys were adjusting their actions based on both their actual and counterfactual outcomes. Specifically, following a loss or tie, all three monkeys tended to choose the move that would have produced a winning result during the previous trial. Similar to Lee et al.'s (2005) claim, this led the authors to assert the monkeys were using belief learning to complete the task.

Hayden et al. (2009) presented two rhesus macaques with eight identical target stimuli positioned in a circle around the starting point onscreen. Seven of these targets produced a small reward and one target produced a varying reward amount that could be higher or lower than the outcome of the other seven. After the monkeys selected their stimulus, the trial ended and the value of each target was revealed, with the color indicating reward amount. Results of this study provided further support for the ability of nonhuman primates to recognize, respond to, and utilize counterfactual outcomes. Here, the choices that would have generated a win in the previous trial tended to influence the monkeys' stimulus choice in the following trial (i.e., monkeys were more inclined to choose or not choose these locations based on their value in the previous trial). The results also indicated a prioritization of theoretically non-beneficial information as the trials were independent and completely randomized, making the information gained on one trial of no advantage on the next. If confirmed that the monkeys were using knowledge of fictive outcomes to pick a stimulus, this would provide evidence that nonhuman primates are able to acknowledge the possibility of an alternative reality and that they can use those counterfactuals to modify their future behaviors and choice patterns. However, as may be true for this study as well as the rock-paper-scissors studies (Abe & Lee, 2011; Lee et al., 2005), the monkeys could have been selecting based off a rule of choosing the last stimulus to provide the greatest reward, without the need to produce a counterfactual thought.

Kim et al. (2015) conducted a study with rats where they manipulated the magnitude of factual and fictive rewards to test for influences of counterfactuals on behavior. From a start box, a rat traversed a short distance and chose between one of two adjacent goal boxes. The barrier between these goal boxes was transparent and had small holes to allow visual and olfactory access. Once the subject chose a goal box, the researchers placed a counterfactual (and unobtainable) reward in the unchosen box. After the rat had the opportunity to obtain information about the counterfactual reward magnitude, that reward was removed from the unchosen box and the rat was given the (factual) reward magnitude associated with the box they chose. The researchers found that the magnitude of the counterfactual outcome tended to predict the rats' choice on the trial that immediately followed. Much like the findings with rhesus macaques (Abe & Lee, 2011; Hayden et al., 2009; Lee et al., 2005), the results of Kim et al. indicate that the capability to modify behavior based on counterfactual knowledge may not be uniquely human.

If the capacity to recognize, use, and seek out counterfactuals is indeed present in nonhuman animals, it would be of value to assess their ability to use counterfactual knowledge to adapt behavior. As suggested in the Functional Theory, storing information through a content-specific pathway is most effective for particular modifications in behavior (Epstude & Roese, 2008). Often, employing a content-specific pathway may necessitate prospective memory to help an individual remember to carry out an intended behavior in the future. Multiple studies have supported the use of prospective memory in nonhuman primates (including rhesus macaques and capuchin monkeys), sometimes in a human-like capacity (Evans & Beran, 2012; Evans et al., 2014; Perdue et al., 2014). This suggests that if counterfactual information was available, some nonhuman primates could store and recall this information to use in a future situation. However, it would likely be more common for animals to store information in a content-neutral pathway. This would still need an individual to (on some level) recognize the presence of a counterfactual, but it would be a more simplified way to utilize the information as it is applied more broadly and not to a specific context.

To show full counterfactual comprehension, the capacity to think divergently and to know that more than one possibility exists is critical. Previous studies (Redshaw & Suddendorf, 2016; Suddendorf et al., 2017, 2020) attempted to identify whether nonhuman primates can mentally represent multiple versions of the future, but those studies showed inconclusive results. Redshaw and Suddendorf (2016) designed an inverted Y-shaped apparatus that allowed researchers to drop a ball or food reward down a single hole with the possibility of it coming out one of two exits on the bottom. Children as young as two years old, but not chimpanzees and orangutans, understood the two exit possibilities and repeatedly covered both holes instead of only one. By three years of age, many of the children possessed this ability and most 4-year-olds successfully covered both openings. Other studies used this apparatus with chimpanzees, orangutans, and three species of monkeys (including a capuchin monkey; Lambert & Osvath, 2018; Suddendorf et al., 2017, 2020). All resulted in a similar outcome; none of the nonhuman primates consistently succeeded at the task.

Considering that nonhuman primates have shown no strong evidence of this type of divergent thinking ability, there may be limited capacity for the creation of counterfactual thought in nonhuman primate species. However, these studies might not have truly demonstrated the abilities of the nonhuman primates, as a deficit in motor coordination or the demands of attention may have impacted the results (Lambert & Osvath, 2018). Additionally, previous training of the nonhuman primates in cognitive studies likely focused on always making a single choice, providing a puzzling situation when the task at hand is looking for the subjects to choose both exit points.

An interesting question is whether cognitive processes in monkeys and other nonhuman primates are developed enough to understand and produce counterfactuals similar to what we see in humans during later childhood and into adulthood. However, the ability to be curious about counterfactuals may emerge at an earlier cognitive stage (around 4 or 5 years old; FitzGibbon et al., 2019) than the spontaneous production and full comprehension of counterfactual reasoning used in preparation for the future (around 12 years old; Rafetseder et al., 2010, 2013). This prompts a second question of whether nonhuman primates actively seek out counterfactuals, regardless of their ability to understand what the counterfactual represents. Because counterfactual curiosity appears to be a precursor to counterfactual thought and reasoning, this seems like a more appropriate first question. Despite many species displaying information-seeking behaviors (e.g., Glickman & Sroges, 1966), it is not clear whether the same intrinsically motivated exploration is present in animals. It is also unclear whether nonhuman primates possess the capacity to recognize multiple situational outcomes or use counterfactuals to their full future-benefiting extent (e.g., Redshaw & Suddendorf, 2016). However, the ability to use observed counterfactuals (even in the likely absence of spontaneous production abilities) may exist in nonhuman animals, as displayed in rhesus macaques and rats (Kim et al, 2015; Lee et al., 2005). Additionally, multiple features enable a counterfactual to be as simple or as complex as necessary to fit the presented situation and characteristics of the user (e.g., age, level of anxiety, species). For example, there are observable counterfactuals in which no imagined outcome is necessary (e.g., revealing a card during a game of Blackjack). Counterfactuals can also surround fact-based or structural knowledge (such as recognizing the value of the cards), and they do not need a stated consequent that directly projects into the future (e.g., "I stayed at 16 and the next card was a queen").

If monkeys show patterns of counterfactual curiosity, it may suggest a human-like desire to obtain information that is deep within our evolutionary roots. The presence of counterfactual usage in nonhuman primates would also indicate similar cognitive mechanisms used for problem solving, decision making, and behavior adaptation in humans. With this knowledge, we could analyze human counterfactual usage in a comparative light, employing nonhuman primate models to help pinpoint potential causes for the limitations and biases found within the ways we utilize counterfactuals (e.g., hindsight bias, consequences from excessive production). The ability to recognize these faults would provide us with the understanding necessary to overcome biases and use this tool to its full advantage. While previous studies have provided support for animals' capacity to seek information about alternative outcomes and use knowledge gained from counterfactuals, the body of literature is still small and necessitates further studies that might provide support in either direction.

2 THE CURRENT STUDY

Years of research and extensive evidence have supported the idea of counterfactual curiosity, thoughts, and reasoning in adult humans. Comparatively, there is limited evidence of this capacity in nonhuman primates. Only a few studies have demonstrated the potential use of counterfactual information (Abe & Lee, 2011; Hayden et al., 2009; Lee et al., 2005) and evidence that monkeys, like humans, seek out this information, even at a cost (Wang & Hayden, 2019).

In this study, I used a gambling task to observe counterfactual curiosity, applying similar methods to three species: humans, capuchin monkeys, and rhesus macaques. Multiple species of monkeys, including rhesus macaques and capuchins, have the ability to accurately judge quantities (e.g., Beran et al., 2012; Brannon et al., 2000), a necessary skill for my task. Capuchins have also demonstrated an ability to logically solve gambles involving uncertainty, specifically during tasks in which there was one visible reward and one unknown reward displayed (Beran et al., 2012). Before this study, rhesus macaques were the only nonhuman primates to have participated in experiments specifically focused on counterfactuals, making them an ideal species to provide a direct comparison between the current study and the previous literature. There was also an increase in the sample size as previous relevant nonhuman primate studies have only included a maximum of three participants. Presenting capuchin monkeys with this task also introduces a new species to the literature, provides support through a large nonhuman primate sample, and offers an interesting perspective between old world and new world monkeys. Furthermore, this is the first study to directly compare the choices of humans to nonhuman primates in a counterfactual task.

Studies with humans indicate an interest in gaining the counterfactual information (FitzGibbon et al., 2019, 2021). Similar results in either or both monkey species would provide new insight into decision-making in nonhuman primates and give support to the potential for nonhuman animals to modify future behavior based on the outcome of past events. This would also suggest the monkeys' potential to conceptualize at least one alternative reality, and indicate the ability to think divergently, at least to some degree. However, evidence of counterfactual curiosity does not guarantee the presence of the advanced cognitive abilities required to produce counterfactual thought and reasoning. Showing no signs of counterfactual curiosity would not rule out the possibility that they possess these capabilities but may indicate that the task at hand does not appropriately fill their need to seek out counterfactual information. Reversely, null results in the monkey species could indicate a lack of curiosity stemming from the disuse or inability to employ counterfactuals to modify future behaviors, but the scope of this study could not confirm this. Differing behavior patterns may also signify species differences resulting from our evolutionary histories and will allow us to better parse out what mechanisms and situations may be necessary to provoke curiosity about counterfactuals. Focusing investigations on nonhuman primate populations additionally may shed some light on the human developmental nature of counterfactual curiosity and thinking, the cognitive mechanisms behind these processes, and the prevalence of decision-making biases surrounding uncertainty in humans.

In this experiment, I focused on the resolution of uncertainty by providing participants with information about a reward value they could have obtained if they made a different choice. In this study, I aim to answer the following questions: do monkeys possess counterfactual curiosity under times of uncertainty? Will monkeys actively seek out counterfactual information when there is no immediate, or obvious benefit in doing so? Finally, under what conditions will a monkey choose to receive additional information about a past event?

In Experiment 1, I will assess whether monkeys are curious about counterfactual information, and specifically the choice option they could have chosen but ultimately decided against. In Experiment 2, I will assess how important this counterfactual information is to them. In other words, if the monkeys have a preference for the informative option in Experiment 1, then Experiment 2 will provide a sense of when the costs outweigh the benefits of information. If the monkeys show a preference for choosing the noninformative option over viewing the counterfactual information in Experiment 1, then Experiment 2 will demonstrate what level of reward produces a great enough benefit to choose to view the counterfactual information.

In Wang and Hayden's (2019) design, two unknown reward values with likelihood proportions were available for subjects to choose from. Some trials allowed subjects to gain counterfactual information, indicated by a blue dot. Here, only one of the proportions would result in the accompanying information. These methods resulted in situations in which there was an inner-gamble risk as the monkeys would choose between two unknown reward values in which there is no guarantee of the desired reward. The current study presented more simplified methods and consistently presented subjects with one guaranteed reward. These changes depict a clearer representation of the subject's choice to gain (or not gain) counterfactual information by allowing them the exact same reward outcome whether they chose the informative option or not; the choice to view counterfactual information was not forced based on the gamble they wanted to take. Finally, Wang and Hayden (2019) always indicated the choice to gain information with a pre-gamble visual stimulus and a lack of the visual stimulus with gaining no information. A general attraction to the additional stimulus may have emerged, causing the macaques to choose the option to gain information. To address this, the presented methods equally emphasized the two information-related response options (informative or noninformative) to remove the chance of a bias towards the counterfactual.

I predicted that this task would elicit counterfactual curiosity in all three species. Specifically, I hypothesized that 1) all species would possess counterfactual curiosity when presented with the same methods but that 2) the adult human participants would show the strongest patterns of counterfactual curiosity compared to rhesus macaques and capuchin monkeys. This prediction is supported by the literature, as rhesus macaques have been shown to possess this pattern (Wang & Hayden, 2019) and during other gambling tasks, monkeys have paid to obtain information that has no impact on reward outcome (Blanchard et al., 2015). I also predicted that in the gambling task, 3) the number of items in visible sets would impact information collection rates; trials where gambling is most risky (e.g., visible values 5-8) would see an increase in information collection rates due to the greater levels of uncertainty. Lastly, I hypothesized that 4) when provided with trials that required a cost to view the counterfactuals, both monkey species would greatly decrease their rate of information collection.

3 PILOT STUDY

I conducted a pilot study as a feasibility assessment for the methods proposed in this thesis. In this section, I will describe the pilot study methods, discuss results, and consider potential weaknesses of those methods. This pilot study has provided insight on necessary method modifications to give nonhuman primate subjects a more appropriate task and to support the obtainment of counterfactual information.

3.1 Participants

For the pilot study, we tested a small number of monkeys from Georgia State University's Language Research Center (LRC): four capuchin monkeys (two females, two males; *Sapajus apella*) and two rhesus macaques (both males; *Macaca mulatta*). These monkeys were ideal candidates because they all had a long history of participation in cognitive tasks, including gambling and two-choice tasks. These monkeys also had extensive experience working with computerized testing systems and manipulating joystick controllers (e.g., Beran et al., 2012; Smith et al., 2017).

The capuchin monkeys were all socially housed in groups ranging from four to nine individuals. Each day, they had the option to separate from their group and receive food rewards during testing sessions that lasted up to five hours. The rhesus macaques were singly housed but had a compatible social partner that they could interact with for four hours each day. The remaining twenty hours provided the macaques an opportunity to participate in the computerized test for food rewards and to engage in other forms of environmental enrichment at their choosing.

Monkeys were never food nor water deprived. Aside from food rewards provided during testing, all monkeys, regardless of participation, received daily fruits and vegetables. All procedures in this study were approved by the Animal Care and Use Committee and adhere to the LRC's Standard Operating Procedures.

3.2 Apparatus

Subjects viewed the program on individual computer systems with 17-inch color monitors assigned to each subject. Pellet dispensers distributed 45 mg Bio-Serv food pellets as rewards. The test program code was written and presented with Visual Basic 6.0 software. Choice responses were recorded by the movement of a joystick controller mounted vertically to a clear faceplate on the testing enclosure. For details on the computerized testing systems, see Evans et al. (2008) and Richardson et al. (1990) for the capuchin and macaque systems, respectively.

3.3 General Procedure

Subjects first saw a start screen before each trial. This consisted of a white screen and a light blue rectangle labeled with the word, "Start." To begin a trial, the subject touched the start button by moving the computer cursor with the joystick. After passing the start screen, and dependent upon task progress, the subject saw either two black boxes, two sets of squares with random quantities, or a combination of one black box and one square grouping. These groupings corresponded with a set reward amount when selected. For example, a cluster of three squares produced three pellet food rewards. The number of squares ranged from zero to eight in each set, with the restriction that pairs could not exceed a 4:5 ratio. Additionally, no pairs of consecutive numbers (with the exception of 1 and 2) were presented to the subjects. These criteria were important as it was necessary for the monkeys to be able to differentiate between the sets. This also allowed the subjects to make easier and quicker discriminations between groupings. The randomized quantity sets had a maximum numerical difference of five items. These restrictions resulted in pairs in which quantities of six, seven, and eight would always be the maximum value, when presented.

Once presented with the stimuli, subjects were able to choose one stimulus option (either a visible set or the black box representing an unknown square quantity). They did this by moving the cursor to the stimulus. Choosing the black box made it disappear to reveal a randomized number of squares. Immediately after making a choice, the reward quantity associated with the chosen set dispensed and depending on the study phase, the subject either saw the word, “Go,” the word, “Show,” or both of those words presented simultaneously. The choice of one of these end-of-trial stimuli fully completed the trial. After selection, an intertrial interval of 20 seconds commenced.

3.4 Pre-Training

The Pre-Training phase served two purposes: to allow the subjects to recognize how the stimuli related to the rate of reward distributed, and to teach the subjects that reward choices could be nonvisible and found under opaque black boxes. During Pre-Training trials, subjects first saw the start screen. Next, either two randomized sets of squares or two black boxes appeared as choice stimuli (Figure 3.1). Touching a stimulus indicated a choice. The number of pellets dispensed as a reward were equivalent to the number of squares in the chosen stimulus set. During trials that presented two black boxes, contacting one box would reveal the nonvisible quantity set and dispense the associated reward. The subject’s goal was to choose the stimulus with the highest quantity of squares to maximize their reward. After the reward dispensed, the word, “Go” appeared at the bottom of the screen. Touching this button would end the trial and start a 20-second intertrial interval consisting of a blank white screen. To progress past the Pre-Training phase, subjects had to correctly complete 42 trials within the last 50. A correct response was one in which the subjects chose the set containing the higher number of items. Correctness only mattered on trials in which both quantities were unknown, only for trials presenting two visible sets.

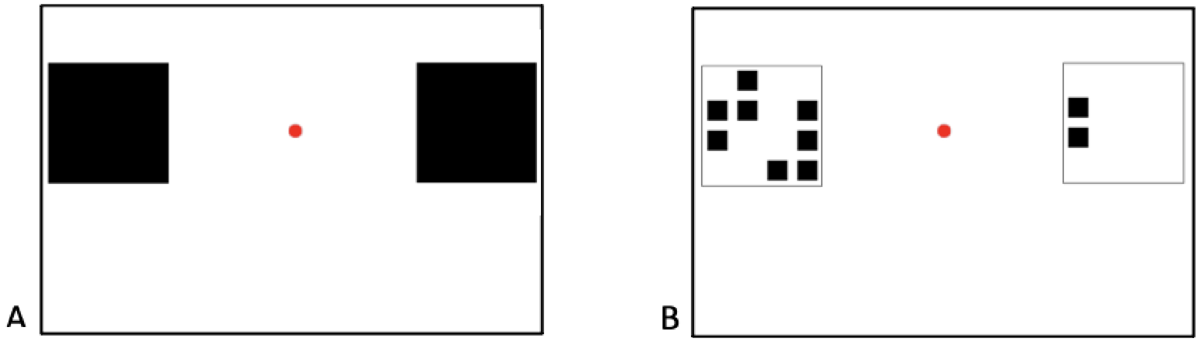

Figure 3.1 Pre-Training and Training Trials
Note. Image A depicts two nonvisible quantities before a selection occurred. Image B depicts a visible trial, allowing subjects to choose their reward set based on two visible options.

3.5 Training

The training phase allowed subjects to learn the outcomes associated with each intertrial interval choice. Training trials followed Pre-Training methods. One exception was that on half of the trials, subjects were presented with the word “Show” instead of “Go” after their reward selection (Forced choice trials, Figure 3.2). Each stimulus corresponded to a different intertrial interval. These intertrial interval types consisted of gaining counterfactual information or viewing a control screen. The gaining counterfactual information screen (Show) removed any remaining black boxes to display all potential choice stimuli. This informed participants about the rewards they could have received if they had made a different selection. Choosing the control screen (Go) displayed a blank, white screen for the entire interval. Both intertrial interval choices displayed for 20 seconds before the next start screen appeared. Subjects randomly encountered each intertrial interval type 50 times, for a total of 100 trials before moving to the testing phase.

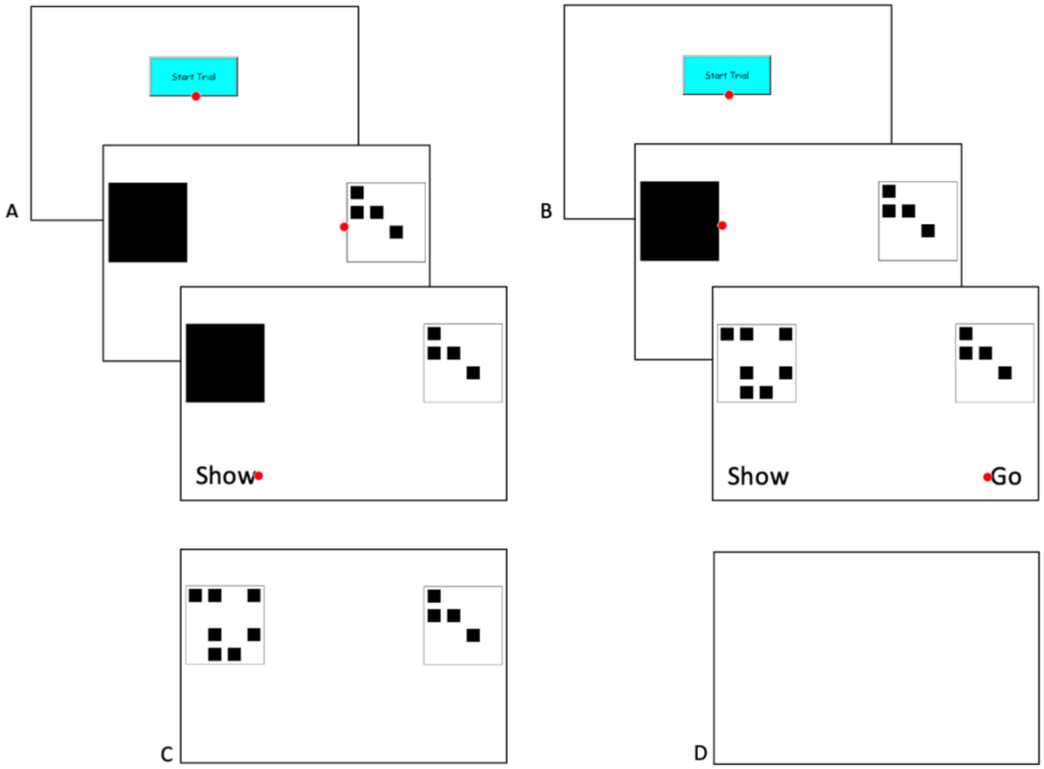

Figure 3.2 Testing Trial Examples
Note. Image A depicts a forced-choice test trial in which the subject chose the visible reward set and had to choose Show. Image B depicts a free-choice test trial in which the subject chose the nonvisible reward value. Image C displays the 20-second intertrial interval after choosing Show. Image D displays the 20-second intertrial interval after choosing Go.

3.6 Test

After selecting the start button, subjects experienced similar task requirements and stimuli to the training phase. However, one choice option was a visible set of squares, and one was an opaque black box. After selecting a set and the resulting reward distribution, the Show and Go stimuli now appeared simultaneously at the bottom the screen (Figure 3.2). Blocks of eight trials helped to remind the subjects of what each stimulus represented. These trial blocks included forced-choice trials and free-choice trials. The first two trials of every 8-trial block presented one forced Show trial and one forced Go trial in a randomized order. Following the two forced-choice trials, subjects engaged with six free-choice trials in which they could select any post-choice stimuli on the screen, all of which led to the same contingencies as outlined in Training. Subjects completed 100 8-trial blocks (600 free-choice trials, 100 Show forced-choice trials, and 100 Go forced-choice trials).

3.7 Results

3.7.1 Pre-Training and Training

All six monkeys completed pretraining and training criteria within two to five sessions, taking an average of 3.67 sessions. Table 3.1 presents the number of trials each monkey needed to pass Pre-Training criterion, their overall proportion of correct trials, and the correlation between percent correct and numerical difference between the two visible quantity sets. In the Pre-Training and Training phases, half of the trials did not allow the monkeys to assertively make correct choices because both choice options were opaque black squares. These trials were left out of the analysis. Monkeys required an average of 182 visible-choice trials to complete Pre-Training, averaging 72% correct choices. All monkeys completed 100 trials of Training to meet criterion. Mean accuracy increased to 87% in the training phase. Correlations between the numerical difference of the two visible sets and task accuracy produced varying results. When averaged across all monkeys, the correlations were strong (Pre-Training $r(3) = .86$, $p = .065$; Training $r(3) = .94$, $p = .016$). For Pre-Training, individual correlations varied greatly ($r(3) = -.13$, $p = .832$ to $r(3) = .87$, $p = .053$). For Training, the same correlations ranged from $r(3) = .16$, $p = .795$ to $r(3) = .97$, $p < .001$.

3.7.2 Test

Analyses were conducted to observe the monkeys' understanding of the choice between one known quantity and one nonvisible quantity. Figure 3.3 depicts the average task accuracy (i.e., choosing the stimulus with the larger reward, regardless of its level of visibility) based on the number of squares visible. Task accuracy was at its highest at the extremities (i.e., when 0 or 8 squares were visible) and lower during trials when there was the most uncertainty about whether the covered set was larger, and therefore had more risk (e.g., 3 or 4 squares visible). Overall, the monkeys displayed a pattern of rarely choosing the lowest numbers when they were visible and almost always choosing the highest numbers when they were visible. This behavior resulted in a strong positive correlation between number visible and proportion it was chosen, $r(7) = .954$, $p < .001$. Table 3.2 shows the rate individuals chose the visible set for each quantity and their accuracy.

Table 3.1 Task Accuracy During Training Phases

Species	Monkey	Trial Type	Trials to criterion [a]	Proportion correct [a]	Correlation: percent correct and numerical difference [a]
Capuchin	Atilla	Pre-Training	143	.70	.14
		Training	——	.82	.97
	Bias	Pre-Training	329	.62	-.13
		Training	——	.86	.29
	Gabe	Pre-Training	194	.78	.87
		Training	——	.78	.16
	Ingrid	Pre-Training	197	.76	.36
		Training	——	.85	.35
	All Capuchins	Pre-Training	215.75	.71	.81
		Training	——	.83	.79
Macaque	Chewie	Pre-Training	67	.82	.87
		Training	——	.94	.73
	Luke	Pre-Training	162	.65	.87

		Training	——	.95	.90
	All Macaques	Pre-Training	114.5	.73	.86
		Training	——	.94	.79
Both	All Monkeys	Pre-Training	182	.72	.86
		Training	——	.87	.94

Note. A report of the required number of trials to reach criterion (Pre-Training only; 42 of the last 50 correct), the overall proportion of correct responses, and Pearson Correlations for task accuracy and the numerical difference between the visible sets of squares.

[a] As trials with two nonvisible quantities were not possible to answer correctly except by chance, they were not included in this analysis.

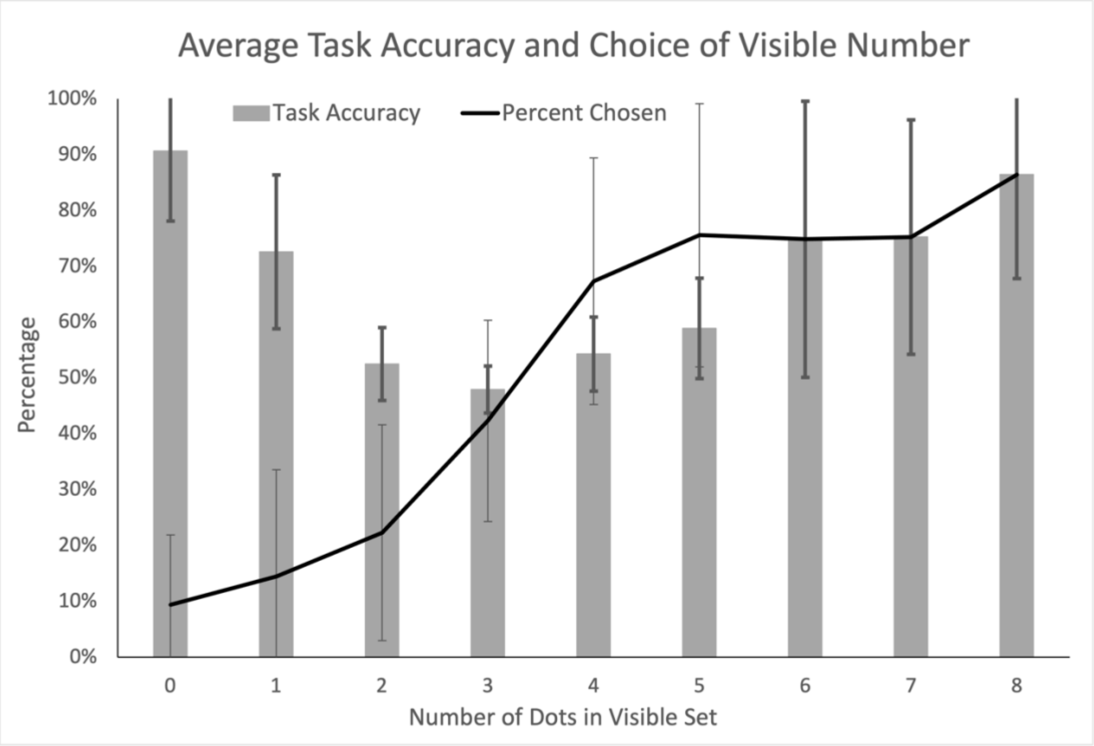

Figure 3.3 Task Accuracy and Number Choice

Table 3.2 Choice of Visible Quantity

Species/ Monkey	%	Visible Quantity								
		0	1	2	3	4	5	6	7	8
Capuchin										
Atilla	Visible Chosen	2***	4***	16***	35*	68*	79***	79**	75***	100***

	Visible Correct	0	50	20*	64	62	59	100***	100***	100***
	Show Chosen	5***	7***	6***	10***	3***	4***	0***	0***	0***
	Show Logical	50	25	20*	27	5***	4***	0***	0***	0***
	Show Illogical	4***	6***	4***	0***	0***	5***	0*	0	—
Bias	Visible Chosen	41***	61***	68***	64*	75***	79***	75***	86*	86***
	Visible Correct	0***	17***	33*	43	60	71**	100***	100***	100***
	Show Chosen	25***	11***	14***	13***	13***	13***	25***	0***	21**
	Show Logical	34	10***	10***	16***	11***	11***	27***	0***	17**
	Show Illogical	19***	13***	21**	8***	19**	24*	20*	0	50
Gabe[a]	Visible Chosen	0***	0***	0***	3***	12***	17***	15***	30	39
	Visible Correct	—	—	—	50	44	82*	100*	100**	100***
	Show Chosen	6***	10***	6***	15***	12***	10***	10***	19**	17**
	Show Logical	—	—	—	0	11*	6***	43	38	11*
	Show Illogical	6***	10***	6***	15***	12***	11***	5***	11***	21
Ingrid	Visible Chosen	0***	2***	11***	46	80***	91***	87***	87**	90***
	Visible Correct	—	100	33	46	57	61*	100***	100***	100***
	Show Chosen	4***	5***	9***	8***	2***	5***	4***	0***	3***
	Show Logical	—	0	0	7	1	4	2	0	0
	Show Illogical	4***	5***	10***	9***	5***	20	17	0	33
Macaque										
Chewie	Visible Chosen	11***	4***	27***	63*	86***	93***	97***	100***	100***
	Visible Correct	0**	0	28*	48	56	76***	100***	100***	100***
	Show Chosen	57	62*	48	66**	41	49	52	41	46
	Show Logical	75	67	60	58	38	48	54	41	46
	Show Illogical	55	62	44	79**	55	67	0	—	—
Luke	Visible Chosen	5***	4***	12***	42	79***	93***	97***	100***	96***
	Visible Correct	0	33	67	43	74***	69***	100***	100***	100***
	Show Chosen	47	27***	48	44	41	28***	21***	20*	25*
	Show Logical	50	33	58	50	40	27***	22***	20*	26*
	Show Illogical	46	27***	46	39	44	50	0	—	0

Note. **Visible Chosen** displays the choice percentage of each visible quantity. **Visible Correct** displays the subjects' percentage of correctness for visible quantity (e.g., visible 4 chosen over unknown 8 marked as incorrect). **Show Chosen** displays the overall percent subjects chose Show for each quantity, independent of whether subjects chose the visible or hidden quantity. **Show Logical** displays the choice percentage of Show when one value was still unknown. **Show Illogical** displays the choice percentage of Show when both values were already known. All

values are percentages. Two-tailed binomial tests determined whether these levels deviated from chance. Data represents free-choice trials only.
[a] Gabe chose the unknown quantity on 91% of free-choice trials.
$^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

During free-choice trials, rhesus macaque Chewie viewed the counterfactual information the most (316 times) while capuchins Atilla and Ingrid viewed it the least (29 times). Figure 3.4 presents the proportion of the choice Show for each monkey during the 600 free-choice trails. Table 3.2 presents the percentage of these choices separated by visible quantity. Two-tailed binomial tests determined if these performance levels deviated from chance. All monkeys, except for Chewie, had choice levels different than chance (Atilla, Bias, Gabe, Ingrid, and Luke p <.001, Chewie $p = .21$). It is of note that most occurrences where Chewie chose Show (231 of 316 occurrences) happened within a single session. During this session, Chewie viewed counterfactual information 80% of the time. Outside of this session, Chewie's levels more closely resembled the other five monkeys, choosing Show only 28% of the time. However, the difference between Chewie's choice rate and the other monkeys was not large enough to be considered an outlier.

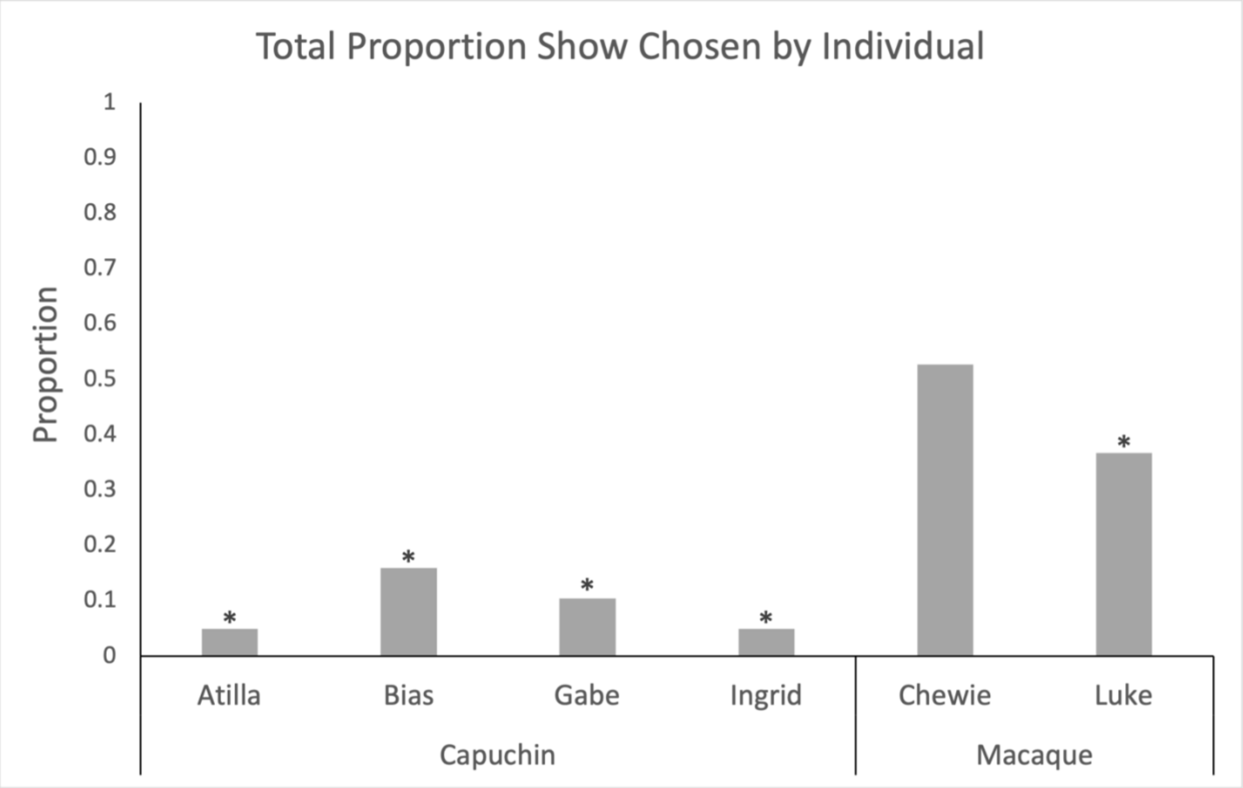

Figure 3.4 Choice to View Counterfactual Information by Individual
Note. Proportion each monkey chose Show during the 600 free-choice trials. Two-tailed binomial tests determined if these rates were different than chance.
**p* <.001.

Figure 3.5 displays the proportion of choice to view counterfactual information by trial block for each species. Here, the 600 free-choice trials were divided into quarters, 150 trials in each. Averaged across all monkeys, the rate of choosing Show decreased from 20% in the first quarter to 13% in the fourth quarter. Separated by species, macaques varied their choice of Show, but the capuchins had a small decrease in each quarter, from 11% in the first quarter to 7% in the fourth. A mixed ANOVA analyzed the effect of trial block and species on choosing Show during free-choice trials. Mauchly's test indicated a violation of the assumption of sphericity. Reported values reflect the Greenhouse-Geisser correction. No significant effect of trial block ($F(1.090, 4.359) = 3.073$, $p = .149$, $\eta_p^2 = .434$) or interaction ($F(1.090, 4.359) = 2.300$,

$p = .200$, $\eta_p^2 = .365$) was found. However, tests of between-subjects effects confirmed a significant main effect of species on choice to Show and accounted for much of the difference ($F(1, 4) = 32.201$, $p = .005$, $\eta_p^2 = .890$).

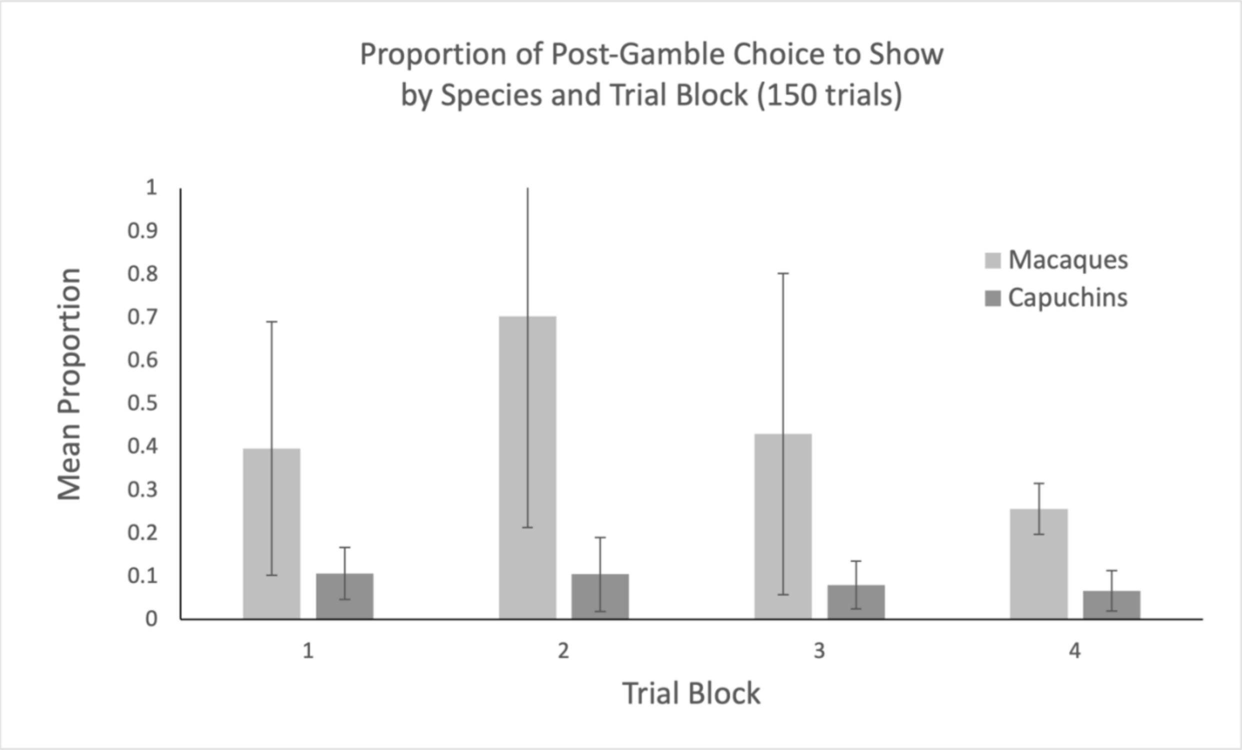

Figure 3.5 Choice of "Show" by Trial Block and Species
Note. Mean choice proportion of Show during each block of 150 trials, separated by species. Error bars represent 95% confidence intervals. Data represents free-choice trials only.

This experiment allowed the monkeys to choose Go or Show irrespective of their gamble choice. This means when a subject chose the visible set (and one quantity was left unknown), they could logically pick either Go or Show. However, a choice of the unknown quantity (resulting in two uncovered sets) still presented both end-of-trial options. In these trials, Go would be the only logical answer, and choosing Show would be unnecessary. Averaged across all monkeys (individual results in Table 3.2), the logical use of Show (i.e., one set was still unknown) occurred on 21% of trials and the illogical use (i.e., both sets were visible) on 23% of trials. A mixed ANOVA conducted with the free-choice data revealed that the visibility of stimuli (both visible or one visible and one unknown) did not have a significant effect on choice of Show ($F(1,4) = 3.873$, $p = .120$, $\eta_p^2 = .492$). Mauchly's test indicated that the assumption of sphericity was violated, so Greenhouse-Geisser degrees of freedom were used to correct this violation. As before, species had a significant effect on choice ($F(1,4) = 26.972$, $p = 007$, $\eta_p^2 = .871$). Figure 3.6 depicts each species' choice to view information when both quantities were visible, or one was still unknown.

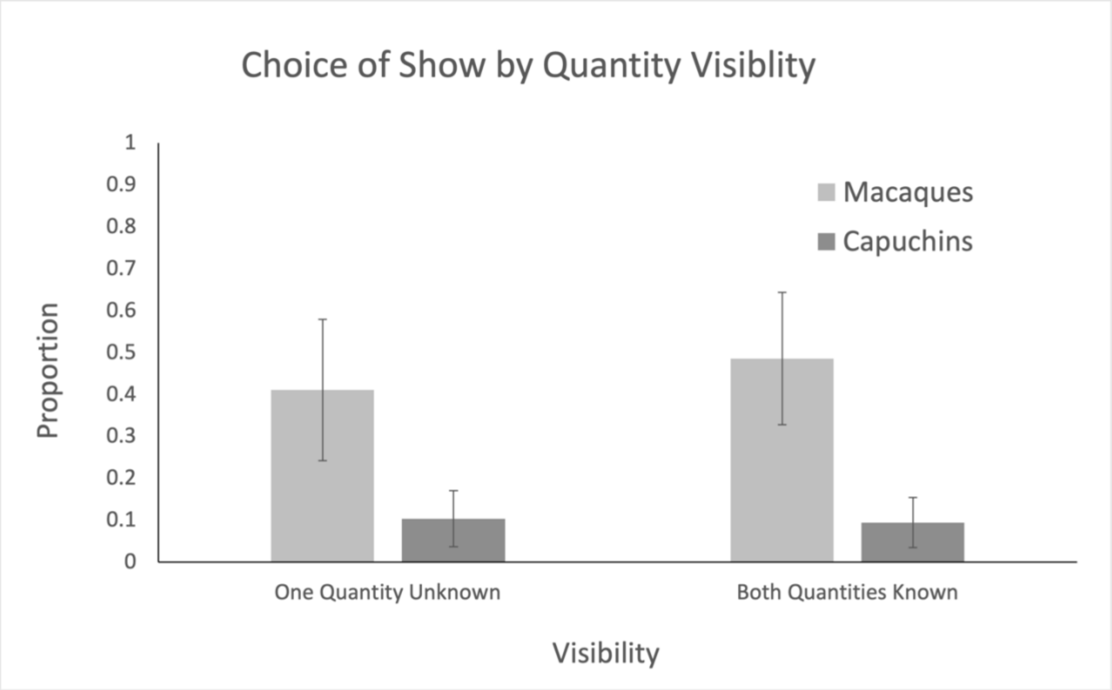

Figure 3.6 Choice to "Show" for Species by Set Visibility
Note. Bars represent choice proportion of Show for each species based on visibility of the quantity sets. Error bars represent 95% confidence intervals. Data represents free-choice trials only.

3.8 Discussion

The pilot study indicated a clear grasp of the basic gambling task by these monkeys. Subjects chose the visible set when it had larger numbers of squares and chose the opaque black box when the visible set of squares was small. Additionally, accuracy increased as quantities reached the extremities and decreased as probabilities reached a 50% chance that the unknown array was greater in quantity than the visible array. However, most participants had significantly low rates of choosing to view counterfactual information and rates remained low throughout the course of the experiment. Species differences that accounted for a majority of the variance in post-gamble choice indicated that the macaques chose more frequently to view counterfactual information. However, the macaques still chose to do so at or below chance levels. Further, the monkeys did not alter their choice to view this information based on whether they could already see both quantities or whether one was still unknown. Method modifications to increase task comprehension may eliminate species differences and issues with illogical choices.

Overall, these results suggest a lack of curiosity on this task. One reason could be that the monkeys understood the information provided was not beneficial as it did not provide hints for future trials. Alternatively, this may not have been an appropriate task to elicit counterfactual curiosity. First, the choice to gain counterfactual information (or not) followed reward selection and delivery. Due to this sequence of events, there may have been a disconnect between the intertrial interval options and the rest of the task since there was no reward associated with making the post-gamble choice. Additionally, in order to teach the monkeys to always associate the Go option with a blank, white intertrial interval screen, Go was introduced during pre-training and before the Show button. This may have produced a bias for choosing Go more frequently during the early stages of the experiment due to simply chained response learning. The methods proposed in this thesis will expand and improve on the methods of this pilot study.

4 METHODS: EXPERIMENT 1

The purpose of Experiment 1 was to determine if counterfactual information is important to the monkeys compared to receiving no information. The counterfactual information produced was neutral as it provided no future or current benefit or cost. Now, participants made a pre-gamble choice to receive counterfactual information in lieu of the post-gamble choice used in the Pilot. One nonvisible stimulus was presented along with two equivalent visible stimuli, each with a border color that indicated whether the participant would gain counterfactual information or not. These methods improved on the pilot study as the pre-gamble selection ensured participants connected the choice to view information as part of the trial, opposed to a separate response class. This eliminated any illogical use of the choice to view counterfactual information, which potentially increased the monkeys' comprehension of the choice and the task. These methods also provided new combinations of quantity sets with a greater maximum reward to allow for more risky set combinations. This ultimately increased the number of trials that might provoke the most counterfactual curiosity.

4.1 Participants

Experiment 1 included human participants and two species of nonhuman primates. Thirty-one adult undergraduate students (M = 11, F = 20) who were recruited at Georgia State University participated. Georgia State University's Institutional Review Board approved the study procedures. Participants voluntarily joined the study and provided written consent before starting the experimental procedures. Participants engaged with highly similar software (in appearance and response demands) to that given to the nonhuman primates to ensure greater comparability across species.

The study population also included 22 adult capuchins (M = 7, F = 15) housed at Georgia State University's Language Research Center that voluntarily separated from their social group. Five singly housed adult male rhesus macaques also participated in this study. The rhesus monkeys all had visual and auditory access to conspecifics throughout the day and some had social partners that they were able to share indoor and outdoor space with for multiple hours each day. Four monkeys (three capuchins, one macaque) that participated in the Pilot study also participated in the current testing procedures. Demographic information for all monkeys is in Table 5.1.

4.2 Apparatus

Monkeys used the same apparatus and reward system as described in the pilot study. Human participants were tested on computers with 17-inch color monitors. Participants made their choice responses by using mouse clicks. The program for all species was written with Visual Basic 6.0 software.

4.3 General Procedure

Participants first saw the start screen (as described in the Pilot study). Contacting the Start button began each trial. Once contacted, two or three stimuli appeared on the screen. Stimuli always included one nonvisible quantity set and either one or two visible quantity sets with colored borders that indicated to participants whether they would see counterfactual information or have a blank screen during the intertrial interval (uninformative option). Training and some testing trials (20%) presented one nonvisible set and one visible set onscreen at the same time to reinforce the association between border color and intertrial interval outcome. The remaining testing trials presented the nonvisible set and both visible set options at the same time so the participants could freely choose from these three options and decide whether they would gain the counterfactual information or not when picking the visible set. When both were presented, the visible sets always contained the same number of dots. The choice to view counterfactual information (or not) was now made in conjunction with the choice of quantity set. Visible sets contained a randomly chosen quantity of 2 to 11 dots. A nonvisible set could produce reward amounts between 1 and 12 dots to create a greater element of uncertainty (and thus more potential for curiosity) when choosing the visible sets. The quantity of nonvisible dots was random but proportional to the visible number (e.g., if the visible quantity was 3, there was 2/11 chance the nonvisible quantity would be lower and a 9/11 chance it would be higher). Participants received the reward amount equivalent to the number of dots in the set that they chose. If a participant chose the nonvisible set or the visible set that indicated the choice of the non-informative option, they saw the control intertrial interval screen (i.e., a blank, white screen). For monkeys, the intertrial interval time was 10 seconds for the first version of pre-training and training; all other phases consisted of a 20 second intertrial interval. For human participants, intertrial intervals were 5 seconds due to time limitations for completing their testing session.

4.4 Nonhuman Primates

4.4.1 Mac Training

One macaque, Mac, was much less familiar with computerized testing and before this study he had only completed training programs to learn how to use joystick controllers and the general procedure of computerized tasks. Because he was the only monkey to not have the same experience with computers and quantity studies, he participated in an extra training program before starting Pre-Training Version 1. Generally, this study was designed to provide pellets to the monkeys regardless of choice to reinforce the quantity differences between the sets of dots.

This training phase presented two visible sets of dots, but only reinforced trials in which Mac chose the greater quantity. Mac completed training trials until he chose the correct quantity set in at least 90% of the last 1,000 trials.

4.4.2 Pre-Training Version 1

Pre-Training was designed to ensure that all subjects could accurately choose the greater quantity between two visible dot stimulus sets and to teach the monkeys that they would receive a reward when choosing a nonvisible set. Methods for Pre-Training were the same as in the Pilot Study's Pre-Training; subjects saw two visible sets of dots or two nonvisible sets (Figure 3.1). During trials that presented two nonvisible sets, contacting one opaque black box revealed the number of items beneath it. These nonvisible item sets contained between 1 and 12 dots, whereas the visible sets only ranged from 2 to 11 dots. The monkeys immediately received the number of food rewards equal to the number of items in their chosen set. The intertrial interval was 10 seconds of a blank, white screen. To successfully pass this pre-training phase, subjects had to correctly complete 42 of the last 50 visible set trials. Correct trials were ones in which the subjects chose the set containing the higher number of items. Because it was not possible to answer correctly except by chance during trials where both sets were nonvisible, only trials with two visible sets determined whether a monkey met criterion.

4.4.3 Training Version 1

Training introduced the gambling task. Here, the monkeys saw one nonvisible set and one visible set of dots. This training phase also introduced the two intertrial interval choices resulting from the visible quantities: collecting information about the nonvisible quantity (i.e., what they could have received if they chose differently) and a blank, white control screen. This phase allowed the subjects to learn the association between each stimulus and its outcome. After the start screen, one visible quantity of dots and one nonvisible quantity of dots (an opaque black box) appeared onscreen. One visible set now had a yellow border, and one had a blue border. Choosing the border that represented the “Counterfactual” stimulus uncovered the nonvisible reward quantity and left all set quantities on the screen for five seconds of the intertrial interval before switching to a white screen for the remaining five seconds. Choosing the “Noninformative” stimulus did not show participants the set quantity under the black square. Instead, it immediately resulted in an intertrial interval that presented a white screen for 10 seconds. Selecting the nonvisible quantity removed the black box and revealed the number of nonvisible items before starting the 10 second intertrial interval with a white screen. The visible choices to gain information or not (i.e., the blue and yellow borders) did not appear simultaneously (Figure 4.1). Monkeys were assigned randomly to have either yellow or blue as the border color for the Counterfactual condition with the other color assigned for the Noninformative condition. This color assignment did not change between training and testing phases. Subjects randomly encountered each border type 100 times, for a total of 200 trials.

4.4.4 Pre-Training Version 2

After the first few monkeys completed Training Version 1, it was obvious that they were not gambling as intended (see Table 5.1). This was likely due to the highly lucrative methods resulting from every option producing at least some reward. To overcome this, the intertrial interval was increased from 10 seconds to 20 seconds so that there was greater motivation to maximize reward on each trial. Apart from this change, the methods of Pre-Training Version 2 were the same as Pre-Training Version 1. To advance, subjects had to correctly complete 42 of the last 50 visible set trials.

4.4.5 Training Version 2

In Training Version 2, the intertrial interval time remained at 20 seconds (Figure 4.1). Monkeys completed a minimum of 200 trials over the course of at least two testing sessions to ensure they had enough experience to form an association between border color and intertrial interval outcome. Also, the monkeys needed to show a Pearson correlation between number of dots visible and their choice proportion over the course of their last 200 trials that met or exceeded .90. This criterion ensured that the monkeys were gambling optimally and that they had some consistency in their gambling habits. If a monkey did not reach the second criterion but had a Pearson correlation of at least .90 over the course of 1,000 trials, they also progressed to the testing phase.

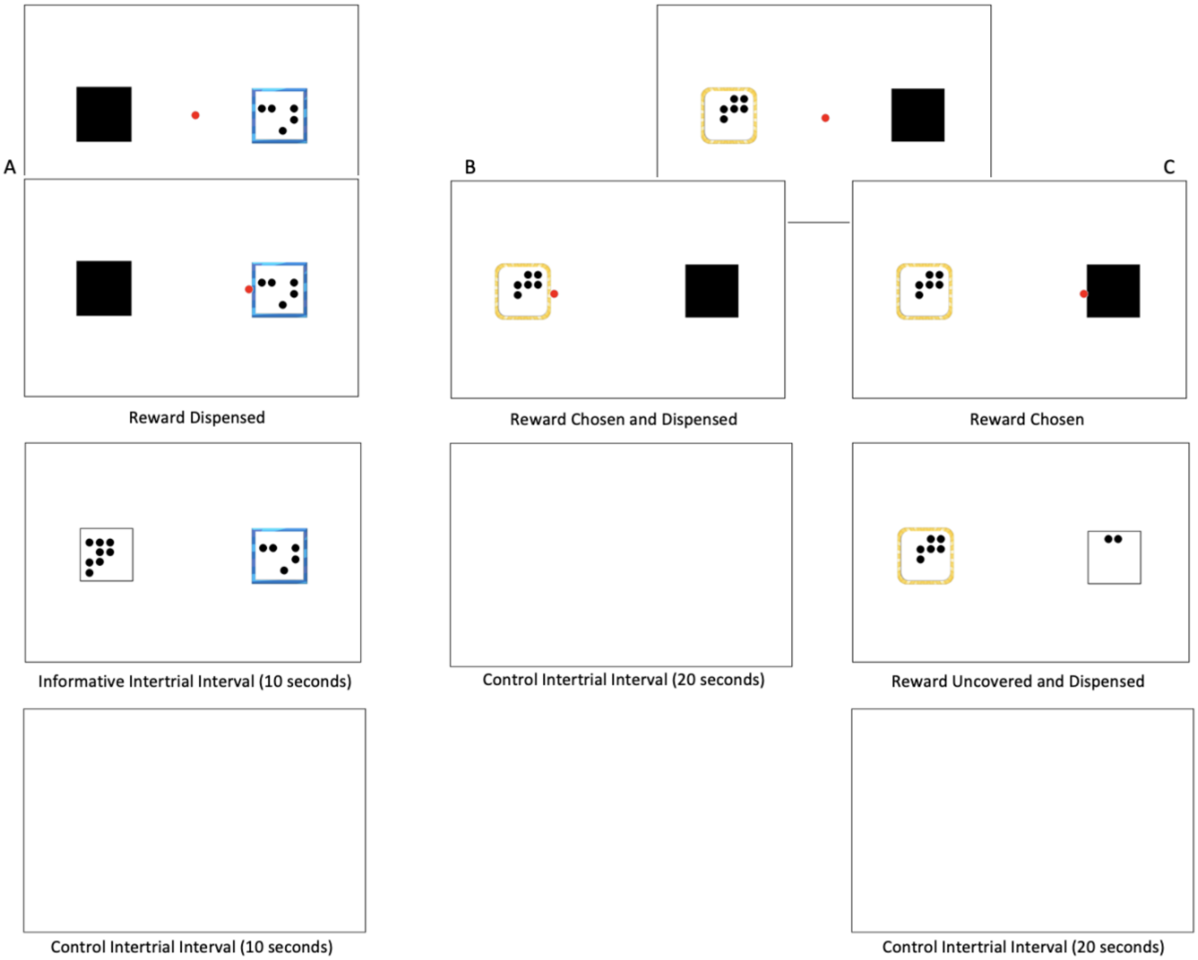

Figure 4.1 Forced-Choice Trials and Their Outcomes
Note. Figure depicts forced-choice trials for a participant assigned to blue as the counterfactual border. Choice of the counterfactual is shown in A and choice of the noninformative stimulus is shown in B. During either trial type, choosing the nonvisible quantity uncovered the set of dots before presenting a blank, white screen (C).

4.4.5.1 De-Bias Training: Overemphasizing Gambling Loss

Some monkeys had extreme biases to pick the nonvisible set (more than 85% of the time), no matter where it was on the screen (see Results and Table 5.3). These individuals were put on de-bias training when they showed no signs of proper gambling habits after multiple sessions and approximately 1,000 trials of experience. De-bias training consisted of Training Version 2 methods with a couple of modifications. First, high visible quantities (9-11) occurred during 50% of the trials to make the monkeys more likely to choose the visible set. If the monkey still chose the nonvisible set, that gamble would present an extreme loss: at least 40% of these trials resulted in a nonvisible quantity of one or two. Individuals restarted the regular training methods after at least 200 trials and two sessions of typical gambling behavior (i.e., choosing the visible quantity when high and the nonvisible quantity when low). If their bias persisted after roughly 1,000 trials, the monkeys moved to De-Bias 0 Training.

4.4.5.2 De-Bias 0 Training: Introducing Zero

If a monkey persisted in over-choosing the nonvisible set after De-Bias Training, they moved to this second version of bias training. Here, a monkey could see zero dots after uncovering the nonvisible set. De-Bias 0 Training still oversampled the high visible quantities and now emphasized loss with 60% of the trials resulting in zero, one, or two when choosing the nonvisible set. Individuals that successfully completed De-Bias 0 Training by showing typical gambling behavior restarted the regular training methods. Otherwise, individuals did not progress further in this study.

4.4.6 Test

The test phase of Experiment 1 consisted of 10-trial blocks. The first two trials within each trial block were identical to Training – one nonvisible set and one visible set (Figure 4.1). In a randomized order, one of the two trials provided the informative visible option, and the other trial presented the noninformative visible option. The consistency of forced-choice trials reminded the subjects of the outcome of each stimulus border. The remaining eight trials in each block presented the subjects with all three stimuli at the same time: two equivalent visible quantities (each with a different colored border) and one nonvisible quantity (Figure 4.2). The stimuli appeared randomly in one of three locations, all an equal distance from the center of the screen and the starting point of the cursor.

Trials with visible numbers between 5 and 8 provided the greatest amount of uncertainty, perhaps inducing higher levels of curiosity because gambling is approximately equally likely to give a larger reward or a smaller one. As the most informative trials occurred when there was greater risk, these trials appeared more frequently than trials where the visible sets were at the minimum or maximum quantities (i.e., 2-4 and 9-11). Each visible quantity between 5-8 occurred during 14-16% of the testing trials. Monkeys completed 80 trial blocks, equaling 800 trials (80 information forced-choice, 80 control forced-choice, and 640 free-choice).

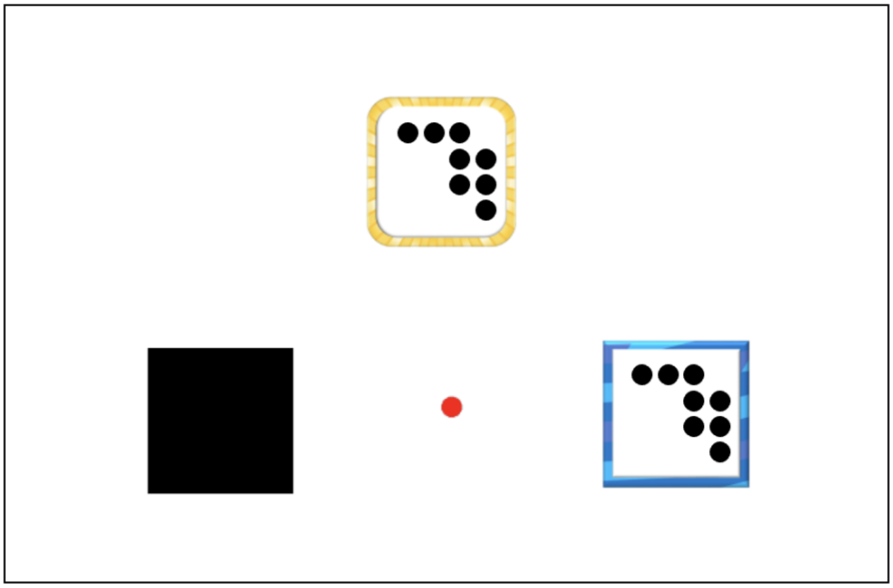

Figure 4.2 Free-Choice Testing Trial for Experiment 1

4.5 Humans

Due to time constraints and humans' ability to reliably count the number of dots on the screen, human participants did not complete pre-training and training trials. Instead, participants read instructions about the gambling task, the outcome of the different border colors, and how to collect points (rather than food pellets). Human participants only ever saw the three-choice task (one nonvisible and two visible quantity sets) and were not provided with border reinforcement (training) trials. The text below appeared on-screen before testing began. The intertrial interval for humans was five seconds. Participants were instructed to attempt to maximize the number of green dots they collected while engaging with the program. After collecting 2,000 points (dots), the testing session was over. To motivate responding, participants could leave as soon as they finished, and the participant that collected 2,000 points within the fewest number of trials received a $25 gift card at the end of the experiment. Aside from these changes, testing trials mimicked those that the nonhuman primates completed. An a priori power analysis using G*Power 3.1.9.6 software (Faul et al, 2009) indicated that 20 individuals were necessary to achieve a power of .95 when testing the difference between two groups (stimulus presentation) using a mixed ANOVA with an alpha level of .05 and estimated effect size of .35. The instructions to humans were as follows:

> *"You will be presented with trials that will require you to choose between three on-screen images. These images will be of two different colored square borders, each surrounding a number of smaller green dots, and a single large black square. You will use the mouse to click on one image to make your selection. If you choose the large black square, it will be removed to show you some number of small green dots. Before making this choice, you will not know how many green dots are under the black square. When you choose the set of green dots with the YELLOW border, you will also get to see how many green dots were under the black square. You will not get those green dots, but you will get to see how many had been there. If you choose the set of green dots surrounded by the BLUE border, you will NOT get to see how many green dots were under the large*

black square. The two visible sets of dots will always have the same number of dots in both sets.

Each small green dot in your chosen set will represent 1 point. Your goal is to gain 2,000 points. After each choice, your total number of points will be updated on the bottom of the screen. There will be a short delay between each trial. You can finish the experiment more quickly if you choose efficiently.

REMEMBER - choosing a set of green dots with a YELLOW border lets you know how many dots were hidden under the black square. Choosing the set of green dots with a BLUE border will not give you that information.

The experiment will last for a maximum of one hour, but you can leave earlier if you perform efficiently. Also, the participant who collects 2,000 points in the fewest number of trials (not necessarily the fastest) will be given a $25 gift card, so you will always want to figure out how to get the most green dots on every trial. However, if the hour expires before you collect all 2,000 points, you will be out of the running for the gift card.

Please let the researcher know if you have any questions before you begin. Once you are ready to start the experiment, please select the "Begin Experiment" button at the bottom of the screen."

5 RESULTS: EXPERIMENT 1

All five rhesus macaques completed all training and experimental procedures. Additionally, 18 of the 22 capuchins introduced to the task completed Experiment 1. The remaining four capuchins did not separate from their group frequently enough to fully participate (Applesauce, Ivory, Mason) or had an irreversible bias to choose the nonvisible set (Gretel). Table 5.1 shows the demographic information of all the monkeys that participated in the task. All 31 humans completed the testing phase of this experiment. Table 5.2 presents human demographic information.

5.1 Training

5.1.1 Pre-Training Version 1

In pre-training phases, half of the trials consisted of two visible sets and the other half of trials were two nonvisible sets of dots. Capuchins completed the first version of pre-training in an average of 168 trials (CI: 114, 222). Overall, capuchins chose the highest dot quantity during trials with two visible sets (86% correct, CI: 82%, 91%). The macaques finished this phase in an average of 93 trials (CI: 83, 104). Their accuracy on trials with two visible sets was quite high, at 95% (CI: 91%, 100%) correct. Table 5.1 reports individual trial counts and accuracy proportions. During his additional pre-training training, Mac completed 1,791 trials where overall, he correctly chose the highest quantity on 82% of trials. He showed greater success in his last 1,000 (93%), 500 (91%), and 200 (95%) trials.

5.1.2 Training Version 1

During the first version of training, most monkeys completed 200 trials, however there were four capuchin monkeys that exceeded this number (see Table 5.1), bringing the average trials up to 226 per capuchin monkey. A Pearson correlation to view the relationship between the visible quantity and its choice proportion was calculated for each participant (Table 5.1). Individual performances showed mixed results. Overall, both species showed a strong relationship, choosing the visible number when it was a high quantity and the nonvisible stimulus when the visible number was low, indicating a learned association between the quantity of dots and reward value, as well as the representation of the opaque black box as a different reward than what was presented and visible (capuchins, $r(10) = 0.96$, $p < .001$; macaques, $r(10) = .91$, $p < .001$).

5.1.3 Pre-Training Version 2

In the second version of Pre-Training, the capuchins, on average, required slightly fewer trials to reach criterion (152 trials; CI: 59, 245) and had a higher overall accuracy when choosing between visible sets (92%; CI: 88%, 95%). The macaques required more trials on average (143 trials; CI: 99, 186) compared to the first version but had similar rates of accuracy on visible set trials (96%, CI: 93%, 98%). Individual trial counts and accuracy proportions are presented in Table 5.1.

5.1.4 Training Version 2

Differing from the first version of training, criterion to pass the second version was reaching a Pearson correlation equivalent or greater than 0.90 between number visible and choice proportion within the past 200 trials (over at least 2 sessions) or reaching the same correlation over all Version 2 training trials (after a minimum of 1,000 trials). The capuchins needed an average of 1,242 trials (CI: 730, 1,753) to reach criterion and the macaques needed an average of 1,074 trials (CI: 760, 1,389). As before, both species showed strong correlations over all training trials (capuchins, $r(8) = .98$, $p < .001$; macaques, $r(8) = .99$, $p < .001$; see Table 5.1 for individual performances). During this phase, six capuchins participated in bias training. In all cases, these capuchins were choosing to gamble (i.e., take the nonvisible set) nearly every trial with no indication that this pattern would resolve on its own (minimum 918 trials). After an average of 1,158 trials (CI: 988, 1330), the first version of bias training (overemphasizing gambling loss) successfully shifted four of the six monkeys to gamble at more typical rates compared to the other monkeys. They were then returned to the regular training methods. The other two monkeys required a second version of bias training that introduced zeros. These methods worked to get one of the two monkeys to return to the original training methods; the second monkey was removed from the study. All bias training trial counts are in Table 5.3.

Table 5.1 Monkey Demographic Information and Individual Differences

					Pretraining v1		Training v1		Pretraining v2		Training v2		E1 Test		E2 Test (baseline)	
Species	Sex	ID	Age	Pilot	No trials to criteria	Vis. Set Prop Correct	No trials to criteria	Visible No & Correct Choice Corr	No trials to criteria	Vis. Set Prop Correct	No trials to criteria	Visible No & Correct Choice Corr	Choice Vis/Info Prop	Binomial p-value	Choice Vis/Info Prop	Binomial p-value
Capuchin	Male	Albert	11	No	438	0.71	200	0.96	67	0.93	419	0.91	0.48	.719	0.38	.087
		Atilla[b]	10	Yes	439	0.74	200	0.45	108	0.77	2352	0.99	0.52	.527	0.44	.419
		Griffin	25	No	139	0.91	200	0.22	65	1.00	1367	0.91	0.50	.954	0.51	1.000
		Liam[b]	19	No	93	0.91	200	0.27	78	0.98	2177	0.97	0.99	<.001	0.99	<.001
		Logan[b]	17	No	72	1.00	200	0.65	81	0.98	4616	0.95	0.45	.111	0.45	.428
		Mason[a]	24	No	94	.89	200	.26	789	.60	515	.94	-	-	-	-
		Nkima[b]	14	No	86	0.98	200	0.93	90	0.98	487	0.96	0.46[g]	.839[g]	0.49	1.000
	Female	Applesauce[a]	17	No	229	.83	200	.76	98	.88	2441	.57	-	-	-	-
		Bailey[e]	22	No	92	0.89	200	0.88	81	0.98	600	0.93	0.23	<.001	0.12[g]	<.001[g]
		Bias	35	Yes	346	0.71	200	0.50	969	0.72	1876	0.91	0.47	.217	0.44	.241
		Gambit	26	No	83	0.84	200	0.10	195	0.82	1376	0.80	0.87	<.001	0.49	1.000
		Gretel[a]	18	No	172	.89	201	.64	150	.97	3173	.65	-	-	-	-
		Ingrid[d]	10	Yes	88	0.95	200	0.74	89	0.95	607	0.99	0.55[h]	.149[h]	0.61	.117
		Ira[d,f]	11	No	99	0.95	200	0.87	78	0.93	600	0.98	0.68[h]	<.001[h]	0.76[h]	<.001[h]
		Irene	20	No	105	0.80	300	0.19	105	0.88	2131	0.99	0.73	<.001	0.76	<.001
		Ivory[a]	23	No	81	.93	200	.85	391	.77	411	.39	-	-	-	-
		Lily[b,c,e]	25	No	191	0.82	200	0.97	89	0.91	2077	0.93	0.50[g]	1.000[g]	0.43[g]	1.000
		Lychee[f]	24	No	82	0.93	300	0.92	167	0.94	320	0.90	0.58	.002	0.53[h]	.291[h]
		Nala	20	No	242	0.76	383	0.80	137	0.82	469	0.94	0.40	.009	0.30	.020
		Paddy[d,f]	12	No	188	0.94	200	0.56	79	0.98	328	0.94	0.60[h]	<.001[h]	0.52[h]	.385[h]
		Widget	14	No	147	0.79	298	0.94	155	0.93	274	0.95	0.44	.058	0.31	.011
		Wren	20	No	97	0.91	200	-	97	1.00	271	0.94	0.56	.043	0.43	.328
Macaque	Male	Han[d,f]	20	No	86	0.98	200	0.77	162	0.94	1279	0.93	0.94[h]	<.001[h]	0.80[h]	<.001[h]
		Lou[d,f]	23	Yes	96	1.00	200	0.93	79	1.00	862	0.95	0.35[h]	<.001[h]	0.76[h]	<.001[h]
		Luke[d,f]	29	No	85	1.00	200	-0.26	193	0.95	696	0.95	0.56[h]	.073[h]	0.48[h]	.883[h]
		Mac[d,f]	8	No	84	0.93	200	0.87	192	0.91	855	0.98	0.64[h]	<.001[h]	0.69[h]	.010[h]
		Murph[c,e]	29	No	116	0.86	200	0.27	87	0.98	1679	0.97	0.54[g]	.586[g]	0.51[g]	.925[g]

Note. Demographic information and individual results for training and testing phases.

[a] Individuals dropped from the study for not separating to test frequently enough or for having an irreversible bias
[b] Individual participated in bias training (see Table 5.3).
[c] Individual removed from Experiment 1 analyses for gambling more than 85% of trials.
[d] Individual removed from main Experiment 1 analyses for directional biases.
[e] Individual removed from Experiment 2 analyses for gambling more than 85% of trials
[f] Individual removed from main Experiment 2 analyses for directional biases.
[g] Based on high levels of gambling
[h] Based on directionally-biased data

Table 5.2 Human Demographic Information and Individual Differences

Sex	ID	Age	Trials	Choice Vis/Info Prop	Binomial p-value
Male	1101	21	276	0.92	<.001
	1102[a]	18	309	0.53[b]	0.761[b]
	1105	20	279	0.93	<.001
	1106	21	267	0.59	0.033
	1107	21	287	0.51	0.866
	1108	18	285	0.87	<.001
	1112	19	278	1.0	<.001
	1113	20	263	0.99	<.001
	1124	18	286	0.99	<.001
	1126	18	265	0.01	<.001
	1130	18	269	0.99	<.001
Female	1103	20	274	0.91	<.001
	1104	21	285	0.52	0.537
	1109[a]	22	303	0.61[b]	0.243[b]
	1110	18	281	0.38	0.002
	1111	19	272	0.61	0.013
	1114[a]	19	308	0.35[c]	<.001[c]
	1115	19	281	0.71	<.001
	1116	19	281	0.39	0.011
	1117	18	282	0.89	<.001
	1118	19	275	0.75	<.001
	1119	19	266	0.58	0.071
	1120	19	279	0.63	0.003
	1121	18	285	0.77	<.001
	1122	19	277	0.43	0.077
	1123	18	287	0.72	<.001
	1125	18	276	0.78	<.001
	1127	18	306	0.86	<.001
	1128	20	282	0.98	<.001
	1129[a]	19	295	0.76[c]	<.001[c]
	1131	18	285	0.73	<.001

Note. Demographic information for human participants and individual results from Experiment 1.

[a] Individuals removed from Experiment 1 analyses for gambling less than 15% or more than 85% of trials.

[b] Based on high levels of gambling

[c] Based on low levels of gambling

Table 5.3 De-Biasing Training

	Regular train (1st)		Bias Training		Bias 0 training		Regular train (2nd)	
ID	Sessions	Trials	Sessions	Trials	Sessions	Trials	Sessions	Trials
Atilla	9	1200	3	635			3	517
Gretel[a]	9	1013	4	1,000	7	1,600	-	-
Liam	7	1203	2	286			4	688
Logan	6	1533	4	952	7	2033	3	405
Irene	5	918	3	401			5	812
Lily	6	1085	3	460			3	532

Note. Session and trial counts for individuals that participated in bias training before moving on to the testing phases.

[a] Dropped for showing no signs of reversing her bias for the nonvisible set after 1,600 trials of the second version of bias training.

5.2 Test

All monkeys completed 800 trials in Experiment 1. Of these trials, 640 were testing trials and the remaining 160 were forced-choice trials. Humans did not complete a set number of trials, and they averaged 282 testing trials (CI: 278, 286). Experiment 1 analyses excluded one macaque, two capuchins, and four human participants due to extremely high or extremely low levels of gambling (choosing the opaque black box less than 15% of the time or greater than 85% of the time). Additionally, three capuchins (Ingrid, Ira, and Paddy) and the remaining four macaques (Han, Lou, Luke, and Mac) all had significant directional biases, with the macaques and one of the three capuchins (Ira) completely disregarding the middle option as a choice. For this reason, their choice behavior was not considered reflective of the main aims of the experiment because this bias made it highly unlikely they were even viewing this stimulus as a viable option[1]. The following analyses takes into consideration the data from 13 capuchins and 27 humans. The individuals that showed directional biases are analyzed separately. The remaining data had a normal distribution.

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[1] Note that this was choice behavior, and not equipment or software failure. For whatever reason, these animals simply stopped moving the cursor upward on trials, and thus never selected that stimulus location.

To determine the effect of border condition (which visible stimulus resulted in counterfactual information) on the choice to view counterfactual information in monkeys, an independent samples t-test was conducted. The proportion of trials the monkeys chose to view information when picking between one of the two visible quantities was the dependent variable with border condition (Yellow or Blue) as the grouping variable. The analysis indicated that there was no difference of choice proportion to view the counterfactual information when the border condition was Blue (M = 63%, CI: 49%, 78%) or Yellow (M = 45%, CI: 37%, 52%), $t(11) = 2.119$, $p = .06$. Thus, the data were collapsed across border color condition for the remaining analyses.

As during training, there was a positive relationship between the visible quantity and its choice proportion (Figure 5.1). A mixed ANOVA was conducted to determine whether visible quantities (categorized as low (2-4), mid (5-8), and high (9-11)) and species impacted the choice to obtain information when the visible quantity was chosen. Some individuals never chose the lower quantities when presented (visible 2, 3, and 4) and were excluded from analyses that involved these data (i.e., comparisons involving overall and low quantity data). Excluded were one capuchin (12 capuchins total analyzed) and six humans (21 humans total analyzed). The remaining analyses (i.e., mid and high quantities) did not exclude any participants. The assumption of sphericity was violated (W = .246, χ^2 (2) = 42.124, p < .001), so the Greenhouse-Geisser corrected values are reported. There was a main effect of visible quantity choice in the participant’s decision to view the counterfactual information ($F(1.140, 62) = 6.222$, $p = .014$; Figure 5.1). To understand this difference, paired samples T-test were conducted to compare the three quantities levels with a Bonferroni correction, resulting in an alpha of .017. Participants chose to view counterfactual information when presented with a low visible quantity (2-4; M =

76%, CI: 68%, 85%) significantly more than both the mid quantities (5-8; M = 66%, CI: 59%, 73%), *t*(32) = 2.529, *p* = .02, and high quantities (9-11; M = 63%, CI: 56%, 71%), *t*(32) = 2.944, *p* = .006. There was no significant difference in the information collection rate when presented with mid and high quantity sets, *t*(39) = 1.887, *p* = .07. There was no interaction between visible quantity and species (*F*(1.140, 62) = .137, *p* = .75). However, species was a significant factor (*F*(1, 31) = 10.662, *p* = .003) with the capuchins (M = 53%, CI: 44%, 62%) choosing to view information at a significantly lower rate than human participants (M = 72%, CI: 63%, 81%).

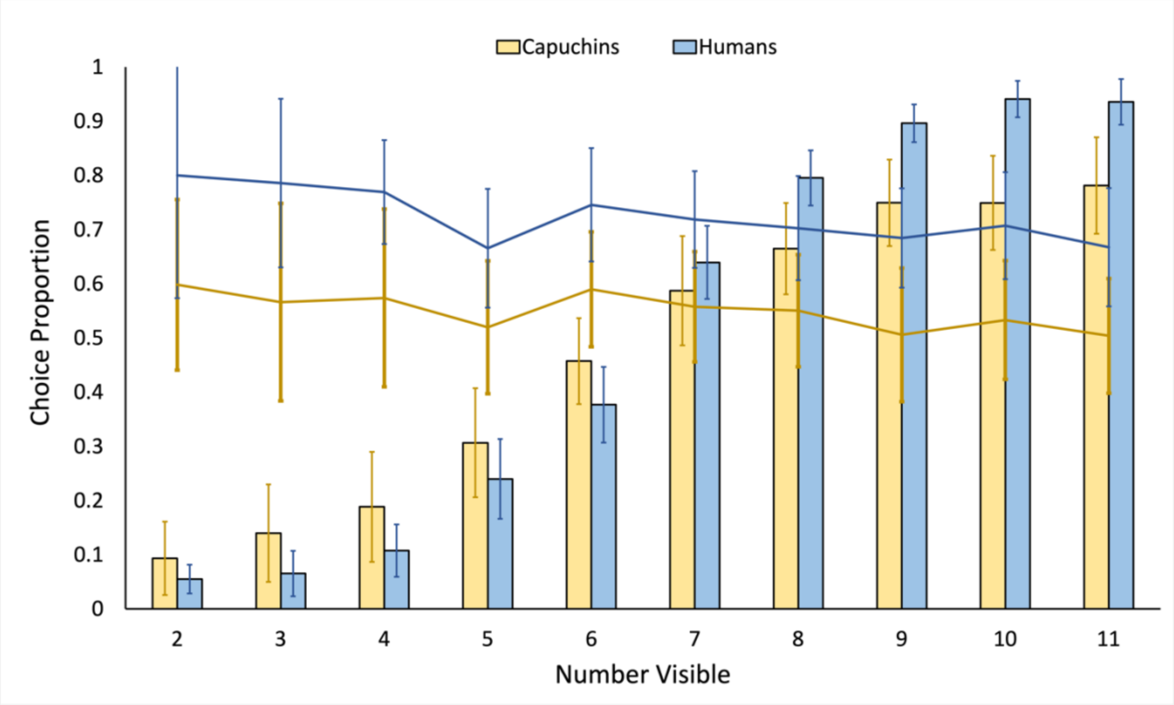

Figure 5.1 Number Visible by Choice Proportion
Note. Bars represent the choice proportion of each number when presented as a visible quantity for each species. Lines represent the proportion of time information was gained during trials in which each species chose the visible number. Error bars represent 95% confidence intervals.

To assess individual differences, binomial probability tests compared choice frequency for gaining information when choosing the visible quantity to 50% chance level. Most human participants had a bias for choosing the informative option (20 participants; all *p* < .03), three participants had a bias for no information (all $p < .01$), and the remaining four participants showed no bias. Out of thirteen capuchins, five had a bias for collecting information (all $p < .05$), two had a bias for collecting no information (all $p < .01$), and the remaining six had no directional bias. Individual binomial results and information choice proportions for monkeys are in Table 5.1 and in Table 5.2 for humans. Because the monkeys completed a wide range of training trials, a correlation between number of training trials and tendency to view counterfactual information was conducted. Across all monkeys, there was no correlation between these two variables, $r(13) = .186$, $p = .54$. Although individually some monkeys did choose to view counterfactual information (or no information) at rates different than chance, two-tailed one sample t-tests comparing overall proportion for each species to 0.5 revealed that information collection rates of capuchins did not differ from chance, $t(12) = .643$, $p = .53$. Only humans as a group collected information at rates significantly above chance, $t(26) = 4.685$, $p < .001$.

To determine the effect of trial number on the likelihood to view counterfactual information, the data were split into quartiles and analyzed within species. Monkeys completed 640 testing trials, producing quartiles comprised of 160 trials. The minimum number of trials humans completed was 263, so the analysis considered the first 260 trials of each human participant, with 65 trials in each quartile. Repeated measures ANOVAs revealed no main effect of quartile for either species (capuchins: $F(3) = 1.110$, $p = .36$; humans: sphericity violated, $W = .523$, $\chi^2\,(5) = 16.017$, $p = .007$, Greenhouse-Geisser correction used, $F(2.344) = .975$, $p = .39$). Repeated measures ANOVAs conducted for the first 260 test trials (spilt into quartiles with 65 trials each) for capuchins allowed for a more direct comparison to the humans. Similarly, no main effect of quartile was found, $F(3) = 1.742$, $p = .18$. Figure 5.2 displays quartile averages across species.

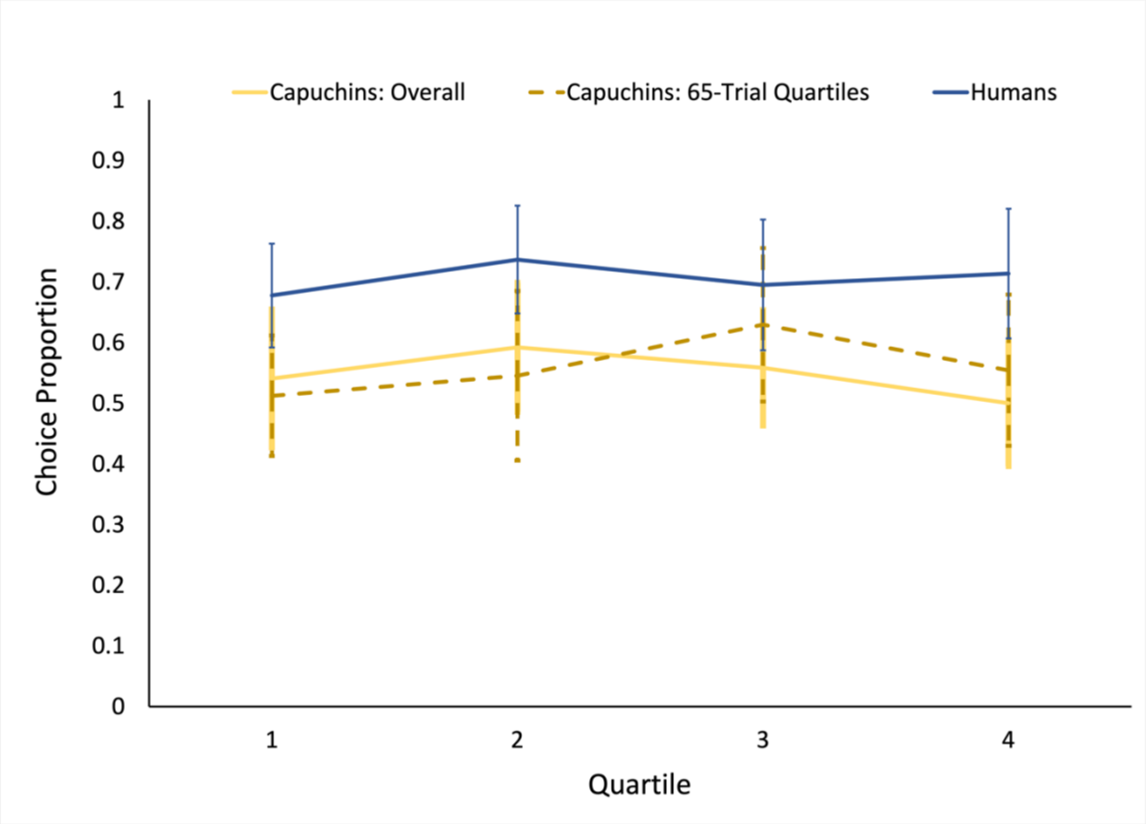

Figure 5.2 Choice to View Information by Quartile
Note. Overall trial count for monkeys was 640 (160 per quartile). Human and monkey data are also reported for the first 260 trials (65 trials per quartile). Error bars represent 95% confidence intervals.

The final goal of Experiment 1 was to assess whether gaining counterfactual information (and the resulting realization of a winning or losing gamble) impacted a participant's future choice on trials with similar risk levels. To achieve this, trials where 1) the participant chose to view counterfactual information and 2) the trial immediately after it presented the same visible number, or a number within one item of it, were separated from the dataset (e.g., a participant chose a visible 6 and to view information on trial 1 and on trial 2 they saw with a visible 7). In cases where two or more trials in a row met these criteria (i.e., back-to-back-to-back trials), the analysis only considered the first pair of trials in the sequence to account for any interference of multiple similar trials. Two mixed ANOVAs included species as the between-subjects variable and the outcome of trial 1 (realized win or loss) as the within-subjects variable. The first ANOVA assessed whether a realized win or loss influenced participants to choose the counterfactual information again on the second trial. There was no difference in how participants chose to view counterfactual information after a realized loss (M = 43%, CI: 31%, 54%) or a realized win (M = 46%, CI: 34%, 58%), *F*(1, 33) = .002, *p* = .96. Additionally, there were no species differences, *F*(1, 33) = 4.033, *p* = .053. The second ANOVA assessed whether participants were more likely to gamble (i.e., take the nonvisible set) after a realized loss (M = 41%, CI: 30%, 52%) or win (M = 32%, CI: 21%, 43%). There was no main effect of trial 1 choice, *F*(1, 33) = .753, *p* = .39, or species differences, *F*(1, 33) = .491, *p* = .49.

Four macaques (Han, Lou, Luke, and Mac) and one capuchin (Ira) showed a directional bias and consistently chose the right and left options. They all had some level of experience with the middle stimulus; however, they overwhelmingly chose to not use it. The data of these individuals were separated from the other monkeys for the following analyses. When presented with a gamble between the left and right stimuli (i.e., the nonvisible set and either visible set), choice proportions indicated that these moneys were not choosing at random. Like the other monkeys, this subset chose the visible set when it was a high quantity and the nonvisible set when the visible set was a low quantity (Figure 5.3). During trials in which both visible options were presented in the left and right positions, repeated measures ANOVAs also revealed that they had similar response patterns to the main group. There was no main effect of visible quantity, *F*(2) = .561, *p* = .59, quartile, *F*(3) = 2.568, *p* = .10, or quartile subset (first 260 trials), *F*(3) = 1.659, *p* = .23. Individually, two macaques and one capuchin did choose to view the counterfactual information differently from chance, as determined by binomial probability tests (all *p* < .001). Of the remaining individuals, one macaque did not respond differently than chance (*p* = .07), and one macaque tended to choose the noninformative option (*p* < .001). To determine how the group viewed counterfactual information compared to chance levels, a one-sample t-test was conducted. Like the others, this group of monkeys did not gather counterfactual information at a rate significantly different from chance *t*(4) = 1.412, *p* = .23.

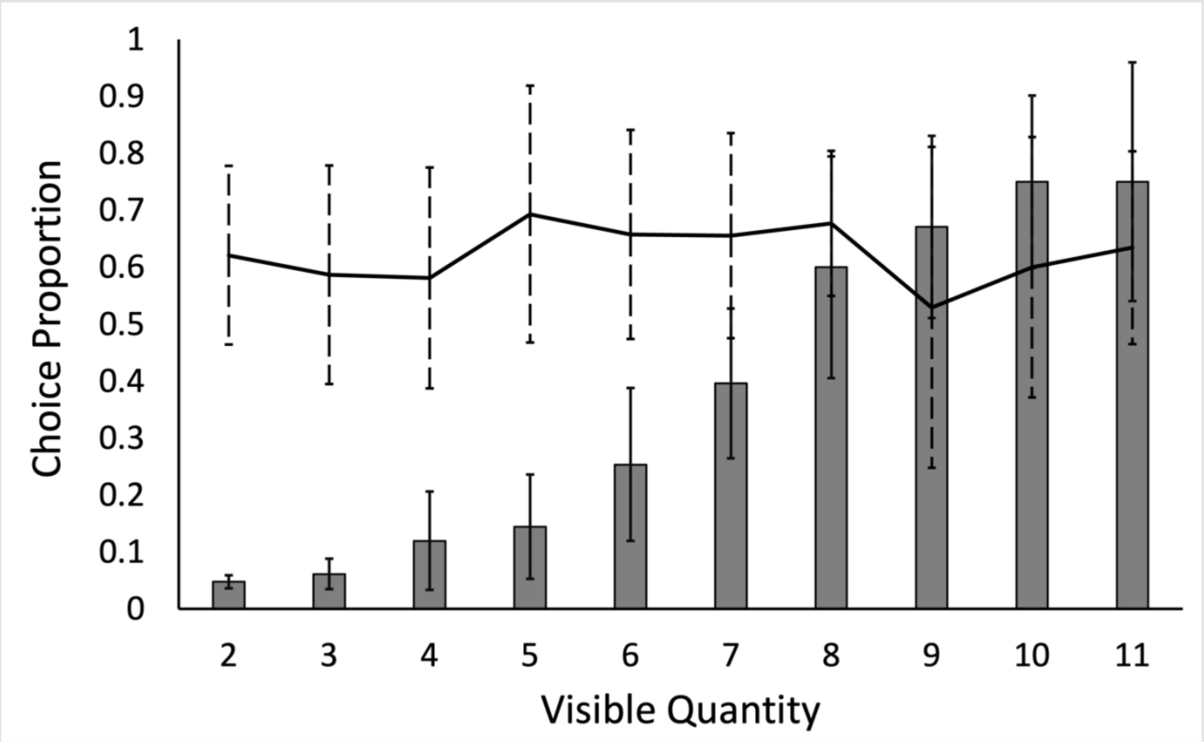

Figure 5.3 Number Visible by Choice Proportion: Biased Subset
Note. Bars represent the choice proportion of each number when presented as a visible quantity. Lines represent the proportion of time information was gained during trials in which individuals chose the visible number. Error bars represent 95% confidence intervals.

6 METHODS: EXPERIMENT 2

The first experiment offered subjects counterfactual information that was neutral. The information gained was random (but proportional) and could not help to solve future trials or optimize rewards. The information also did not come at a cost. In Experiment 2, the counterfactual information presented a benefit or cost to participants during some trials in the form of a greater or lesser food reward compared to taking the noninformative visible option. This allowed for an assessment of whether the subjects' choice of counterfactual information fluctuated when presented with an advantage or disadvantage.

6.1 Participants

All nonhuman primates that completed Experiment 1 moved on to Experiment 2. This included eighteen capuchins (M = 6, F = 12) and five male macaques. Because they already had confirmed their willingness to seek counterfactual information in Experiment 1, humans did not participate in this experiment.

6.2 Apparatus

The current experiment used the same testing equipment and rewards as Experiment 1.

6.3 Procedure

Monkeys began Experiment 2 after completing Experiment 1. Only slight modifications to Experiment 1 methods were necessary to prepare the program for Experiment 2. Participants still had the chance to choose between two visible sets and one nonvisible set of dots. Now, the two visible sets sometimes had unequal quantities (Figure 6.1). During these trials, the set producing counterfactual information could have a greater or lesser reward value than the noninformative option. As in Experiment 1, forced trials occurred every 10 trials to remind the monkeys of outcome of the various stimuli (Figure 4.1). Free-choice trials with different visible quantities presented set differences between one and four dots. Visible set quantities that exceeded a difference ratio of .80 never appeared due to concerns of discriminability. Additionally, proportional differences less than .5 did not occur, except for sets within a numerical difference of four (e.g., three paired with seven, but never with ten). Visible set quantities were pseudorandomized in pre-determined pairs to ensure all trials conformed to the restrictions (Table 6.1). After the subject chose a stimulus, the same 20 second intertrial intervals as described in Experiment 1 occurred. Monkeys completed 1,000 trials consisting of 100 trial blocks. This resulted in 100 information forced-choice trials, 100 noninformative forced-choice trials, and 800 free-choice trials. For all free-choice trials, 20% were the same as in Experiment 1 and displayed visible quantities of equal value ("baseline" trials; Figure 4.2), 40% gave the chance to view counterfactual information as the greater-quantity set, and 40% provided counterfactual information with the lesser-quantity set. To allow for a closer look at choice when presented with higher-risk values (visible quantities 5-8), 70% of trials presented the high-risk quantities, 15% presented the lower quantity visible sets (visible quantities 2-4), and 15% presented the higher quantity visible sets (visible quantities 9-11; Table 6.1). All contingencies for rewards were the same as in Experiment 1.

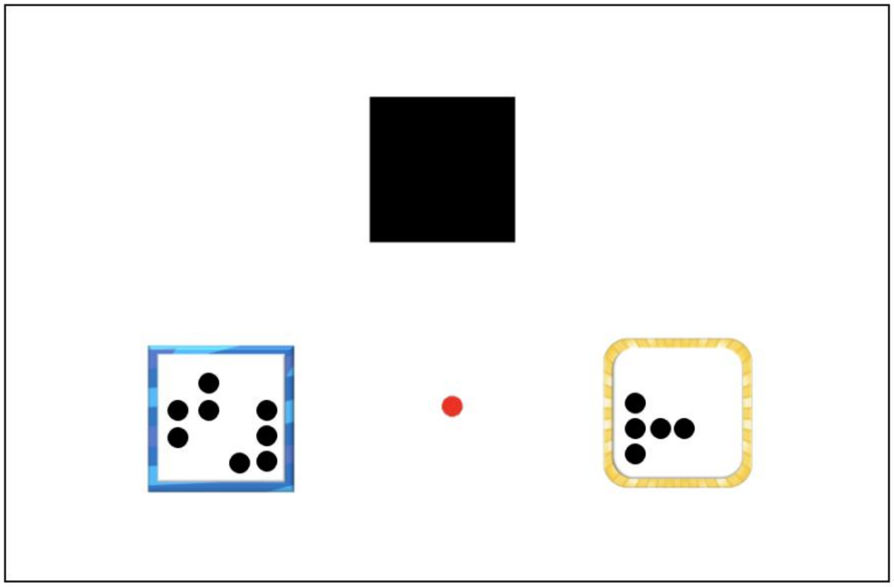

Figure 6.1 Free-Choice Testing for Experiment 2

Table 6.1 Experiment 2 Visible Quantity Sets

Lower Risk; Low Quantities			Higher Risk			Lower Risk; High Quantities		
Low	High	Proportion Difference	Low	High	Proportion Difference	Low	High	Proportion Difference
2	3	.67	4	5	.8	6	10	.6
2	4	.5	4	6	.67	7	10	.7
2	5	.4	4	7	.57	7	11	.64
2	6	.33	4	8	.5	8	10	.8
3	4	.75	5	7	.71	8	11	.73
3	5	.6	5	8	.63			
3	7	.43	5	9	.56			
			6	8	.75			
			6	9	.67			
			7	9	.78			

Note. All possible combinations of visible set quantities during Experiment 2

7 RESULTS: EXPERIMENT 2

All 23 monkeys that completed Experiment 1 also completed Experiment 2. The monkeys completed 1,000 trials, comprising of 200 forced-choice trials to reinforce the border association, 160 “baseline” trials that were the same as in Experiment 1, and 640 trials with unequal visible quantity sets. The only exceptions were capuchin Albert and macaque Luke. Due to an error with the program, Albert completed 1,442 trials and Luke completed 1,163 before experiencing all trial combinations necessary. All additional trials were included in the analyses. Due to extreme levels of gambling, one macaque (Murph) and two capuchins (Lily and Bailey) were excluded from the analyses. Additionally, three capuchins (Ira, Lychee, and Paddy) and the remaining four macaques (Han, Lou, Luke, and Mac) were excluded for directional biases. The following analyses therefore included data from 13 capuchins.

First, I examined whether information collection differed between Experiment 1 and Experiment 2 by analyzing the baseline trials. Border color condition (Yellow or Blue) did not significantly impact choice, $t(11) = 2.062$, $p = .06$, so analyses were combined across color condition. The monkeys still showed a strong correlation between the visible set and its choice proportion, $r(10) = .982$, $p < .001$. A paired samples t-test determined that there was no significant difference in information collection between Experiment 1 (M = 53%, CI: 44%, 62%) and Experiment 2 (M: 50%, CI: 40%, 60%), $t(12) = .696$, $p = .500$.

Repeated measures ANOVAs were used to assess any differences produced by the visible set quantity and the quartile of trials on information choice proportion. Neither visible quantity set, (Assumption of sphericity was violated, $W = .344$, χ^2 (2) = 8.537, $p = .014$; the Greenhouse-Geisser corrected values are reported) $F(1.208) = .442$, $p = .56$, or quartile, $F(3) = .417$, $p = .74$, were significant variables. Individual differences were present, with fewer monkeys showing trends different than chance (tendency to view the counterfactual: 2 monkeys, $p < .001$; tendency to take the noninformative option: 2 monkeys, $p < .05$), and the majority of monkeys (nine individuals) displayed no significant bias. Overall, the monkeys did not collect information in a pattern different than chance, $t(11) = .143$, $p = .89$.

As in Experiment 1, the same capuchin (Ira) and four macaques (Han, Lou, Luke, and Mac) only touched the right and left stimuli choices in Experiment 2. Their choice proportions were compared between the two experiments. On trials that presented a gamble between the left and right choices, the monkeys continued to demonstrate typical gambling patterns, the visible quantity and their choice proportion of that quantity had a strong, positive correlation, $r(10) = .971$, $p < .001$. A paired samples t-test assessed the overall choice to view counterfactual information during trials in which the left and right stimuli were both visible sets. This subset of monkeys showed no difference in their overall choice to view information from Experiment 1 to Experiment 2, $t(4) = .642$, $p = .556$. Still, in the current experiment, their group choice proportion did differ significantly from chance, $t(4) = 3.403$, $p = .027$. Individually, three macaques and the one capuchin had a tendency to view the counterfactual information ($p < .01$), and the fourth macaque did not deviate from chance ($p = .883$). These significant findings must be interpreted with caution as this is a small group of monkeys that showed strong spatial biases.

The main aim of Experiment 2 was to see whether there would be changes in the monkeys’ response patterns when presented with visible stimuli that produced unequal reward values. To assess this, a generalized linear mixed model was conducted in R version 4.3.1 with the lme4 package (Bates et al., 2015). Fixed effect variables of interest included the largest quantity of the two visible set (quantities 3-11 as 2 was never the largest visible), the difference in quantity between the two visible sets (ranging from -4 to 4, calculated by subtracting the noninformative quantity from the informative quantity), and the quartile (1-4). Monkey ID was included as a random effect. Only the monkeys that did not have biasing patterns were included in this analysis (N = 13). To find the model that best fit the data, a model selection table was generated consisting of 13 unique GLMMs created from every possible combination of the three fixed effect variables and potential interactions (Table 7.1). The model containing all three variables with interactions produced the lowest Akaike Information Criterion (AIC) and had the greatest AIC weight, designating it as the most appropriate model to use. Of all variables and interactions, the only significance came from the difference between the visible quantities, indicating that the greater the informative quantity was compared to the noninformative quantity, the more likely the monkeys were to choose to view counterfactual information (Table 7.2, Figure 7.1). Additionally, the monkeys continued to choose the informative option, on average, just over a fourth of the time (M: 27%, CI: 15%, 39%) when the information was paired with the lower quantity visible set (Figure 7.2).

Table 7.1 Experiment 2 GLMM Models

Variables	K	AICc	Delta AICc	AICc Wt	Cum. Wt	LL
VisSetDiff * LargestVisSet * Quarter	9	3276.32	0.00	0.45	0.45	-1629.13
VisSetDiff * LargestVisSet	5	3276.53	0.21	0.40	0.85	-1633.26
VisSetDiff * LargestVisSet + Quarter	6	3278.49	2.17	0.15	1.00	-1633.23
VisSetDiff + LargestVisSet	4	3292.53	16.21	0.00	1.00	-1642.26
VisSetDiff + LargestVisSet * Quarter	6	3292.89	16.57	0.00	1.00	-1640.43
VisSetDiff + LargestVisSet + Quarter	5	3294.51	18.19	0.00	1.00	-1642.24
LargestVisSet	3	4041.77	765.45	0.00	1.00	-2017.88
LargestVisSet + Quarter	4	4043.69	767.37	0.00	1.00	-2017.84

LargestVisSet * Quarter	5	4043.97	767.65	0.00	1.00	-2016.98
VisSetDiff	3	4330.26	1053.94	0.00	1.00	-2162.13
VisSetDiff * Quarter	5	4330.40	1054.08	0.00	1.00	-2160.19
VisSetDiff + Quarter	4	4331.91	1055.59	0.00	1.00	-2161.95
Quarter	3	5058.87	1782.55	0.00	1.00	-2536.43

Note. Presented in this table are all the GLMMs that were created and the accompanying information of how well that particular model fits the data.

Table 7.2 Experiment 2 Best Fitting GLMM

Fixed Effects	Coeff.	SE	z	aOR	95% CI	p
(Intercept)	-0.68	0.66	-1.04	-	[-1.98, 0.61]	.300
VisSetDiff	0.73	0.23	-3.21	2.07	[0.29, 1.17]	.001
LargestVisSet	0.09	0.07	1.35	1.09	[-0.04, 0.22]	.176
Quarter	0.39	0.21	1.89	1.48	[-0.01, 0.80]	.059
VisSetDiff:LargestVisSet	-0.04	0.03	-1.71	.96	[-0.09, 0.01]	.088
VisSetDiff:Quarter	0.03	0.08	0.38	1.03	[-0.13, 0.19]	.707
LargestVisSet:Quarter	-0.05	0.02	-1.94	.95	[-0.09, 0.00]	.053
VisSetDiff:LargestVisSet:Quarter	-0.00	0.01	-0.04	1.00	[-0.02, 0.02]	.972

Random Effects	Groups	Obs	SD	Variance
ID	13	3218	1.144	1.309

Note. The output of the best fitting GLMM with all three fixed effect variables (difference in visible set, largest visible set quantity, and quarter) and one random effect variable (ID). Also included are the adjusted odds ratios and confidence intervals for each fixed effects variable and interaction.

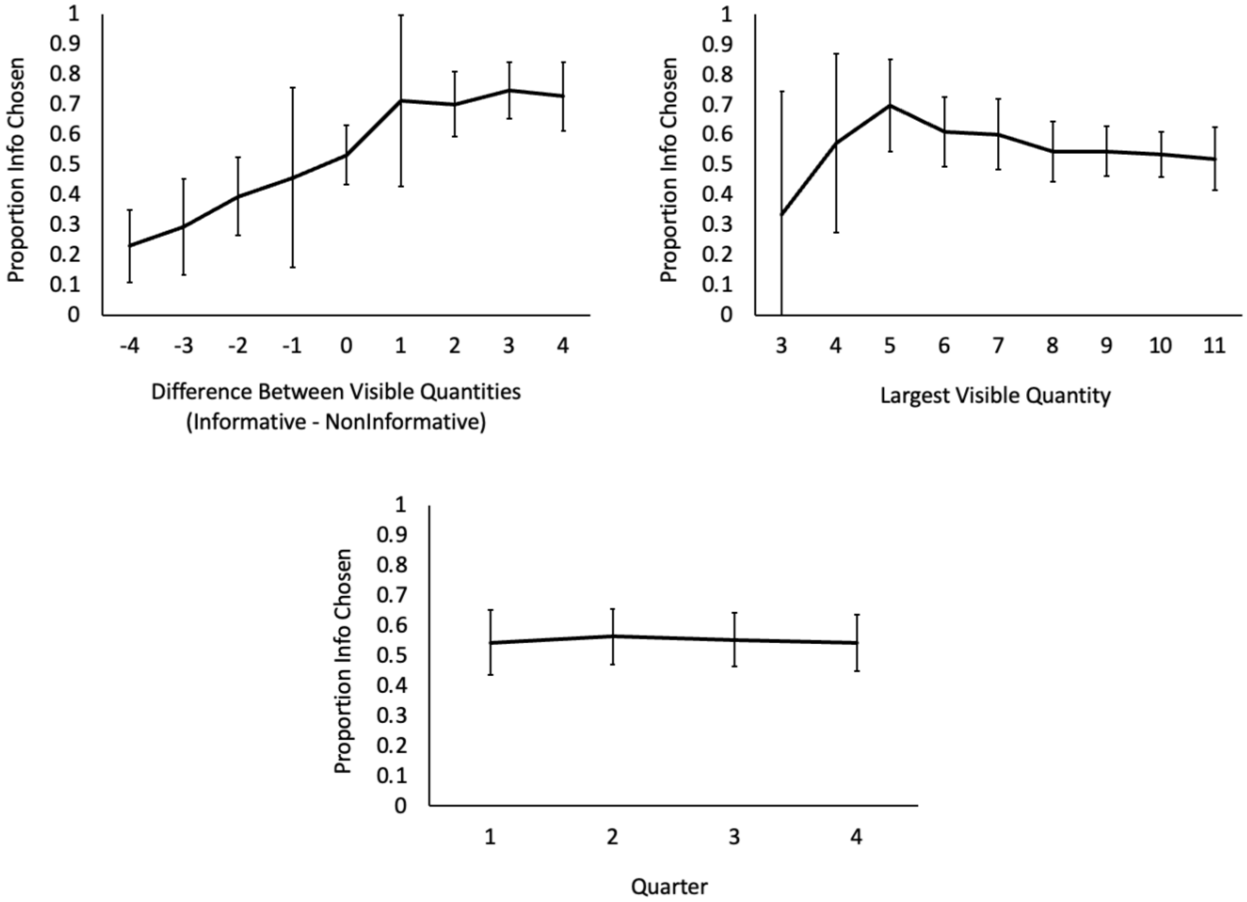

Figure 7.1 Information Choice Proportion by the Variables of Interest

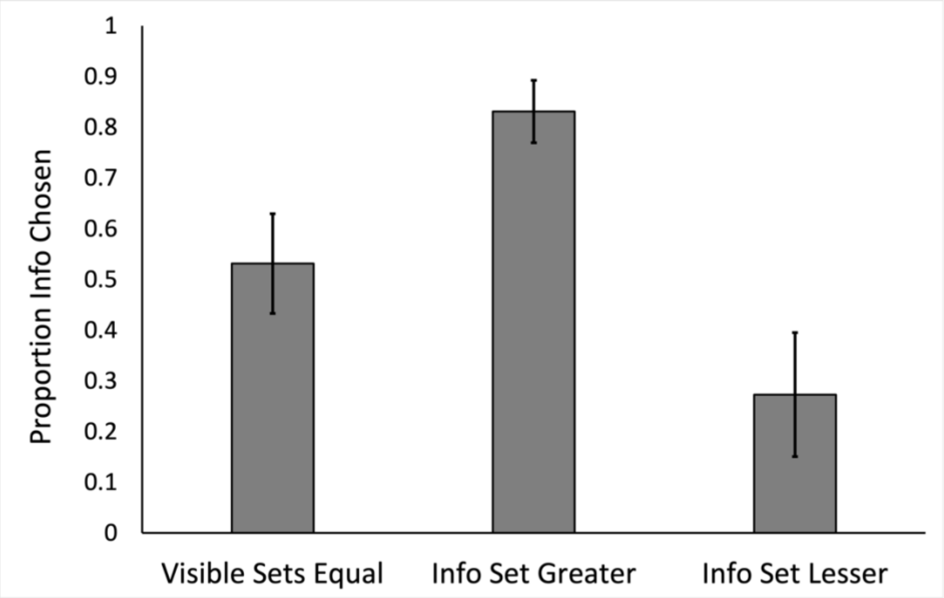

Figure 7.2 Information Choice Proportion by Size of Informative Set Compared to the Noninformative Set

Note. Error bars represent 95% confidence intervals.

8 DISCUSSION

Many species display behaviors associated with curiosity and information collection (e.g., Glickman & Sroges, 1966; Hall et al., 2018). Gaining information, specifically counterfactual information, can be extremely beneficial in understanding consequences of actions and learning how a single event may result in multiple different outcomes. Ultimately, counterfactual information collected can help inform future choices by allowing an actor to understand how to improve on their past behavior or recognize that their behavior resulted in the best outcome (Epstude & Roese, 2008). When used correctly, counterfactual curiosity, thinking, and reasoning are incredibly effective tools for shaping and enhancing behavior and helping an individual adapt to their constantly changing environment. Previous studies have provided evidence that rhesus macaques may collect counterfactual information (Wang & Hayden, 2019) and that they are able to use counterfactuals to inform future choices (Abe & Lee, 2011; Lee et al., 2005). However, it is not fully understood whether nonhuman primates comprehend the presence of multiple situational outcomes (e.g., Redshaw & Suddendorf, 2016) or mentally create alternative scenarios (although this ability is not necessary for all counterfactual recognition).

The goal of the current study was twofold: 1) to better understand nonhuman primate curiosity and explore the possibility that other species may seek out counterfactual information in a similar way to the human population (Experiment 1) and 2) to provide information on how nonhuman primates value the counterfactual information they receive (Experiment 2). Ultimately, extreme biases displayed by each participating macaque hindered this goal, and so I am discussing in large part a comparison of two species (humans and capuchins), although I will discuss some of the results from those animals that showed these extreme biases.

Throughout the training and testing phases, humans and capuchins gambled in patterns that resulted in the optimization of points or food rewards. Strong positive correlations between visible number and its choice proportion were present for each species. This means that participants chose the visible quantity when it was high and the nonvisible (unknown) quantity when the visible number was low. Overall, these results provide evidence that the monkeys comprehended the fundamentals of the task. Specifically, the results showed that 1) monkeys associated the number of dots onscreen with the general quantity of reward that they would receive and 2) the monkeys learned that the black box represented a reward quantity that was both unknown and different than the visible quantity they saw on the screen.

For the first experiment, I hypothesized that each species would prefer to view the counterfactual information, but humans would prefer counterfactuals more often. The data only partially supported these hypotheses. Individually, participants of both species had tendencies to collect counterfactual information. However, this only included about a third of capuchins, but nearly three quarters of humans. Previous studies have demonstrated that humans exhibit individual differences surrounding counterfactuals (e.g., Kasimatis & Wells, 1995) and counterfactual collection rates in the current study support this. However, the same cannot be said about capuchins, as this study provided at best only weak evidence of individual differences, since half the subjects showed no preference for the information. At the group level, only human participants chose counterfactual information in a way that was higher than chance levels of responding. The human counterfactual information collection rates in this study aligned with previous literature, where adults gathered counterfactual information at no cost on a multi-trial task 67% of the time (FitzGibbon et al., 2021; compared to 72% in this study). Thus, humans confirmed this task with these parameters can elicit counterfactual curiosity. However, such curiosity did not emerge in the monkeys.

Overall, the results demonstrated that all species were consistent in how they collected counterfactual information, regardless of risk level, task experience, or counterfactual outcome. In Experiment 1, there was a main effect of the visible quantity, indicating that the lowest quantities (2-4) produced the greatest curiosity in subjects. However, these results should be interpreted with caution, as the participants were gambling so proficiently that these lower quantities were scarcely chosen (some participants never chose these lower numbers when visible). Taking Experiment 2 baseline trials into consideration, overall, the visible number (and level of risk) had no impact on how the monkeys collected counterfactual information. Neither did task experience as demonstrated by a lack of collection differences between the quartiles and no significant correlation between the monkeys' proportion of information collection and training trials completed. This indicates familiarity with the task and the potential realization that the counterfactual provides no benefit (except to gauge task success and a general reinforcement of gambling probabilities) did not change task interaction. Additionally, in Experiment 1, I analyzed whether the realized outcome (win or loss) of a trial impacted the following stimulus choice when that visible quantity was similar (equal or within one item) to the previous visible quantity. Visualizing a win in the first trial of the pair did not alter choices in the second trial. Neither did visualizing a loss. This is similar to the results in Wang and Hayden's (2019) macaques, as any potential emotional output or strategic adjustment from viewing the counterfactual did not alter behavior on the immediately subsequent trial for any species when presented with a similar gambling situation.

During this task, a small subset of monkeys developed an extreme directional bias for the left and right choice options (mainly rhesus macaques). This was likely due to the highly lucrative nature of this task. On other tasks, the monkeys typically receive one or two pellets per correct trial. This task provided between one and twelve pellets per trial (albeit with a longer intertrial interval) and even produced a reward on trials in which the monkeys gambled incorrectly. Although many monkeys did correctly optimize their reward quantity, it is possible the monkeys that showed choice biases did not engage with the task fully and properly, as every choice they picked resulted in a reward (one that was often greater than the more difficult tasks that are regularly presented to them). Overall, this subset of monkeys did have similar choice patterns compared to the capuchins and humans. They all accurately gambled when presented with left and right stimuli that displayed one visible and one nonvisible reward quantity. These monkeys also showed no difference in counterfactual information collection rates when they were presented with different magnitudes of visible quantities or progressed through the quartiles. In Experiment 1, this group of monkeys collected information at chance levels. However, there was a significant difference from chance in how they collected information during Experiment 2 baseline trials, but this result should be cautiously interpreted due to the small and response-biased sample.

In Experiment 2, I asked if monkeys would pay for the information (i.e., sacrifice a greater guaranteed reward) or if they would need an incentive to take the information (i.e., only choose the counterfactual when it came with the largest visible reward). Using the same three-choice gambling design as Experiment 1, in the second experiment the monkeys saw trials in which some of the visible quantities were unequal in value. I predicted that nonhuman primates would place more importance on a greater quantity reward over receiving information during trials in which the visible sets were unequal, ultimately decreasing their rate of counterfactual information collection when the payout was the lesser quantity. The data support this hypothesis, indicating that the difference between the two visible sets was the main contributing factor to their choice. This is unsurprising due to the monkeys' inclination to optimize reward. Although the monkeys did pay for the counterfactual information on some trials, the reverse was also true; the monkeys also sometimes chose the noninformative reward on trials in which the information would have maximized reward. This may be a reflection of how the monkeys did not always gamble perfectly, as they sometimes (although infrequently) took a visible two reward or gambled when presented with a visible eleven.

In summary, the current study provides evidence that humans are interested in counterfactual information on a computerized gambling task, even when the benefit of learning this information is low and not applicable to subsequent choices. The two experiments also provided evidence that capuchin monkeys do not collect counterfactual information about a simple gambling task in a pattern that is different than chance. Nor do they collect this information at a rate that is similar to human counterfactual information collection. The most salient feature to the capuchins' decision to gain counterfactual information was the information's rate of pay compared to the noninformative option; the monkeys simply gravitated toward the response pattern that, in most trials, optimized their reward.

One reason for the difference between humans and monkeys in the choice to gain counterfactual information could be from a general lack of curiosity created by the current task. The uncertainty scenarios produced by the task may have elicited human curiosity to a greater degree as humans more frequently engage in these game-like gambles, providing us with more useful content-neutral information. Constant interaction with counterfactuals in everyday human life may positively reinforce our tendencies to obtain this information, whereas monkeys in a captive setting do not have the similar abundance of opportunity to collect counterfactual information, decreasing the realization of its functionality and, ultimately, its collection rate. However, it is important to note that counterfactual curiosity has only been studied in industrialized, modern cultures. It would be of interest to observe counterfactual information collection in more diverse cultures and testing environments to determine whether the collection rate observed in the current study is robust across cultures and settings.

It is also possible that this highly rewarding task for these monkeys made the counterfactual information less desirable because the monkeys could receive a greater reward than in other tasks that they perform by simply following a general gambling structure. They were generally good at the basic task and could maximize their reward without the need to add cognitive load by gaining counterfactuals to further analyze the task payout structure. This would be in direct contrast to the Wang and Hayden (2019) results, where the methods provided more uncertainty and their water deprived monkeys would have had a greater need to gain counterfactual information to aid in water reward optimization. The monkeys in this task simply did not have the same external pressures to gain information, and this may have been a key factor in their choice. It is possible that in natural environments (or in the case of water deprived macaques) where there is more uncertainty about a situation and when one will receive a necessary resource, there may be a larger temptation to seek out counterfactual information to improve future welfare.

Alternatively, these results may indicate differences in the evolutionary histories of humans and monkeys. However, this conclusion is premature to make from the current study and previous literature alone. Ultimately, if the collection and use of counterfactual information is as functional as theorized (Epstude & Roese, 2008), then the inability of nonhuman primates (and animals in general) to collect, use, and store this information would provide support for the belief that counterfactuals have significantly aided in human cognitive evolution. Examples of this include improving on our ability to avoid dangers, increasing innovation, and enhancing higher cognitive functions such as learning, problem solving, and decision making. Continuing to learn about these differences will allow us to better understand what cognitive mechanisms are necessary to collect and use counterfactuals and how our evolutionary lineage is distinct. Testing more individuals and new species on novel tasks assessing counterfactual collection and use would greatly contribute to our understanding of this topic.

Although this study provides evidence that capuchin monkeys are not counterfactually curious for the sake of gaining information, it is still possible that nonhuman primates may be counterfactually curious in some circumstances and further research should be conducted. In this study, the monkeys only obtained counterfactual information when it provided a benefit (i.e., an immediately greater pellet reward). I believe that if the counterfactual was informative in a way that it would directly provide a future benefit (opposed to a general understanding of the gambling probability), the monkeys would be more likely to collect it. It is possible that we, as humans, have taught ourselves to seek out information whenever we can obtain it, even when it may be irrelevant or even maladaptive (FitzGibbon et al., 2021; Mercier et al., 2017; Sanna et al., 2002) while other species obtain the information only when assumed to be useful. To further investigate counterfactual curiosity across nonhuman primates, future studies should continue to focus on simple procedures that allow an individual to directly observe counterfactual information, opposed to relying on an assumed nonhuman ability to manufacture a counterfactual. Additionally, uniformly emphasizing the counterfactual and noninformative stimuli is crucial. Researchers might also consider providing less lucrative reward options to ensure participants are properly engaging with the task. To date, researchers have not utilized manual tasks to assess counterfactual curiosity. This type of task may have advantages that are not present in computerized ones. To investigate whether monkeys will gain counterfactual information when it is obviously functional, researchers could also observe whether there is an increase in the collection rates of counterfactual information when the counterfactual on one trial aids the monkeys in optimizing their choice in a future trial.

In conclusion, obtaining counterfactual information is a valuable way to understand how to modify future behaviors to produce outcomes that we view as more favorable. Humans overwhelmingly collect this information across many settings, including during the simple gambling task introduced in the current study. On the same computerized gambling task, capuchin monkeys did not share the human tendency to collect information. Unlike humans in previous studies (e.g., FitzGibbon et al., 2019), the capuchins were also unwilling to pay for information, only increasing collection rates when there was a direct benefit involved. This could indicate that the collection of counterfactuals is a human-unique phenomenon, or this task may simply not evoke monkey counterfactual curiosity to the same extent that it does in humans.

Assessing whether these differences are real or a result of variation in task interest and interaction would be informative to our understanding of the mechanisms of learning, problem solving, and decision making in humans and animals alike. Given the limited research conducted on counterfactual curiosity across species, we are only in the early stages of assessing whether animals, and specifically nonhuman primates, collect and use counterfactual information. Further research using novel approaches should be conducted to parse out alternative explanations and help determine whether this trait is uniquely human.

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