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For the Sake of Curiosity: Humans but not Capuchins (*Sapajus apella*) Collect Counterfactual Information on a Computerized Gambling Task

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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 by informing future choices. Humans have demonstrated the desire to collect counterfactual information when it is perceived as useful, during times of uncertainty, and even when it comes at a cost. The comparative literature on counterfactual use and curiosity is small but suggests that rhesus macaques may possess similar tendencies to humans. The goal of the current study was to add a new species, capuchin monkeys (*Sapajus apella*), to the comparative counterfactual literature and to test capuchins and humans on nearly identical tasks. This study involved a three-choice gambling task that consisted of one hidden and two visible reward values. Visible reward values were always equivalent but had differently colored borders to indicate whether participants would view the counterfactual information associated with the gamble or not on trials when they chose not to gamble. Only humans showed evidence of counterfactual curiosity and collected the information at levels different than chance. Humans also collected counterfactual information significantly more than capuchins, indicating a species difference. However, it is not clear whether this difference is simply due to the capuchins' lack of curiosity surrounding this particular task or whether there is a broader species difference for seeking counterfactuals resulting from different evolutionary histories of these species.

Keywords – Counterfactual, Curiosity, Capuchin monkeys, Gambling, Decision making, Comparative cognition

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? As humans we create numerous thoughts about past events that allow us to understand what the situational outcome could have been if an alternative choice had been made. These thoughts are termed counterfactuals. Some people experience these thoughts to a higher degree than others, but most people produce these reflections at least occasionally (Epstude & Roese, 2008). Although counterfactuals are frequently thoughts or reasonings that we create and imagine ourselves, they can also be concrete pieces of information. For example, if you are playing Blackjack in a casino, and you decide to "stay" with your hand, the next person "hitting" would reveal counterfactual information – if you would have busted or not on your next card.

Past research has provided evidence that considering counterfactuals aids in decision making and future problem solving (Medvec et al., 1995). The Functional Theory of Counterfactual Thinking suggests that the main function of counterfactuals is to reflect the goals of an individual and implement necessary behavioral changes. These behavioral changes are proposed to be guided by 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. The content-neutral pathway results in a more generalized behavior. This stems from a broader desire for a behavior change and is not always directly related to the information gained from the counterfactual (e.g., "I could have done better").

Enhancing behaviors through counterfactual thought and reasoning helps to shape future behavior to match one's goals and adapt to a constantly changing environment. Utilizing counterfactual curiosity, which is the desire to seek out counterfactual information, people may "stock up" on all available information to help learn and better prepare for any future circumstance. Humans tend to seek counterfactual information when it is perceived as useful for the future and under circumstances with greater uncertainty (Shani et al., 2008; Shani & Zeelenberg, 2007). Humans have even sought counterfactuals when the desired information has little importance. For example, on a Balloon Analogue Risk Task, adult humans "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 more times they could have pumped the balloon after choosing to stop on 67% of trials. When the same information came with various costs (monetary, physical, time), participants continued to collect the information, but to a lesser degree (18-56% of the time).

Like humans, nonhuman 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. Currently, there is limited evidence that species other than humans are able to create, identify, or use counterfactuals due to the lack of available studies. However, results from a few studies have suggested that captive rhesus macaques (*Macaca mulatta*) can apply their knowledge of counterfactual outcomes to future trials. On a computerized rock-paper-scissors game, rhesus 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 (Abe & Lee, 2011; Lee et al., 2005). Further, when presented with eight identical targets in a circle and all but one produced the same reward, rhesus macaques were more inclined to choose or not choose the location for their next reward based on the payout of that location in the previous trial (Hayden et al., 2009). However, for all these studies, it is possible that 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.

To date, only one study that we know of has observed 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. 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 this task, the monkeys 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. Importantly, the acquired information provided no benefit and did not help the monkeys on future trials.

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. 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. Counterfactual thought, production, and reasoning likely call on developed abilities of working memory, cognitive control, and cognitive flexibility, as well as the capability to produce abstract thought. However, the capacity to be curious about counterfactuals does not require all of these abilities, and thus, 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 counterfactuals (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 capuchin monkeys and many other species displaying information-seeking behaviors and an interest in novel objects and variety (e.g., Addessi et al., 2010; Fragaszy et al., 1997; Glickman & Sroges, 1966; Hall et al., 2018), it is not clear whether this same intrinsically motivated exploration is present in animals.

In the current study, a gambling task was used to observe counterfactual curiosity, applying similar methods to adult humans and capuchin monkeys (*Sapajus apella*). Capuchins are ideal candidates for this task as they have shown the ability to accurately judge quantities (e.g., Beran & Parrish, 2016; Beran et al., 2008), and logically solve gambles involving uncertainty, specifically during tasks in which there was one visible reward and one unknown reward displayed (Beran et al., 2012). Presenting capuchin monkeys with this task also introduces a new species to the literature that has not yet been tested in similar tasks. Previous studies with humans indicate an interest in gaining counterfactual information (FitzGibbon et al., 2019, 2021). Similar results in monkeys would provide new insights into decision-making in nonhuman primates. However, evidence of counterfactual curiosity in capuchin monkeys 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 the monkeys possess these capabilities but may indicate that the task at hand does not appropriately fill their need to seek out counterfactual information. Differing behavior patterns may also signify species differences resulting from distinct evolutionary histories and documenting such patterns could allow us to better parse out what mechanisms and situations may be necessary to provoke curiosity about counterfactuals. Focusing investigations on nonhuman primates 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 the current study, we 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. The goal of the study was to provide insight on whether capuchin monkeys possess counterfactual curiosity under times of uncertainty, if they will actively seek out counterfactual information when there is no immediate, or obvious benefit in doing so, and if they collect this information at a similar rate to humans. In Experiment 1, adult humans were presented with a 3-choice computerized gambling task that allowed them to choose an unknown reward quantity, or one of two equivalent visible reward quantities, one that showed them counterfactual information, and one that showed a blank, white intertrial interval screen. In Experiment 2, capuchin monkeys (*Sapajus apella*) were exposed to the same task, with slight modifications to suit nonhuman primate participants. Considering the previous literature, it was predicted that this task would elicit counterfactual curiosity in both species. However, it was also predicted that humans would possess a higher state of curiosity, shown by obtaining information at a greater rate. We also predicted that the risk level of the gamble would impact information collection rates; trials where gambling was most risky (e.g., visible values 5-8) were predicted to result in an increase in information collection rates compared to near-guaranteed wins (visible values 9-11) or losses (visible values 2-4) due to the greater levels of uncertainty.

Experiment 1

Method

Ethics Statement

Methodology and study procedures conducted with human participants were approved by the Institutional Review Board of Georgia State University, USA. All testing was voluntary.

Participants

Participants were 31 undergraduate students (males = 11, females = 20) between the ages of 18 and 22 who were recruited at Georgia State University, USA. Participants voluntarily joined the study and provided written consent before starting the experimental procedures. Table 1 presents demographic information for these participants.

Apparatus

Participants were tested in the psychology laboratory of the authors on individual computers with 17-inch color monitors. Participants made their choice responses by using mouse clicks. The computer program was written with Visual Basic 6.0 software.

Procedure

To start each trial, participants first saw a screen in which they had to click a button with the word "start" to present the next trial. Following this, three stimuli appeared on the screen. Stimuli included one nonvisible quantity set and 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; Figure 1). The yellow-bordered visible quantity set always indicated gaining counterfactual information while the blue-bordered visible set indicated no counterfactual information. 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. Visible sets always contained the same number of dots so that there was no reward benefit between gaining information or not gaining it. 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). The nonvisible quantity was never equivalent to the visible quantities. Participants always 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 (blue border), they saw the blank white intertrial interval screen. If the informative visible dot set (yellow border) was chosen, the black box would be removed from the nonvisible set to reveal the number of dots underneath for the intertrial interval. 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.

Figure 1

Three-Choice Testing Trials and Their Outcomes

Note. Choice of the counterfactual is shown in column A and choice of the noninformative stimulus is shown in column B. Choosing the nonvisible quantity uncovered the set of dots before presenting a blank, white screen (column C).

Each participant was tested on an individual computer. Before the task began, instructions were displayed on the screen and participants read about the general rules of the gambling task, the outcome of the different border colors, and how to collect points. 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 dots they collected while engaging with the program. After collecting 2,000 points (dots), the testing session was over. At the bottom of the screen, each participant had a point countdown system to let them know how many points they still needed to collect. To motivate responding, participants could leave as soon as they finished, and the participant who collected 2,000 points within the fewest number of trials received a $25 gift card at the end of the experiment. The specific instructions 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 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 dots. Before making this choice, you will not know how many dots are under the black square. When you choose the set of dots with the YELLOW border, you will also get to see how many dots were under the black square. You will not get those dots, but you will get to see how many had been there. If you choose the set of dots surrounded by the BLUE border, you will NOT get to see how many 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 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 dots with a YELLOW border lets you know how many dots were hidden under the black square. Choosing the set of 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 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."

Results

All 31 individuals that participated in the task fully completed the experiment. However, four individuals gambled too often (>85%) or too little (<15%) to provide enough data for the analyses, and these individuals were removed from the analyses. The remaining 27 participants completed an average of 278 (range: 263-295) testing trials to collect all 2,000 points necessary to finish the task.

Participants produced a strong correlation between the number visible and its choice proportion ($r(10) > .98$; $p < .001$; Figure 4). The main goal of Experiment 1 was to determine the rate at which humans collected counterfactual information on the current task and what factors influenced this choice. To obtain this rate, we considered trials in which one of the two visible options were chosen to view how frequently the informative set was picked over the noninformative set. On a group level, the human participants collected information 72% of the time and significantly above chance, as determined by a one-sample t-test, $t(26) = 4.69$, $p < .001$, $d = 0.90$. 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 (Table 1).

Table 1

Human Demographic Information and Individual Differences

Sex	ID	Age	Trials	Choice of Info Prop	Binomial *p* value
Male	1101	21	276	0.92	<.001
	1102[a]	18	309	0.53	0.76
	1105	20	279	0.93	<.001
	1106	21	267	0.59	0.03
	1107	21	287	0.51	0.87
	1108	18	285	0.87	<.001
	1112	19	278	1.00	<.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	0.58
	1109[a]	22	303	0.61	0.24
	1110	18	281	0.38	0.002
	1111	19	272	0.61	0.01
	1114[a]	19	308	0.35	<.001
	1115	19	281	0.71	<.001
	1116	19	281	0.39	0.01
	1117	18	282	0.89	<.001
	1118	19	275	0.75	<.001
	1119	19	266	0.58	0.07
	1120	19	279	0.63	0.003
	1121	18	285	0.77	<.001
	1122	19	277	0.43	0.08
	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	<.001
	1131	18	285	0.73	<.001

Note. Demographic information for human participants and individual results from Experiment 1. Choice of Info Prop indicates the proportion of trials in which a participant chose to view the counterfactual information when they picked one of the two visible quantity sets.
[a] Individuals removed from Experiment 1 analyses for gambling less than 15% or more than 85% of trials.

A repeated measures ANOVA was conducted to determine whether visible quantities (categorized as low (2-4), mid (5-8), and high (9-11)) impacted the choice to obtain information when the visible quantity was chosen. The assumption of sphericity was violated (W = .28, χ^2 (2) = 24.33, p < .001), so the Greenhouse-Geisser corrected values are reported. There was a main effect of visible quantity choice in the participants' decision to view the counterfactual information (F(1.16, 23.23) = 5.97, p = .019, η_p^2 = .23; Figure 4). To understand this difference, two-sided paired samples t-test were conducted to compare the three quantity levels with a Bonferroni correction, resulting in an alpha of .017. Participants marginally chose to view counterfactual information more when presented with a low visible quantity (2-4; M = 85%, CI: 76%, 93%) compared to high quantities (9-11; M = 69%, CI: 61%, 79%), t(20) = 2.61, p = .017, d = 0.40. There was no significant difference between low and mid quantities (5-8; M = 73%, CI: 63%, 81%), t(20) = 2.31, p = .032, d = 0.33, or mid and high quantities, t(26) = 1.28, p = .21, d = 0.42.

To determine the effect of trial number on the likelihood to view counterfactual information, the data were divided into quartiles. 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 (sphericity violated, $W = .523$, χ^2 (5) = 16.02, $p = .007$, Greenhouse-Geisser correction used, $F(2.34, 60.95) = .98$, $p = .39$, $\eta_p^2 = .04$).

Finally, we assessed 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 were used in which 1) the participant chose to view counterfactual information and 2) the trial immediately after that trial presented the same visible number, or a number within one item of it. For example, trials would be included in this analysis if a participant chose a visible six and to view information on Trial 1, and on Trial 2 they saw a visible five, six, or seven. 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. Paired samples t-tests were conducted to observe how the outcome of Trial 1 (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 = 49% choice of counterfactual after loss, CI: 31%, 64%) or a realized win (M = 54% choice of counterfactual after win, CI: 39%, 72%), $t(21) = -0.36$, $p = .73$, $d = -0.08$. The outcome of Trial 1 also did not impact their choice to gamble (i.e., take the nonvisible set) after a realized loss (M = 39% choice to gamble after loss, CI: 25%, 58%) or win (M = 28% choice to gamble after win, CI: 13%, 43%), $t(21) = 0.97$, $p = .34$, $d = 0.21$.

Discussion

In this task, adult humans had a tendency both on the individual and group level to collect counterfactual information, and they did so at a rate that was significantly above chance. Generally, the participants did not change their rate of collection based on level of risk, task experience, or the outcome of the gamble. There was a significant difference in how they collected information when presented with low-quantity gambles (a near-guaranteed loss when choosing the visible set) compared to high-quantity gambles (a near-guaranteed win if the visible set was chosen). This could indicate a stronger desire to collect information when taking greater risks. However, this result 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). Overall, these results show that the methods do elicit human counterfactual curiosity and validate the task for use with nonhuman primates.

Experiment 2

Methods

Ethics Statement

Georgia State University's animal research program has been accredited by the Association for Assessment and Accreditation of Laboratory Animal Care (AAALAC). All methodology and care standards were approved by the Institutional Animal Care and Use Committee (IACUC) of Georgia State University, USA.

Participants

This experiment included 22 adult capuchin monkeys (males = 7, females = 15) housed at Georgia State University's Language Research Center, USA. These monkeys were excellent candidates because they all had a long history of participation in cognitive tasks, including gambling tasks. These monkeys also had extensive experience working with computerized testing systems and manipulating joystick controllers (e.g., Beran et al., 2012). The capuchin monkeys were all socially housed in groups ranging from two to nine individuals. All social groups had access to indoor and outdoor housing before and after designated testing time (0800-1400), weather permitting. During this time, the monkeys also had access to various enrichment devices. Each day, they had the option to separate from their group and receive food rewards during testing sessions that lasted up to six hours. If during this time an animal exhibited any indication of stress, they were immediately returned to their social group housing; however, this was never observed. Monkeys were never food or water deprived. Water was readily available during testing through a lixit. Aside from food rewards provided during testing, all monkeys, regardless of participation, received daily fruits and vegetables. Monkeys engaged with highly similar software (in appearance and response demands) to that given to the humans in Experiment 1 to ensure greater comparability across species.

Apparatus

Monkeys 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).

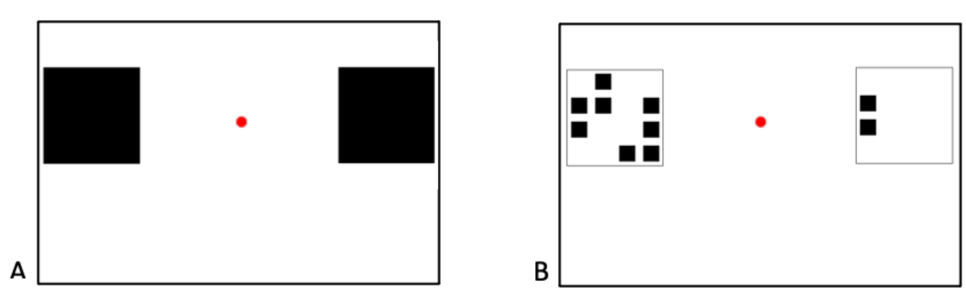
Procedure

The testing program presented to the monkeys was highly similar to that given to humans. Before participating in testing trials, the monkeys were provided with training methods to ensure they had an accurate association between the quantity set chosen and the resulting reward as well as a general understanding of the basic gambling task.

Pre-Training Version 1. Pre-Training was designed to ensure that all subjects could accurately choose the greater quantity between two visible dot sets and to teach the monkeys that they would receive a reward when choosing a nonvisible set. All trials (training and testing) began with a start screen (a rectangle centered on screen that had to be contacted with the cursor). Once past the start screen, subjects chose between either two visible sets of dots or two nonvisible sets (Figure 2). 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 monkeys 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.

Figure 2

Pre-Training Trials



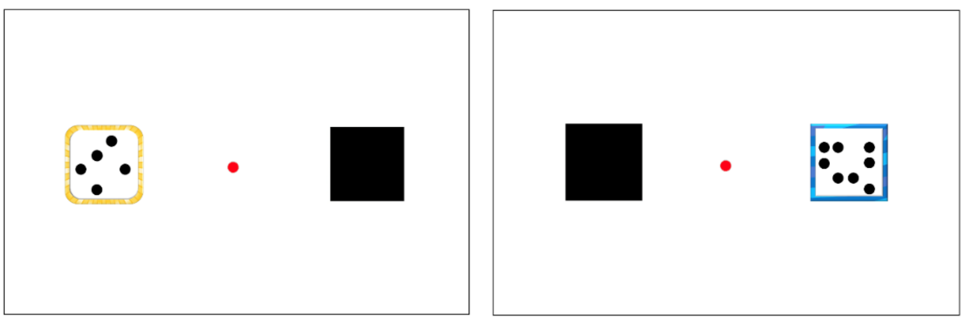
Note. Image A depicts two nonvisible quantities before a selection occurred. Image B depicts a visible trial, allowing subjects to choose their reward set based on two visible options.

Capuchins completed this first version of pre-training in an average of 168 trials (CI: 114, 222). All capuchins showed patterns of choosing the highest dot quantity during trials with two visible sets (86% correct, CI: 82%, 91%). Table 3 presents individual trial counts and accuracy proportions.

Training Version 1. Training introduced the gambling task. Here, the monkeys saw one nonvisible set (an opaque black box) and one visible set of dots. Visible sets of dots could now have a yellow or blue border surrounding them (Figure 3). This phase allowed the subjects to learn the association between each colored border and its outcome. 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, this choice resulted in reward distribution immediately followed by 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 during reward distribution 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 3). To control for potential color biases, the 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.

Figure 3

Two-Choice Gamble Trials



Note. Figure depicts two-choice gamble trials for both the informative and noninformative trial types

During the first version of training, most monkeys completed 200 trials, however there were four capuchin monkeys that exceeded this number (see Table 3), 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 3). Overall, the capuchins showed a strong positive relationship, $r(10) = .96, p < .001$).

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 3). 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.

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%). Individual trial counts and accuracy proportions are presented in Table 3.

Training Version 2. In Training Version 2, the intertrial interval remained at 20 seconds. In these trials, monkeys were presented with the same training task as Training Version 1. The difference between these versions was the criteria needed to progress. Like the first version of training, the 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. In addition, 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 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.

The capuchins needed an average of 1,242 trials (CI: 730, 1,753) to reach criterion. As before, they showed strong correlations over all training trials ($r(8) = 0.98$, $p < .001$; see Table 3 for individual performances).

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 (Table 2). These individuals were put on de-bias training when they showed no signs of variable gambling behavior 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 a monkey still chose the nonvisible set, that gamble would present an extreme loss: 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 more variable (and typical) gambling behavior (i.e., choosing the visible quantity when high and the nonvisible quantity when low).

Table 2

De-Biasing Training

	Training Version 2 (1st)		De-Bias Training		De-Bias 0 Training		Training Version 2 (2nd)	
ID	Sessions	Trials	Sessions	Trials	Sessions	Trials	Sessions	Trials
Atilla	9	1200	3	635			3	517
Gretel[a]	9	1013	4	1000	7	1600	-	-
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] Removed from study for showing no signs of reversing her bias for the nonvisible set after 1,600 trials of the second version of bias training.

Six capuchins participated in this de-bias training. In all cases, these capuchins were choosing to gamble (i.e., take the nonvisible set) nearly every training trial with no indication that this pattern would resolve on its own (minimum 918 trials). After an average of 1,158 de-biasing trials (CI: 988, 1330), the gambling behavior of four monkeys was corrected, resulting in more typical nonvisible collection rates. These monkeys were then returned to the regular training methods. The other two monkeys had a bias that persisted after roughly 1,000 trials, and they were moved to a second de-bias training that introduced zeros.

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 de-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.

These methods successfully shifted the gambling patterns of one of the two monkeys. The second monkey was removed from the study. All bias training trial counts are shown in Table 2.

Test. The test phase consisted of 10-trial blocks. The first two trials within each block were identical to the Training Version 2 phase – one nonvisible set and one visible set (Figure 3) were presented. In a randomized order, one of the two trials provided the informative visible option, and the other trial presented the noninformative visible option. The presentation of these trials reminded the subjects of the outcome of each stimulus border color. The remaining eight trials in each block were the same methods as what was presented to the humans, with the exception of the countdown point system. Here, the monkeys were given all three stimuli at the same time: two equivalent visible quantities (each with a different colored border) and one nonvisible quantity (Figure 1). Monkeys completed 80 trial blocks, equaling 800 trials (80 information two-choice gambles, 80 no-information two-choice gambles, and 640 three-choice gambles).

Results

Of the 22 capuchins presented with the task, 18 individuals completed the experiment. The remaining four capuchins either did not separate from their group frequently enough to fully participate or had an irreversible bias to choose the nonvisible set. Table 3 shows the demographic information of all monkeys that participated in the task.

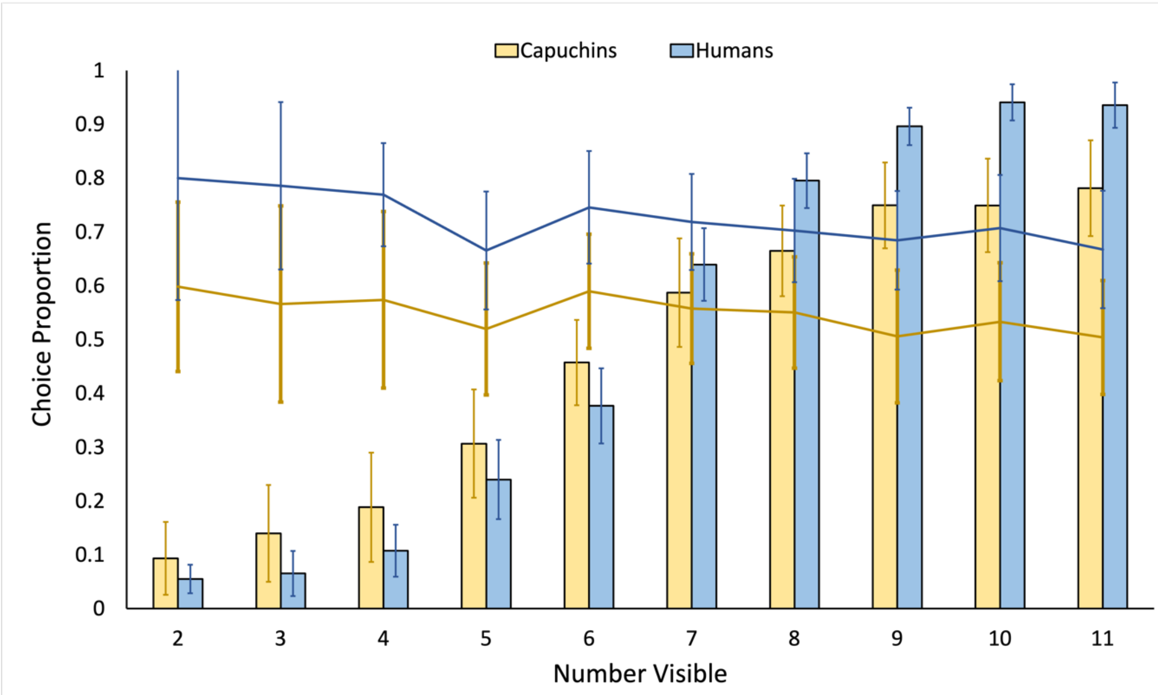
Test

Monkeys completed 800 trials. Of these trials, 640 were testing trials and the remaining 160 were two-choice gamble trials. Experiment 2 analyses excluded two capuchins due to extremely high levels of gambling (choosing the opaque black box greater than 85% of the time). Additionally, three capuchins had significant directional biases, choosing stimuli only in one part of the screen. The highly biased choice behavior of these monkeys was not considered reflective of the main aims of the experiment because the biases made it highly unlikely that they were interacting with the task correctly. These biases were likely due to the nature of the task, as it was less complex, required low effort, and always produced a reward that was usually greater in quantity compared to other tasks that the capuchins participated in during the same period of time. The following analyses removed these individuals and thus included data from 13 capuchins.

As during training, there was a positive relationship between the visible quantity and its choice proportion (Figure 4). 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%), $t(11) = 2.12$, $p = .06$, $d = 1.18$. Thus, the data were collapsed across border color condition for the remaining analyses.

Figure 4

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.

Regarding individual differences, five of thirteen capuchin monkeys had a bias for collecting information as indicated with a binomial test (all $p < .05$), two had a bias for collecting no information ($p < .01$), and the remaining six had no directional bias (Table 3). Overall, capuchin monkeys collected information on 53% (CI: 44%, 62%) of trials when they chose a visible set. Although individually some monkeys did choose to view counterfactual information (or no information) at rates different than chance, a two-tailed, one sample t-test comparing overall proportion for this species to 0.5 chance level revealed that information collection rates of capuchins did not differ from chance, $t(12) = 0.64$, $p = .53$, $d = 0.18$. Additionally, an independent samples t-test was conducted to compare the collection rates of the humans and capuchins. Humans collected significantly more counterfactual information than the capuchins, $t(38) = -2.46$, $p = .019$, $d = -0.83$.

To determine if there was an impact of visible quantity on the capuchins' choice to view the counterfactual information (Figure 4), a repeated measures ANOVA was conducted. There was no difference in visible number on the monkeys' choice proportion of counterfactual information, (Greenhouse-Geisser corrected values are reported due to the violation of sphericity, $W = .18$, χ^2 (2) = 17.37, $p < .001$), $F(1.10, 12.06) = 1.61$, $p = .23$, $\eta_p^2 = .13$.

Because the monkeys completed a wide range of training trials (including de-biasing training trials), which contributed to task experience and overall knowledge of gambling probabilities, 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, $r(13) = .19$, $p = .54$. There was also no significant difference in the amount of information collected between monkeys who completed de-bias training (M = 67%; CI: 47%, 88%) and those who did not (M = 47%; CI: 40%, 54%), $t(11) = -2.15$, $p = .06$, $d = -1.29$. To determine the effect of experience on the task, the data were split into quartiles of 160 trials. A repeated measures ANOVA revealed no main effect of quartile, $F(3, 36) = 1.11$, $p = .36$, $\eta_p^2 = .09$.

To allow for a more direct comparison of the monkeys' and humans' choice patterns over time, we also conducted a repeated measures ANOVA for the first 260 test trials that the monkeys completed (split into quartiles with 65 trials each). Similarly, no main effect of quartile was found, $F(3, 36) = 1.74$, $p = .18$, $\eta_p^2 = .13$.

Finally, to observe if the monkeys' choices were altered on the subsequent trial by the realized loss or win of a gamble (as a result of collecting information on the immediately previous trial), paired samples t-tests were conducted. The choice to continue to collect the counterfactual was not impacted by either a realized win (M = 30% choice of counterfactual after win; CI: 21%, 39%) or loss (M = 35% choice of counterfactual after loss; CI: 26%, 43%), $t(12) = 0.90$, $p = .39$, $d = 0.25$. Similarly, a known win (M = 39% choice to gamble after win; CI: 30%, 48%) or loss (M = 41% choice to gamble after loss; CI: 33%, 52%) did not change the choice proportion of the unknown quantity set, $t(12) = 0.49$, $p = .63$, $d = 0.14$.

Table 3

Monkey Demographic Information and Individual Differences

			Pretraining Version 1		Training Version 1		Pretraining Version 2		Training Version 2		Test	
Sex	ID	Age	# Trials to criteria	Visible Set Prop Correct	# Trials to criteria	Visible # and Choice Correct (*r*)	# Trials to criteria	Visible Set Prop Correct	# Trials to criteria	Visible # and Choice Correct (*r*)	Choice of Info Prop	Binomial *p* value
Male	Albert	11	438	0.71	200	0.96	67	0.93	419	0.91	0.48	.72
	Atilla[b]	10	439	0.74	200	0.45	108	0.77	2352	0.99	0.52	.53
	Griffin	25	139	0.91	200	0.22	65	1.00	1367	0.91	0.50	.95
	Liam[b]	19	93	0.91	200	0.27	78	0.98	2177	0.97	0.99	<.001
	Logan[b]	17	72	1.00	200	0.65	81	0.98	4616	0.95	0.45	.11
	Mason[a]	24	94	0.89	200	0.26	789	0.60	515	0.94	-	-
	Nkima[c]	14	86	0.98	200	0.93	90	0.98	487	0.96	0.46	.84
Female	Applesauce[a]	17	229	0.83	200	0.76	98	0.88	2441	0.57	-	-
	Bailey	22	92	0.89	200	0.88	81	0.98	600	0.93	0.23	<.001
	Bias	35	346	0.71	200	0.50	969	0.72	1876	0.91	0.47	.22
	Gambit	26	83	0.84	200	0.10	195	0.82	1376	0.80	0.87	<.001
	Gretel[a,b]	18	172	0.89	201	0.64	150	0.97	3173	0.65	-	-
	Ingrid[d]	10	88	0.95	200	0.74	89	0.95	607	0.99	0.55	.15
	Ira[d]	11	99	0.95	200	0.87	78	0.93	600	0.98	0.68	<.001
	Irene[b]	20	105	0.80	300	0.19	105	0.88	2131	0.99	0.73	<.001
	Ivory[a]	23	81	0.93	200	0.85	391	0.77	411	0.39	-	-
	Lily[b,c]	25	191	0.82	200	0.97	89	0.91	2077	0.93	0.50	1.00
	Lychee	24	82	0.93	300	0.92	167	0.94	320	0.90	0.58	.002
	Nala	20	242	0.76	383	0.80	137	0.82	469	0.94	0.40	.01
	Paddy[d]	12	188	0.94	200	0.56	79	0.98	328	0.94	0.60	<.001
	Widget	14	147	0.79	298	0.94	155	0.93	274	0.95	0.44	.06
	Wren	20	97	0.91	200	0.90	97	1.00	271	0.94	0.56	.04

Note. Demographic information and individual results for training and testing phases. Choice of Info Prop indicates the proportion of trials in which a monkey chose to view the counterfactual information when they picked one of the two visible quantity sets.
[a] Individuals discontinued in the study for not separating to test frequently enough or for having an irreversible bias.
[b] Individual participated in bias training (see Table 2).
[c] Individual removed from analyses for gambling more than 85% of trials.
[d] Individual removed from analyses for directional biases.

Discussion

Overall, the monkeys were highly skilled on the basic gambling task presented, although this did require some additional phases of training. When the visible quantity was numerically larger, they tended to choose it, and they chose the nonvisible reward quantity when the visible set was of a smaller number of items. This indicates a learned association between the quantity of dots and reward value, as well as the recognition that the opaque black box resulted in a reward that was revealed as underneath the box. On the three-choice gambling task presented during the test phase, some capuchin monkeys collected information at a rate greater than chance. However, as a group, the monkeys did not differ from chance in their collection rates, and they collected significantly less information than the humans did in the same task.

It is possible that this task did not spark curiosity in the capuchins to the same extent as the human participants, or it may indicate a broader difference between the two species. While they did display significantly lower levels of collection rates, the monkeys did show similar patterns to the human participants in how they collected information, as it did not change with various risk levels, their knowledge of the task outcome, or the recognition of a win or loss.

General 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 effective tools for shaping and enhancing behavior and helping an individual adapt to their constantly changing environment. These are important abilities that would allow many animals to both survive and thrive. Determining the prevalence of this curiosity-driven precursor in nonhuman species could provide information as to whether certain species may also experience similar preparatory advantages of full counterfactual thought and reasoning, and during what situations they may do so.

The goal of the current study was to better understand nonhuman primate counterfactual curiosity and to explore the possibility that other species may seek out counterfactual information in a similar way to the human population. We hypothesized that both species would be interested in the counterfactual information, but humans to a greater extent. The data did not support this hypothesis. 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 that this task with these parameters can elicit counterfactual curiosity even when the benefit of learning this information is low and not applicable to subsequent choices. However, such curiosity did not emerge in the monkeys; they did not collect counterfactual information about a simple gambling task in a pattern that is different than chance, nor did they collect this information at a rate that is similar to human counterfactual information collection.

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 consistent 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 diverse cultures and testing environments to determine whether the collection rate observed in the current study and in previous studies with humans 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 were generally good at the basic gambling 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. Implementing studies with greater uncertainty on populations that are not food or water deprived could be an interesting next step to gain further insight on whether collecting the information is based on task uncertainty or the availability of resources.

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. 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 as in the current task), the monkeys might be more likely to collect it. It is also 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 investigate whether monkeys will gain counterfactual information when it is obviously functional, researchers could observe whether there is an increase in the collection rates of counterfactual information when the counterfactual on one trial aids the monkeys in optimizing 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. 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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aided in the development of methodology and designed the program software. M.J.B. also reviewed and edited the manuscript.

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