Wild rhesus monkeys generate causal inferences about possible and impossible physical transformations in the absence of experience

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Human infants and adults generate causal inferences about the physical world from observations of single, novel events, thereby violating Hume's thesis that spatiotemporal cooccurrence from prior experience drives causal perception in our species. Is this capacity unique or shared with other animals? We address this question by presenting the results of three experiments on free-ranging rhesus monkeys (*Macaca mulatta*), focusing specifically on their capacity to generate expectations about the nature of completely unfamiliar physical transformations. By using an expectancy violation looking-time method, each experiment presented subjects with either physically possible or impossible transformations of objects (e.g., a knife, as opposed to a glass of water, appears to cut an apple in half). In both experiments, subjects looked longer when the transformation was impossible than when it was possible. Follow up experiments ruled out that these patterns could be explained by association. These results show that in the absence of training or direct prior experience, rhesus monkeys generate causal inferences from single, novel events, using their knowledge of the physical world to guide such expectations.

cognitive evolution | expectation | innate representations | primate cognition

The British philosopher David Hume argued that there is no evidence of cause in the world (1). Cause, so he claimed, is inferred from the frequent cooccurrence (spatial and temporal) of two previously experienced events. We know that a pool cue will move a ball because we have seen some form of this cause–effect relationship many times before. But as the psychologist David Premack argued (2), although Hume's logic was sound, his psychology was not: cause is often inferred, by human adults and infants, from single, novel events and sometimes not inferred even after hundreds of cooccurrent and familiar events (3–11). For example, when human adults (7, 12, 13) and even 27-week-old infants (5, 6) watch an animation of a moving block make contact and launch a stationary block, they immediately perceive the causal force of this event even though it is novel and only viewed once. Moreover, although every human on earth experiences day following night, no one infers that night causes day. These amendments to Hume's thesis about causality leave open two other questions: is our capacity to draw causal inferences restricted to or specialized for certain domains of knowledge (9, 14), and is this capacity unique to our species or shared with other animals? In this article, we take up the second of these questions. At present, relatively little is known about the evolution of our capacity to generate causal inferences, and most of what we do know comes from studies looking at learned causes in which frequent cooccurrence yields the right inference (2, 15–19). Here, we present the results of three experiments on free-ranging rhesus monkeys that provide evidence of inferred cause based on a single unfamiliar event, while also revealing rather surprising knowledge of the physical world.

The theoretical foundation for our studies is Premack's work on captive chimpanzees (2, 18). The logic of these studies was a form of sentence completion in which subjects picked either an appropriate causal agent for transforming one object into another or picked the transformed state after the implementation of a causal agent. Each test took advantage of the fact that these chimpanzees had prior training with a human-created language involving plastic symbols and, especially, their knowledge of the question mark symbol. For example, in one condition, Premack presented chimpanzees with APPLE _?_ APPLE HALVES, accompanied by three potential transforming objects: a knife, a glass of water, and a tape dispenser. Chimpanzees replaced the question mark with a knife; when given APPLE KNIFE _?_, they picked APPLE HALVES from the alternatives. This suggests that chimpanzees understand that a knife is a likely transforming agent, at least when compared with the other two alternatives. Additional conditions ruled out the possibility of familiarity and prior association. In one condition, Premack reversed the more familiar temporal sequence (e.g., APPLE HALVES _?_ APPLE). Here, the chimpanzees selected the tape dispenser as the missing agent, even though both the knife and glass were also present as alternatives. A second series of studies used highly novel objects and even anomalous transformations, including a glass with writing on it. Here again, chimpanzees picked the appropriate transforming agent or the most likely transformed state. These findings, together with others, suggest that chimpanzees can draw inferences about cause and effect on the basis of single, and in some cases, highly unfamiliar events.

Premack's experiments leave open two challenges to Hume's view of causality: (*i*) To what extent are these findings generalizable to species without any history of laboratory experience and, especially, to animals with no language-relevant training and no history of tool manufacture and use? And (*ii*), to what extent would any primate (or any other animal) be surprised to witness a physically impossible transformation, such as a glass of water cutting an apple in half? Restating the last question, even though chimpanzees picked the appropriate causal agent in Premack's experiments, would they reject the other objects as implausible or even impossible agents? The experiments presented next address these two questions.

Previous work leads to several predictions concerning the rhesus monkeys' performance in these experiments. First, given that there are no reports of wild rhesus monkeys using tools in the wild or, for that matter, of rhesus monkeys showing any interest in object manipulation, one might expect failure. That is, in the absence of any prior selective pressure to attend to and manipulate details of the physical environment, rhesus monkeys should show little sensitivity to physical transformations. However, if the capacity to draw causal inferences is domain-general and independent of prior experience, then rhesus monkeys should be sensitive to physically possible and impossible transformations. Second, although rhesus monkeys do not use tools, recent studies of other primate species that do not naturally use

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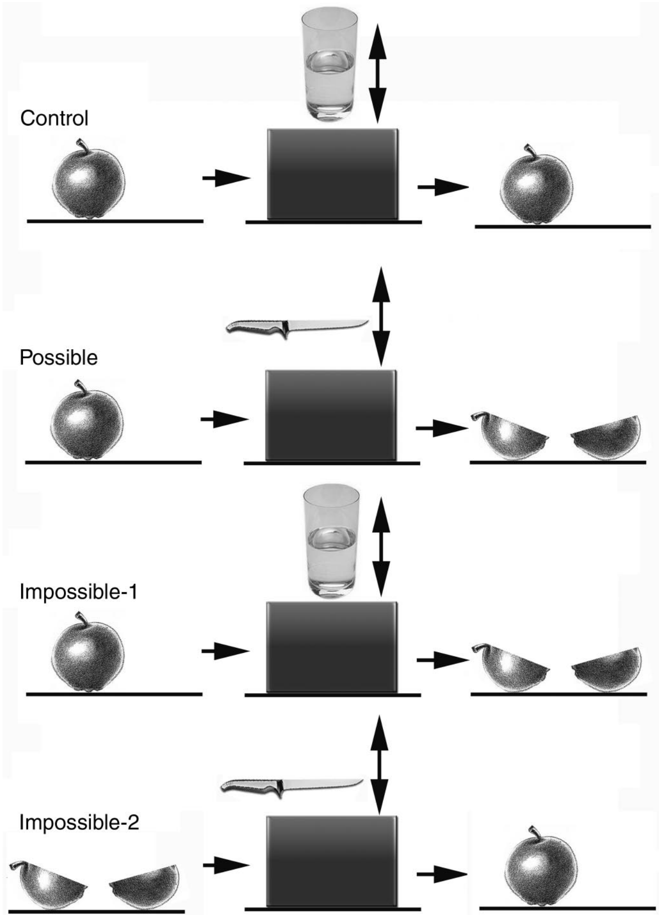

Fig. 1. A conceptual replication of Premack's apple study. Row 1 shows the possible control in which a glass of water is lowered and causes no change to the whole apple. Row 2 shows a possible transformation in which a knife is lowered and causes a transformation of the apple into two half apples. Row 3 shows an impossible transformation in which a glass is lowered and appears to cause a transformation of the apple into two half apples. Row 4 shows an impossible transformation in which two half apples appear to be transformed into a whole apple by a knife.

tools in the wild or in captivity (i.e., cotton-top tamarins and vervet monkeys) show quite exquisite sensitivity to the design features of tools when placed in a tool-selection task (20–22). Thus, tamarins and vervet monkeys show a competence for using tools that may emerge from the more general domain of object knowledge. If the implications of these studies carry over to rhesus monkeys, then we might expect them to succeed in the transformation experiments, relying on their more domain-general knowledge of objects.

Experiment 1: Procedure, Results, and Discussion

This first experiment provides a conceptual replication of Premack's apple study described above; Fig. 1 illustrates the experimental design. In the control test, an experimenter placed a whole apple on a white foam-core stage and then placed an occluder in front of it, blocking the stage. Then, the experimenter lowered and raised a clear glass behind the occluder, removed the occluder, and revealed an unchanged apple. In the possible test, the experimenter again placed a whole apple on the stage and placed the occluder in front of it. The experimenter then replaced the whole apple with two apple halves that had been hidden behind the stage, without allowing the subject to see these actions. The experimenter lowered and raised a knife

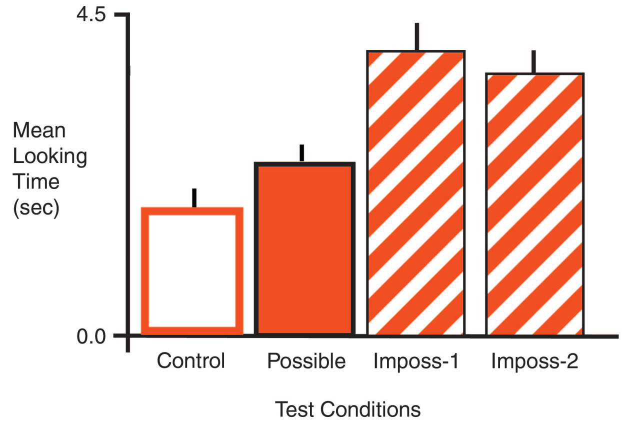

Fig. 2. Mean (+SD) looking time (in seconds) for each of the four conditions involving whole and half apples and either a knife or a glass as transforming agents. Two-tailed *P* value levels are indicated for each contrast based on *t* tests. Imposs-1, the impossible-1 test; Imposs-2, the impossible-2 test.

behind the occluder and removed the occluder to reveal the two apple halves. The impossible-1 test mimicked the possible test, except that we used the glass instead of the knife. The impossible-2 test was designed to rule out the possibility of familiarity or associations with the knife, paralleling Premack's reversal conditions. Specifically, although rhesus monkeys only rarely see humans using knives and many will have never seen them, whatever association they have may cause them to look for shorter periods than when a glass appears. The impossible-2 test, therefore, reversed the order of the possible test, showing two apple halves, occluder with knife lowered and raised, and then a whole apple.

Even though each condition entailed different events, the overall length of time was kept constant. The time required to lower and raise either the glass or the knife was also the same.

Fig. 2 illustrates the results from Experiment 1. An ANOVA revealed a highly significant condition effect ($F = 11.30$; df = 3, 69; $P < 0.0001$). Based on a Bonferroni post hoc test with P value set to 0.008, there were no statistically significant differences between the control and possible conditions or between the two impossible test conditions. However, both impossible test conditions were significantly different from the control ($0.0005 < P < 0.006$) and possible test ($P < 0.0001$) conditions.

Looking-time data provide a measure of expectation. Longer looks map to relatively greater expectancy violation. In the present context, the apparent capacity of a glass to cut an apple in half represents a more significant violation than when a knife does the same. As mentioned, some rhesus monkeys potentially have seen humans using knives to cut various objects on the island. They have also seen humans drinking from glasses; if anything, exposure to glasses is more common than to knives. Exposure or familiarity is therefore unlikely to explain these results. Nonetheless, it is possible that knives are inherently less interesting to look at than glasses. To control for this possibility, we flipped the temporal order of the possible test event. Again, we found that rhesus monkeys looked longer at this impossible sequence when compared with both the control and the possible test event. Together, these results suggest that rhesus monkeys form causal inferences based on a single, novel event, using their knowledge of objects and their material properties to generate expectations about possible transformations.

Experiment 2: Procedure, Results, and Discussion

To further explore the rhesus monkeys' capacity to make causal inferences about material transformations, we ran Experiment 2 using the same design but different subjects and transforming

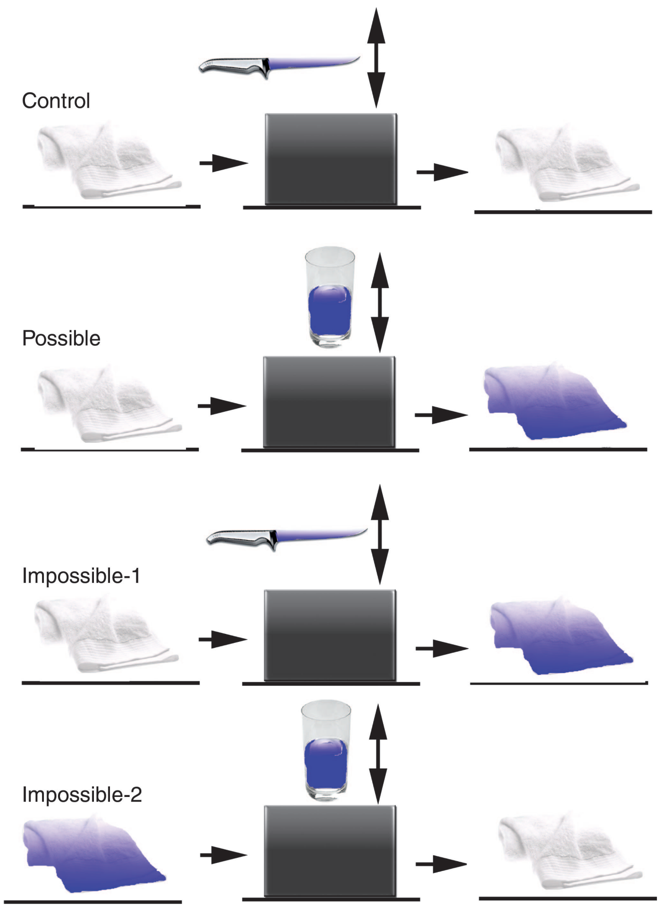

Fig. 3. Conditions for Experiment 2. Row 1 shows the possible control in which a blue knife is lowered and causes no change to the white towel. Row 2 shows a possible transformation in which a glass of blue paint is lowered and causes a transformation of the white towel into a blue towel. Row 3 shows an impossible transformation in which a blue knife is lowered and appears to cause a transformation of the white towel into blue towel. Row 4 shows an impossible transformation in which the blue towel appears to be transformed into a white towel by a glass of blue paint.

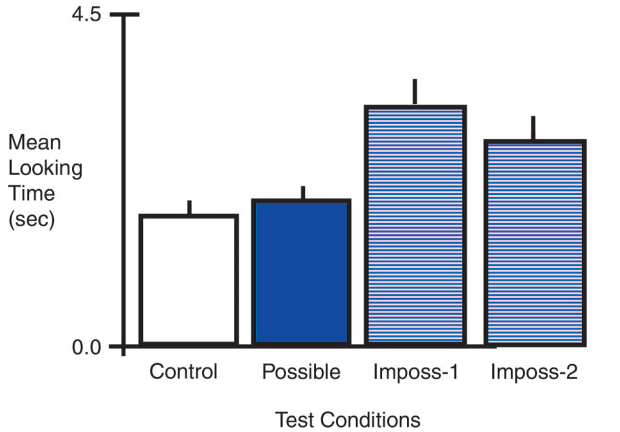

Fig. 4. Mean (+SD) looking time (in seconds) for each of the four conditions involving white and blue towels and either a blue knife or a glass with blue paint as transforming agents. Two-tailed *P* value levels are indicated for each contrast based on *t* tests. Imposs-1, the impossible-1 test; Imposs-2, the impossible-2 test.

agents. The object acted on in this experiment was a dry white towel, and the two causal agents were a clear glass containing blue paint and a knife that had been painted the same color blue; Fig. 3 illustrates the experimental design. Paralleling Experiment 1, rhesus monkeys have only limited experience with paint. Once a year, juvenile animals on the island are trapped and dyed to keep track of which monkey was captured for biomedical treatment and tattooing. Every animal on the island over the age of two years has therefore had this personal experience, and everyone on the island has witnessed this event at some level, either seeing the process or the outcome.

In the control test, an experimenter placed a white towel on the stage and then blocked the monkey's view of the stage with an occluder. The experimenter then lowered and raised a blue knife behind the occluder, removed the occluder, and revealed an unchanged white towel. In the possible test, the experimenter again placed the white towel on the stage, followed by the occluder. Behind the occluder, the experimenter then switched the white towel with a towel that had been painted with the same blue paint, lowered and raised the glass with blue paint, removed the occluder, and revealed the blue towel. In the impossible-1 test, the experimenter lowered and raised the blue knife, removed the occluder, and revealed a blue towel. In the impossible-2 test, designed to rule out familiarity and association, we presented a rhesus monkey with a blue towel, occluded it, raised and lowered the blue glass of paint, removed the occluder and revealed a white towel. The blue paint remained in the glass throughout each presentation.

Results (Fig. 4) mirror those presented in Experiment 1. An ANOVA revealed a statistically significant condition effect ($F = 6.72$; df = 3, 69; $P < 0.0005$). Based on a Bonferroni post hoc test with P set at 0.008, there were no statistically significant differences between the control and possible conditions or between the two impossible test conditions. However, both impossible test conditions were significantly different from the control ($0.001 < P < 0.003$) and possible test ($0.0001 < P < 0.009$) conditions.

In the present context, the apparent capacity of a blue knife to turn a white towel blue represents a more significant violation than when a glass of blue paint does the same. Rhesus monkeys have some experience, both personal and through observation, of paint transforming the color of an object. As with knives, however, this is a highly limited experience, occurring only once a year and sporadically distributed over the course of 2 months. The paint they see is not poured from a glass, but rather, taken from an opaque can with a brush. It is nonetheless possible that they used this experience to drive expectation. It is possible that the mere association between paint and a color change reduces attention, leading to a relatively shorter look than for the blue knife event. To control for this possibility, we flipped the temporal order of the possible test event. Again, we found that rhesus monkeys looked longer at this impossible sequence when compared to both the control and the possible test event. These results provide further evidence that rhesus monkeys generate causal inferences in the absence of frequent cooccurrences, extending the range of material transformations that they appear to understand from mechanical slicing to changes in color.

Experiment 3: Procedure, Results, and Discussion

One possible explanation for the results from Experiments 1 and 2 is that subjects attend to the relationship between the transforming agent and the outcome object, generating expectations about what typically goes together, while disregarding the details of the starting object. Thus, instead of attending to the whole apple or white towel that appear at the beginning of both the possible and impossible-1 tests, subjects restrict their attention to the knife and glass together with the objects that emerge next in the test events; for example, they expect knife and cut apple to go together but not glass and cut apple. This explanation is consistent with the results of a study by Das Gupta and Bryant (11) in which 3-year-old children, but not 4-year olds, pay attention to an object linked to a change in the starting-state object as opposed to the outcome object. Thus, for example, if they see a broken cup that ends up as a wet broken cup, they are more likely to pick a hammer than a glass of water. Although this argument (along with the developmental data that appear to support it) is difficult to sustain for blue paint and blue towels, because rhesus monkeys on Cayo have no experience with these objects, it is possible that some animals have some prior association with knives and cut fruit, perhaps even an occasional apple. To rule out this argument, we ran a third experiment. We presented subjects with an occluded stage and then lowered and raised either a knife (conditions 1 and 2) or a glass of water (conditions 3 and 4) as in Experiment 1 but with no preceding object. For condition 1 and 3, we then raised the occluder to reveal a whole apple; in conditions 2 and 4, we raised the occluder to reveal two half apples. If, based on prior experience, rhesus monkeys expect knives to go together with cut apples, then condition 2 should elicit shorter looks than condition 1. And if rhesus monkeys expect knives to go together with apples more often than do glasses, then they should look longer at conditions 3 and 4 than conditions 1 and 2.

Because the event structure in Experiment 3 (no initial object) differs from that in Experiment 1, it is not possible to statistically contrast the two sets of results. Nonetheless, the mean looking times for all four conditions of Experiment 3 (2.28 s) were more comparable to the control and possible (mean = 1.96) test events in Experiment 1 than to the two impossible tests (mean = 3.65). An overall ANOVA for Experiment 3 revealed no statistically significant condition effect ($F = 0.19$; df = 3, 67; $P = 0.91$). These results indicate that the looking-time patterns presented in Experiment 1 cannot be explained by a prior expectation of which agents and objects go together. Rather, rhesus monkeys must take into account the transforming effects of the agent on the starting object.

General Discussion

Taken together, results from these experiments show that free-ranging rhesus monkeys, using their knowledge of the physical world, spontaneously infer the causal agent of transformation in the absence of frequent exposure to cooccurrences of the relevant events and with virtually no prior experience with any of the objects or transforming objects. To respond to the central question of this article: humans are not alone in their capacity to draw causal inferences from limited experience. This capacity is part of the evolved psychology of rhesus monkeys and most likely other animals as well. Our results build on Premack's by showing that laboratory training, and especially experience with symbols, is not necessary for drawing causal inferences about possible physical transformations. We also eliminate any concern about prior experience by testing with objects and transforming agents that have never appeared on the island. Whether chimpanzees and rhesus monkeys differ in their capacity to draw causal inferences, and why, will require other tests, attempting to rule out the role of laboratory experience as well as differences in these species' natural predisposition to make and use tools and to operate on the physical world more generally.

Several additional questions remain. We briefly consider two here: (*i*) Is the capacity to draw causal inferences in rhesus monkeys, and presumably other animals as well, restricted to the physical domain, or is the capacity more domain-general, capable of being deployed for other functionally relevant problems, especially those related to their social world? And (*ii*) how extensive is a rhesus monkey's knowledge of physical transformations, and are species with more sophisticated tool technologies (e.g., New Caledonian crows and chimpanzees) capable of drawing a wider range of inferences concerning such transformations?

Although we have yet to explore other physical transformations, our sense is that we have tapped only a small corner of this capacity in rhesus monkeys, not to mention species with more extensive abilities to make and use tools, including New Caledonian crows and chimpanzees (23–26). We base this speculation on studies of tool use in animals. In many of these studies, individuals selectively reject tools that have been transformed into materials that no longer play a functional role in the task at hand. For example, in a recent study of common marmosets, individuals ignored tools that were transformed into materials that failed to bring food within reach, even though the shape, size and color of the tool was identical to one that had worked previously (27). Similarly, in studies of West African chimpanzees, Matsuzawa and Yamakoshi (25) have demonstrated that individuals selectively pick appropriately designed rocks and branches to provide a stable and hard surface on which to crack open nuts. Although these studies provide support for the idea that primates have access to information about the material world, other studies suggest that this capacity may be more limited. In cases of failures, however, all of these observations were obtained on the basis of carrying out a motor routine or action in contrast to judging the outcome of an event on the basis of time spent looking. Several studies now reveal that primates, including human infants, show a dissociation in certain contexts between the knowledge that drives looking as opposed to reaching or manipulating (28). It is therefore possible that the knowledge mediating rhesus monkeys' inferences about physical transformations is limited to their perceptual judgments.

Given the success of the looking-time method to uncover heretofore unexpected abilities in rhesus monkeys to draw causal inferences about the physical world, it is now possible to move into different domains of knowledge, asking about their understanding of animate as opposed to inanimate agents and what they can and cannot do. For example, prior work reveals that tamarins and rhesus monkeys generate different expectations about objects based on their capacity for self-propelled motion (ref. 29 and L. Santos, W. Phillips, and M.H., unpublished work), together with certain properties of animacy. Given these observations, we can ask whether they expect other agents (different species) to alter the shape of food through consumption but are surprised if a nonagent, inanimate object does the same.

In conclusion, these studies both reveal a striking continuity between humans and other animals in their capacity to draw causal inferences in the absence of frequent or familiar cooccurrences of the events, and highlight the richness of the primate mind in terms of its understanding of the material world. Our evolutionary legacy is more in line with Michotte and Premack than Hume.

Methods

Subjects. We tested free-ranging rhesus monkeys living on the island of Cayo Santiago, Puerto Rico. This colony has been living and breeding on Cayo Santiago for almost 70 years, and due in part to the lack of predation, the number of individuals in the population today is about 1,000. Their diet consists of monkey chow (supplied daily), as well as leaves, fruits, and insects. We tested both male and female subjects, all over 18 months of age and individually identified.

General Procedure. We used an expectancy violation procedure (30, 31) in which the amount of time spent looking at an event provides a measure of expectation; this method, successfully used in hundreds of studies of human infants and, more recently, several studies of nonhuman primates (17, 32–34), enables us to provide a more direct comparison with infant studies and to test for spontaneous, untrained responses. For each experiment, we expected longer looking times to impossible presentations in which one object, lacking the physical capacity to transform a second object, appeared to do so. Each experiment therefore consists of a possible test event, two impossible test events, and a possible control in which the object remained unchanged. Looking time was scored offline based on a 10-s period after the end of the test event. Each subject participated in only a single trial.

Video recordings were digitized and coded blind to condition and then recoded by a second observer who was naïve with respect to the current hypotheses and design; interobserver reliability for the total time spent looking per test was 94%. We aborted trials if subjects looked away or left at any point during the presentation or if another subject approached during the presentation or looking-time period. There was no difference across conditions with respect to the rate of aborted trials.

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