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Object individuation using property/kind information in rhesus macaques (*Macaca mulatta*)

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Abstract

Around 1 year of age, infants develop the ability to individuate objects in the absence of spatiotemporal information. Some have proposed that this capacity relies on the emergence of language and, in particular, that comprehending an object's label is required to individuate it as a particular kind. One approach to testing this hypothesis is to conduct experiments on pre-linguistic human infants. A second is to test non-linguistic animals. We followed the second approach, exploring whether semi-free-ranging rhesus macaques can individuate objects using property/kind information. To make the results most directly comparable, we adapted a reaching paradigm used to examine property/kind individuation in infants. Results from three experiments demonstrate that, like 12-month-old infants, adult rhesus macaques can use both spatiotemporal and property/kind information to individuate food objects. In a fourth experiment designed to examine which properties are used to individuate food objects, results revealed that rhesus use color, but not shape. These results, together with experiments involving different procedures, provide support for the conclusion that in the absence of linguistic abilities, some non-human primates spontaneously use property/kind information to individuate objects. © 2002 Published by Elsevier Science B.V.

Keywords: Object individuation; Property/kind information; Rhesus macaques

1. Introduction

When we look out into the world, we do not see amorphous blobs of color, free-floating shapes, or unbounded surfaces. Instead, we parse our visual world into a number of discrete objects and categorize these objects into different kinds of things. We do not

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see a pile of objects, for example, but instead perceive a *spoon* sitting in a *cup* on top of a *table*. The capacity to represent objects as members of distinct kinds can greatly ease the problems associated with segmenting the visual world (Carey, 1985; Keil, 1989; Mandler, 1992; Xu & Carey, 1996).

Recent experiments suggest that human infants may represent the objects in their environment somewhat differently than adults. In a now well-known series of experiments, Spelke, Kestenbaum, Simons, and Wein (1995) showed that infants can use spatiotemporal information to individuate the number of objects behind an occluder. They showed infants a display in which an object moved behind a series of two spatially-separated occluders. In one situation, the object moved in a continuous path behind the two occluders, appearing briefly between the two. In a second situation, the object appeared to move behind the first and second occluders without passing through the gap between them. When the occluders were removed, infants successfully predicted that there must be two objects in the second situation. The infants' behavior appears to suggest an understanding that one object cannot jump across space and time, but must retain a consistent path. More precisely, young infants are able to use spatiotemporal information to individuate the number of objects in a display.

To test whether infants can use other types of information (e.g. properties, kinds) to individuate objects, Xu and Carey (1996) familiarized 10- and 12-month-old infants to a display with two different toys. Unlike the Spelke et al. (1995) study, however, Xu and Carey used a single screen with no gap and alternately moved two different toys (e.g. ball and duck) back and forth behind this screen such that the two objects were never seen at the same time. In the test event, the screen was removed to reveal either both objects (the expected event) or only one object (the unexpected event). Twelve-month-old infants looked longer at the unexpected event, suggesting that they used either property (e.g. color, shape, etc.) or kind (e.g. *duck*ness) information to enumerate the number of objects behind the screen. Ten-month-old infants, however, were unable to do this; they looked equally long at the outcomes of one and two objects. From these findings, Xu and Carey argued that while 12-month-olds use spatiotemporal and property/kind information to individuate objects, 10-month-olds rely only on spatiotemporal information for individuation. This 10- to 12-month-old shift in the ability to use property/kind information has been replicated using other paradigms. Xu, Carey, and Welch (1999), for example, demonstrated that 12-month-olds, but not 10-month-olds, can use property/kind information to segment two different objects sitting on top of each other, a procedure that eliminates the role of memory as a potential explanatory variable in the earlier finding involving occlusion.

What developmental changes underlie the 10- to 12-month-old shift? Xu and her colleagues suggest that the critical feature might be a shift in the infants' ability to comprehend words (see Xu & Carey, 1996). In support of this, Xu (1999) noted that the younger infants who were able to pass her original task all knew the labels of the objects used as stimuli. That is, infants who knew the word for an object were more successful at individuating it using property/kind information. More importantly, 12-month-old infants were able to use kind information to individuate objects before they were able to use properties alone; they succeeded in individuating bottles and cups before they were able to individuate blue cups and red cups (Leslie, Xu, Tremoulet, & Scholl, 1998; Xu, Carey, & Quint, 1997). In addition, 10-month-olds succeeded on the Xu and Carey (1996) individuation task when the objects were labeled during presentation (Xu, 2000), implying that providing names for objects helps infants attend to the property/kind information needed to succeed in the task. Such evidence, Xu and colleagues argued, suggests that knowing a linguistic label allows an infant to bind the property information to the object's representation. As such, language is required to form representations of kinds in early infancy. This idea has been dubbed Xu's language hypothesis (see Munakata, Santos, Spelke, Hauser, & O'Reilly, 2000).

Two recent lines of empirical evidence have challenged Xu's language hypothesis. The first of these comes from studies of infants younger than 10 months of age who, though lacking word comprehension, are nonetheless able to individuate simple objects in a modified version of Xu's expectancy violation task (Leslie et al., 1998; Needham, 1998, 1999; Needham & Baillargeon, 1997, 1998; Wilcox, 1999; Wilcox & Baillargeon, 1998a,b; for a review see Needham & Baillargeon, 2000). For example, Needham and colleagues have shown that 6.5-month-olds can use property/kind information to individuate simple objects (i.e. yellow cylinders and blue boxes; Needham, 1998) and that babies as young as 4.5 months of age can use experiential knowledge (i.e. a 15 s prior exposure) to individuate objects (Needham & Baillargeon, 1998). Wilcox and her colleagues (Wilcox, 1999; Wilcox & Baillargeon, 1998a,b) have demonstrated similar capacities in infants younger than 10 months of age (although see Xu & Carey, 2000 for a critique of these studies). These results, so argue Needham and Baillargeon, suggest that language is not essential for property/kind individuation.

In response to these studies and the critiques of Needham and Baillargeon (2000), Xu and Carey (2000) have argued that the reason why younger infants are able to succeed on some individuation tasks using information other than a knowledge of kinds. For example, young infants might solve the Needham (1998) individuation task because the featural information (e.g. blue box and yellow cylinder) unambiguously distinguishes the objects' boundaries and thus, makes parsing the objects in this task relatively simple. For more complicated objects (e.g. duck and truck) like those used in Xu et al. (1999), babies cannot rely on simple, unambiguous featural information to determine where one object ends and another begins. Instead, they are forced to rely on richer kind representations in order to solve the task. Apparently, such kind representations do not come on-line until 12 months of age. In support of this hypothesis, Xu and Carey (2000) reviewed recent evidence from a more demanding task, a reaching time procedure developed by Van de Walle, Carey, and Prevor (2000). In this task, infants are presented with a small box with an opening in the front; infants are able to reach into the box and retrieve an object placed inside, but are unable to see inside the box when they reach. The experimenter alternately removes one of two different toys that have been placed inside the box, holds each in view for a few seconds, and then returns each toy to the box. The box is then pushed towards the infant who is allowed to reach inside and retrieve the toys. On some trials, both toys are left inside the box while on other trials one toy is surreptitiously removed. Van de Walle and colleagues reasoned that if infants were able to individuate the toys then they would notice that one of the toys was missing and continue searching for the missing toy. Accordingly, they found that 12-month-old infants reached more times into the box on the unexpected removal trials than on the trials in which both toys remained in the box. Ten-month-old infants, in contrast, did not show this effect. When the same experiment was run providing spatiotemporal information – taking both toys out at the same time – both 10- and 12-month-olds were able to deduce the number of toys inside the box. Consistent with the Xu and Carey (1996) expectancy violation experiments, 10-month-old infants were unable to individuate objects placed inside a box in the absence of spatiotemporal information. Uller, Leslie, and Carey (2000) replicated these experiments and found a similar 10- to 12-month-old shift in individuating objects, thereby providing further support for Xu's language hypothesis.

A second line of empirical evidence that challenges Xu's language hypothesis stems from work on non-linguistic animals. Xu's hypothesis makes a critical prediction about object individuation in non-human species: if language is in fact necessary for binding featural information to objects, then animals that lack human language should not be able to use property/kind information to individuate objects. To test this hypothesis, Hauser and colleagues have tested non-human primates using paradigms similar to those used to test individuation abilities in human infants. Uller, Xu, Carey, and Hauser (1997) tested adult rhesus macaques (*Macaca mulatta*) using a modified version of the Xu and Carey (1996) task with carrots and squash as stimuli (see also Uller, 1996). In these experiments, monkeys were presented with an event in which a carrot was removed from and then replaced behind a screen, followed by a piece of squash that was removed from and then replaced behind a screen. The screen was then lifted to reveal either a squash and a carrot (the expected event) or only one of these objects (the unexpected event). Like 12-month-old infants, monkeys looked longer at the unexpected event, suggesting that they used property/kind information to correctly predict that two objects were hidden behind the screen.

Rhesus macaques also use property/kind information to individuate objects in the absence of any spatiotemporal information. Munakata et al. (2000) presented adult rhesus macaques with a modified version of the Xu et al. (1999) paradigm. In this study, an experimenter presented a green pepper sitting on top of a potato and either lifted the green pepper alone or lifted the green pepper and the potato together. Rhesus macaques looked longer at the condition in which the green pepper and potato moved together as a bounded whole. This result suggests that rhesus macaques are able to use the properties of these two objects and/or information about the objects' kind to segment the two objects. In contrast with adults, however, Williams and Carey (2000) suggest that 4-month-old infant rhesus macaques do not show this ability, looking equally long when the top object moves alone as when the top object moves with the bottom object. Therefore, like human infants, rhesus macaques appear to begin life without the capacity to segment objects using property/kind information. However, after several months, they too develop the ability to use this information for individuation. Clearly, in the case of rhesus macaques, this developmental shift occurs in the absence of the emergence of linguistic representations for these objects.

The results reviewed thus far suggest that at least one non-linguistic species, the rhesus macaque, can individuate objects using property/kind information alone. One problem with this conclusion, however, is that it depends entirely on the use of one method: the expectancy violation paradigm. If rhesus macaques, like human adults, really use property/kind information to individuate objects, then one would expect to see rhesus macaques use this information when acting on objects. In addition, one would expect to see converging evidence from other methods that demonstrate the same capacities in this species.

We examined whether or not rhesus macaques, like 12-month-old infants, use property/kind information to individuate objects in an active search task, one that might simulate a natural foraging problem. Our experiments are modeled after the paradigm used by Tinklepaugh (1928) which examined whether or not captive rhesus macaques who watch a piece of food placed into a container can remember the identity of that food item. Specifically, an experimenter presented a subject with a highly-preferred food reward (e.g. a piece of banana) and then placed it out of sight under a cup. When the monkey was allowed to search, it found either the expected piece of banana or, due to an unexpected switch, a piece of lettuce, an undesirable kind of food. Tinklepaugh reported that the monkeys seemed surprised and angry when the food was "magically" transformed. This reaction suggests that the monkeys must have remembered information about the object's properties when placed behind the occluder. Watanabe (1996) presented similar results using neurophysiological recordings from the rhesus macaque prefrontal cortex.

In the experiments presented here, we build on the work of Tinklepaugh (1928) and present a novel technique, the searching time method, that adapts the infant reaching task (Uller et al., 2000; Van de Walle et al., 2000) for use with free-ranging and relatively naive rhesus macaques. In these experiments, subjects watch as pieces of food are placed into a small box filled with leaves. After the objects are placed inside the box, subjects are allowed to search the box. Subjects either find the foods they saw placed in the box or foods that are different (either in number or kind) from those placed in the box. We predict that if subjects detect the violation, then they will continue searching for the missing food objects and will thus search longer in the violation conditions than in the consistent conditions. The duration of searching after finding the initial food object therefore provides a measure of knowledge similar to that of expectancy violation paradigms (see Hauser & Carey, 1998). We leave open the possibility discussed by others (e.g. Bogartz, Shinskey, & Speaker, 1997; Haith, 1998; Santos & Hauser, 2002) that the knowledge revealed by these procedures is different.

Our goal in the first two experiments was to extend the findings of Uller et al. (1997) using a searching time measure to demonstrate that rhesus macaques can use property/kind information to individuate objects. In the third experiment, we examined whether, like human infants, rhesus macaques can use spatiotemporal information in the absence of property/kind differences to individuate objects in a reaching task. In a fourth and final experiment, we explored whether rhesus macaques consider some properties more important for individuation than others.

2. Experiment 1: property/kind individuation

2.1. Method

2.1.1. Subjects

We tested 35 adult rhesus macaques (*M. mulatta*) from the Cayo Santiago population (see Rawlins & Kessler, 1987). An additional 38 monkeys were tested but could not be used due to interference, disinterest, and/or experimental error. The Cayo Santiago population consists of around 1100 individuals living in approximately ten social groups. The Caribbean Primate Research Center and The University of Puerto Rico run and maintain the island. The island is provisioned with Purina monkey chow once a day at three feeding stations. The chow represents approximately 50% of the monkeys' diet which is further supplemented by leaves, berries, flowers, and mineral-rich soil found on the island. Water is provided ad libitum throughout the day at a number of natural and human-provided sources.

Subjects in this population are well habituated to human observers. Several experiments have already successfully tested monkeys in this population using the expectancy violation procedure (Hauser & Carey, 1998; Hauser, MacNeilage, & Ware, 1996; Munakata et al., 2000; Santos & Hauser, 2002; Santos, Miller, & Hauser, 2002; Uller et al., 1997; Uller, 1996) and food choice paradigm (Hauser, Carey, & Hauser, 2000; Santos, Hauser, & Spelke, 2001; Sulkowski & Hauser, 2001). Subjects in the experiments reported here were chosen opportunistically by locating individuals who were alone. Subjects were divided into three conditions: *consistent-1* (12 subjects), *consistent-2* (9 subjects), and *violation* (14 subjects).

2.1.2. Apparati and stimuli

The apparatus used was an experimental box (an open-topped opaque flexible plastic cooler approximately 15 cm wide by 25 cm long by 15 cm high). The box was always filled with a standard amount of leaves (approximately 30) which were obtained from a bush native to the island. These leaves were sufficient to completely cover any objects placed in the box. We used two types of food as stimuli: whole purple plums and equal-sized (in cross-section) pieces of coconut meat. We also used two white square (30 by 30 cm) foam-core platforms. All sessions were filmed with a portable JVC digital video camera.

2.1.3. Procedure

Two researchers conducted the experiment; one served as the presenter, and the other as the cameraperson. After locating a subject, the presenter positioned himself directly in front of the subject at a distance of 2–5 m. The cameraperson then chose a location that provided a clear recording of the subject's approach to the presenter's location, no closer than 3 m. Next, the presenter began an experimental session by informing the cameraperson that they were beginning the experimental presentation. The cameraperson never observed the experimental presentation, but rather kept the camera focused on the subject. In this way, the cameraperson had no knowledge of the particular experimental condition and thus could serve as a "blind" judge of the experimental session. The presenter checked to be sure that the subject watched the entire presentation, and aborted the session if the subject looked away for more than 1 s.

Fig. 1 illustrates the three conditions of Experiment 1. Each subject received only one trial. All conditions began with a box with unknown contents and resulted in one piece of food in the box; the conditions differed only in their presentations. The *violation condition* of Experiment 1 began when the experimenter placed the box on the ground without letting the subject see its contents, and then placed the two foam-core platforms down

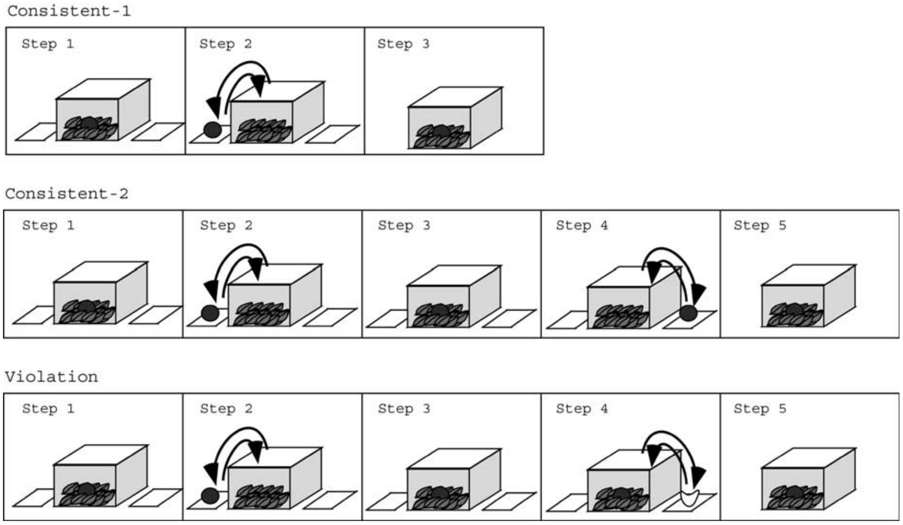


Fig. 1. Illustration of conditions used in Experiment 1.

on either side of the box. The box contained leaves, one plum and one coconut piece. The experimenter then reached into the box, retrieved one of the food objects, and placed it on the right-hand platform (from the presenter's point of view). After leaving it there for 2 s, the experimenter picked up this food object and placed it back in the box. Next, with his hand still in the box, the experimenter repeated this sequence by retrieving the other food object from the box, placing it on the left-hand platform, and placing it back into the box after 2 s. Then, while withdrawing his hand from the box, the experimenter surreptitiously removed one of the food objects. He then proceeded to pick up the platforms and walk away. Both the order of food object presentation and the choice of food object for surreptitious removal were counterbalanced across subjects.

The *consistent-1 condition* began when the experimenter placed the box on the ground and then placed the two platforms on either side of the box. The box contained leaves and one food object, either a plum or a piece of coconut. The experimenter then reached into the box, retrieved the food object, and placed it on the right-hand platform. After leaving it there for 2 s, the experimenter picked up the food object and placed it back inside the box. He then withdrew his hand with a closed fist, picked up the platforms, and walked away. The choice of food object was counterbalanced across subjects.

The *consistent-2 condition* began when the experimenter placed the box on the ground, and placed two platforms on either side of the box. In the consistent-2 condition, the box contained leaves and one food object, either a plum or a piece of coconut. The experimenter reached into the box, retrieved the food object, and placed it on the right-hand platform. After leaving it there for 2 s, the experimenter picked up the food object and placed it back in the box. Next, with his hand still in the box, the experimenter repeated this sequence by retrieving the same food object from the box, placing it on the left-hand platform, and replacing it into the box after 2 s. The experimenter then withdrew his hand with a closed fist, picked up the platforms, and walked away. The choice of food object was counterbalanced across subjects. Note that the two consistent conditions were different only in the number of times that each food object was presented.

Having completed the presentation, the presenter informed the cameraperson that the presentation was complete. The cameraperson filmed the approach of the subject to the box, its discovery of whatever food item was in the box, and continued filming until he decided that the subject was done searching. The cameraperson considered that the subject was "done searching" if: (1) the subject walked more than 10 m away from the box, or (2) the subject was still within 10 m of the box, but at least 3 min had passed since the discovery of the food item and the subject was no longer looking or reaching in the box; we used looking and reaching because often, subjects stopped reaching but visually searched the leaves that they had removed from the box (see below). Since the cameraperson was blind to the experimental condition, he decided when the subject was finished searching. In addition, because the camera had an internal digital clock, he was able to judge the end of a 3 min period while filming the trial.

2.1.4. Video analysis

Video records of each trial were acquired onto a Power Macintosh G3 and were then analyzed with Adobe Premiere 4.2 software. These digitized sequences were scored by two coders blind to the experimental condition. Coding was recorded in frames (30 frames = 1 s). Coding began at the frame where the subject first withdrew the food item from the experimental box and continued until the cameraperson ended the trial. The criteria for searching was: (1) the subject was within 1 m of the box and was looking in the box, or (2) the subject was looking and touching the box or the leaves contained in the box. Thus, monkeys who were merely touching the box or sitting in proximity but not looking in the box were not coded as searching. In addition, monkeys who took the food and immediately walked away would be scored as searching for zero frames. In order to verify the reliability of these coding techniques, four experimenters independently coded ten of the same sessions. The inter-rater reliability of searching time was extremely high, with all four coding samples correlating to the level of at least $r = 0.98$.

2.2. Results

We examined searching times across condition using a factorial ANOVA. The ANOVA revealed a main effect of condition ($F(2, 32) = 4.51$, $P = 0.02$, see Fig. 2). Subjects in the violation condition searched longer ($M = 16.4$ s) than subjects in either the consistent-1 ($M = 8.1$ s) or consistent-2 ($M = 6.1$ s) conditions. To further explore this interaction, we performed contrasts across the three different conditions. Subjects in the violation condition searched significantly longer than those in the consistent-1 condition ($P = 0.03$) and the consistent-2 condition ($P = 0.01$). The duration of searching did not differ between the two consistent conditions ($P = 0.61$). We also found similar results using non-parametric Mann–Whitney U-tests; subjects searched longer in the violation condition than in both the consistent-1 ($Z = 2.78$, $P = 0.006$) and consistent-2 conditions ($Z = 2.58$, $P = 0.01$). There was a non-significant trend of greater searching in the consistent-1 condition than in the consistent-2 condition ($Z = 1.88$, $P = 0.06$).

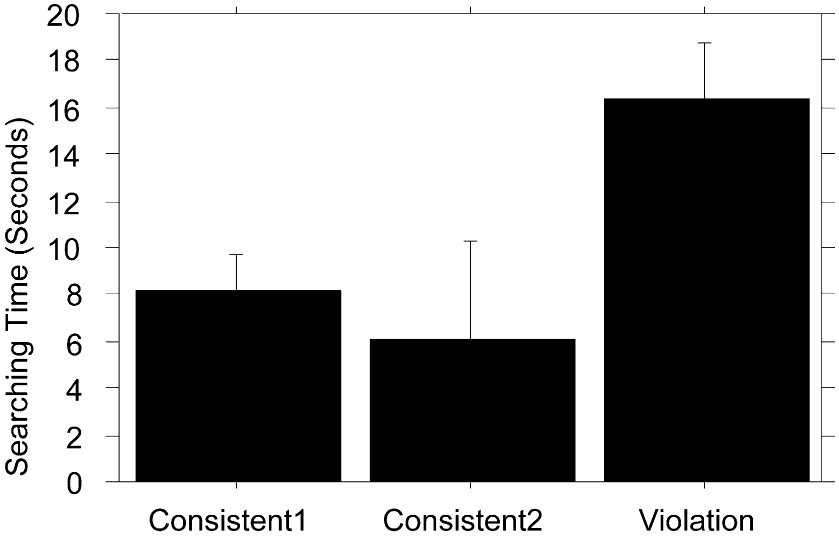


Fig. 2. Mean (±standard error) number of seconds subjects spent searching across consistent-1, consistent-2, and violation conditions in Experiment 1.

2.3. Discussion

Subjects in the violation condition searched the box longer than subjects in either of the two consistent conditions. This finding suggests that subjects in the violation condition used property/kind information to individuate the number of food objects in the box and kept searching in order to find the missing object. These results suggest that, like 12-month-old infants, adult rhesus macaques are able to use property/kind information to individuate objects placed into a box. These results concur with the previously reported data from this population using an expectancy violation paradigm (Munakata et al., 2000; Uller et al., 1997). Like the expectancy violation paradigm results, they provide further support for the hypothesis that property/kind representations are possible in a species lacking linguistic labels for the objects they perceive, and show that this capacity can be robustly demonstrated with both looking and reaching measures.

One problem with this study, however, is that the violation condition presents subjects with more property/kind information than either of the consistent conditions. In the violation condition, subjects are presented with two kinds of objects (e.g. a plum and a coconut); in the consistent conditions, in contrast, subjects only see one kind of object (e.g. a plum). It is possible that seeing more properties in the presentation period compels subjects to search longer in this condition. Similarly, seeing two pieces of food may make subjects more aroused than seeing only one piece, which could also account for subjects' longer searching in the violation condition. If this is the case, then subjects are not actually individuating the number of objects in the box, but instead are merely searching more when they witness more properties or are more aroused during the presentation.

In the next experiment, we attempted to resolve this problem by using a variant of the design used in Experiment 1. Specifically, we allowed subjects to watch as we hid one food item (e.g. a piece of coconut) in a box filled with leaves. Subjects then searched the box to find either the same kind of food originally hidden (i.e. a piece of coconut) or a different kind of food (e.g. a grape). We predicted that subjects would search longer when they found an unexpected kind of food in the box, reasoning that the original piece of food they saw placed inside the box should still be somewhere inside. This new paradigm holds the number of food items constant across consistent and violation conditions.

3. Experiment 2: property/kind II

3.1. Method

3.1.1. Subjects

We tested 33 adult rhesus macaques from the Cayo Santiago population. None of the subjects had previously participated in Experiment 1. An additional 44 rhesus macaques were tested, but their data could not be used due to disinterest, interference, and/or experimental error. Subjects were divided into two groups: the *consistent* group ($n = 18$) and the *violation* group ($n = 15$). Subjects in Experiment 2 were tested approximately 6 months after the completion of Experiment 1.

3.1.2. Apparati and stimuli

We used the same plastic experimental box as in Experiment 1 and filled it with the same kind of leaves. The food stimuli used were a green grape and a chunk of coconut meat equal in size to the grape.

3.1.3. Procedure

The presentation procedure was similar to the previous experiment except for the following details (see Fig. 3). In this experiment, we preloaded the box with the target food object (grape or coconut). The *violation condition* of Experiment 2 began when the experimenter showed the subject that the box was full of leaves, taking care not to let the subject see the food object hidden inside. The experimenter then placed the box on the ground, removed a piece of food from his waist pouch, showed the piece of food to the subject by waving it back and forth, and placed it in the box. This piece of food was different from the one already preloaded in the box. As the experimenter removed his hand from the box, he surreptitiously removed the piece of food just placed inside with a closed fist and walked away thereby allowing the subject to search the box. When the subject approached the box, he found a food object that was different from the one he had seen placed inside the box.

In the *consistent condition*, in contrast, the box was preloaded with the same kind of food that the experimenter pretended to add. In this condition, the experimenter showed the subject that the box was full of leaves, taking care not to let him see the hidden food object already inside. He then placed the box on the ground, removed a piece of food from his waist pouch (e.g. grape), showed it to the subject by waving it back and forth, and placed it inside the box. As the experimenter removed his hand from the box, he surrepti-

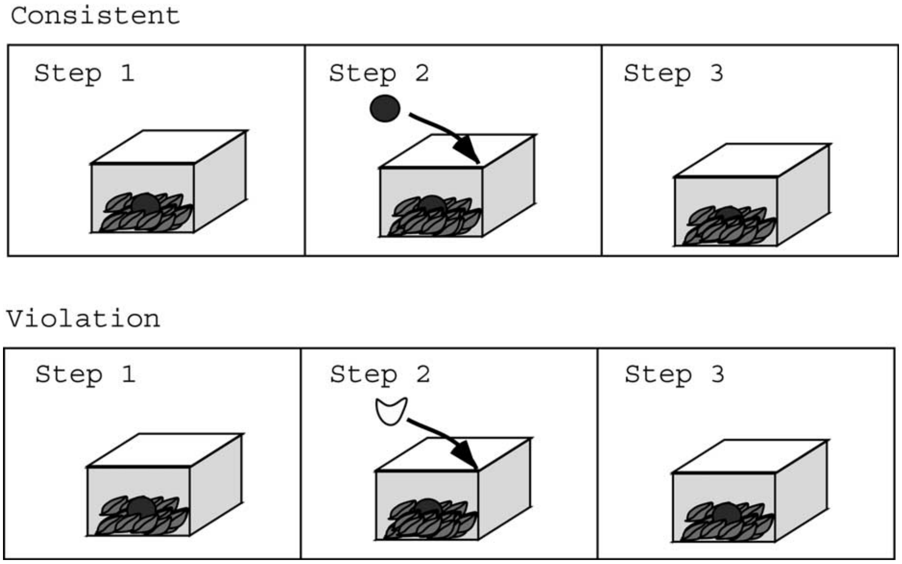


Fig. 3. Illustration of conditions used in Experiment 2.

tiously removed the added food object with a closed fist and walked away thereby allowing the subject to search the box. When the subject approached the box, he found a food object that was the same as the one placed inside the box. The condition (violation or consistent) and object found (grape or coconut) were counterbalanced across subjects.

Having completed the presentation, the presenter informed the cameraperson that the presentation was complete. The cameraperson filmed the approach of the subject to the box and its discovery of whatever food item was in the box. In this experiment, however, the cameraperson filmed for 3 min. If the subject walked out of view or another individual approached the box during that period, the trial was aborted and dropped from the experiment.

3.1.4. Video analysis

Video records from Experiment 2 were coded in the same manner as those of Experiment 1.

3.2. Results

Out of 77 subjects tested, 33 individuals completed the experiment. The number of individuals dropped from the experiment ($n = 44$) was similar to that of Experiment 1 ($n = 38$) despite the fact that subjects in Experiment 2 were filmed for a full 3 min. Results from an unpaired t-test on searching time revealed a significant difference between consistent and violation conditions ($t(31) = 2.94$, $P = 0.006$). Subjects in the violation condition searched significantly longer ($M = 41.07$ s) than subjects in the consistent condition ($M = 22.30$ s, see Fig. 4). This difference was confirmed by non-parametric tests as well (Mann–Whitney: $Z = 2.57$, $P = 0.01$).

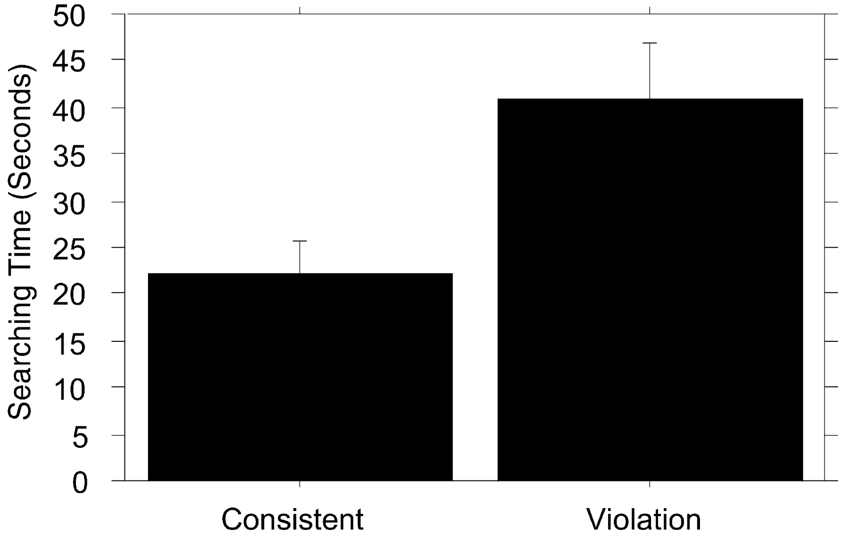


Fig. 4. Mean (±standard error) number of seconds subjects spent searching across consistent and violation conditions in Experiment 2.

We then put the data from Experiments 1 and 2 together in a factorial ANOVA with experiment (1 or 2) and condition (violation or consistent) as factors. There was a main effect of experiment ($F(1,64) = 32.30$, $P < 0.0001$). Overall, subjects in Experiment 2 searched longer (30.83 s) than those in Experiment 1 (10.84 s); this difference presumably had to do with the fact that all subjects in Experiment 2 were followed for an entire 3 min. In addition, there was a significant main effect of condition ($F(1,64) = 16.02$, $P = 0.0002$). Across both experiments, subjects searched longer in the violation conditions than in the consistent conditions. There was no interaction between experiment and condition ($F(1,64) = 1.89$, $P = 0.17$). This suggests that the magnitude of the effect between conditions did not differ across the two experiments.

3.3. Discussion

In Experiment 2, subjects in the violation condition searched almost twice as long as those in the consistent condition. We maintain that subjects searched longer in the violation condition because they expected to find a different kind of object than the one inside the box and continued searching for the missing object. These results demonstrate that rhesus macaques can remember the properties of occluded objects and use this information to individuate them. Specifically, they can store and use this information to generate expectations about the properties of a hidden food object. In addition, because this experiment successfully controlled for some of the problems inherent in Experiment 1, it provides even stronger evidence that adult rhesus macaques have the capacity to individuate objects using property/kind information. The results of Experiment 2 also provide further, more quantitative support for the observations by Tinklepaugh (1928) that captive rhesus macaques attend to changes in a hidden food's properties. Lastly, our results provide additional evidence that a non-linguistic species is capable of property/kind individuation.

In the third experiment, we examined whether rhesus macaques could use other kinds of information to individuate objects, as appears to be the case for human infants. Specifically, we examined whether or not rhesus macaques could use spatiotemporal information to individuate objects in the absence of property/kind information. Such an ability is essential if one is to argue that mechanisms of object individuation are similar across linguistic and non-linguistic species.

To examine the rhesus macaques' capacity to use spatiotemporal information to individuate objects, we used a modified version of the procedure used in Experiment 2. In this task, monkeys watched as either one object or two objects were placed into a box. When monkeys searched the box, however, only one object was present. If monkeys can use spatiotemporal information to individuate objects, then they should search longer in the condition in which two objects were placed into the box than when only one object was placed into the box. Also, because there was high variability across different subjects' searching times within each condition, we decided to switch to a within subject design in Experiment 3.

4. Experiment 3: spatiotemporal individuation

4.1. Method

4.1.1. Subjects

Subjects were 13 adult rhesus macaques from the Cayo Santiago population. None of the subjects had been tested in Experiments 1 or 2. An additional 14 rhesus macaques were tested, but their data could not be used due to disinterest, interference, and/or experimental error. Each subject was run on two conditions: a *consistent* and a *violation* condition.

4.1.2. Apparati and stimuli

We used the same plastic experimental box as in previous experiments. The food stimuli used were triangle-shaped apple chunks (approximately 4 cm). Each piece was 1/8 of a whole apple.

4.1.3. Procedure

The presentation procedure was similar to that of Experiment 2 except for the following details (see Fig. 5). In this experiment, the box filled with leaves was already preloaded with an apple chunk. In the *violation condition*, the experimenter showed the subject that the box was full of leaves, taking care not to let him see the hidden apple chunk already inside. He then placed the box on the ground and removed an apple chunk from his waist pouch. The experimenter showed the apple to the subject by waving it back and forth and then placed it in the box. As the experimenter removed his hand from the box with a closed fist, he surreptitiously removed the piece of apple he had just placed inside. The experimenter then reached into his pouch, removed a second apple chunk and showed it to the subject. After placing this second apple chunk in the box, he surreptitiously removed it as

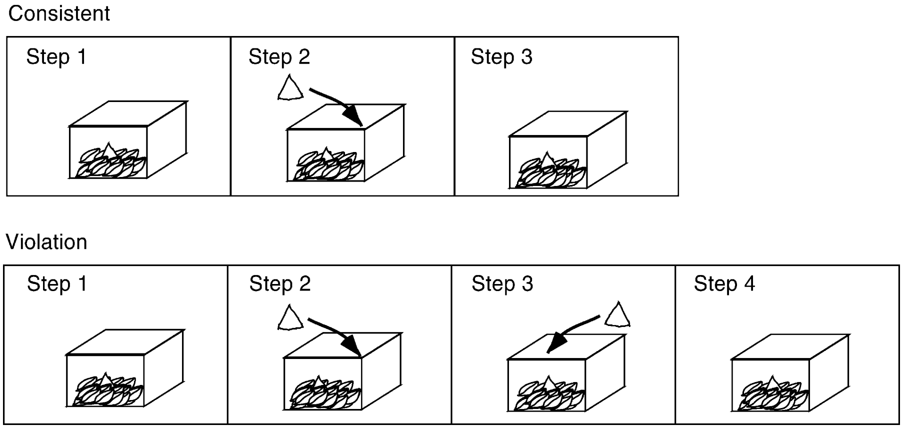


Fig. 5. Illustration of conditions used in Experiment 3.

well using a closed fist. He then walked away allowing the subject to search the box. When the subject approached the box, he found only one apple chunk (the one that was originally preloaded) even though he had seen two apples added to the box.

In the *consistent condition*, in contrast, the experimenter pretended to add only one apple chunk. In this condition, the experimenter showed the subject that the box was full of leaves, taking care not to let him see the hidden apple chunk already in the box. He then placed the box on the ground, removed an apple chunk from his waist pouch, showed it to the subject by waving it back and forth and placed it in the box. As the experimenter removed his hand from the box, he surreptitiously removed the added apple chunk with a closed fist. He then walked away allowing the subject to search the box. As such, when the subject approached the box, he found only one apple chunk similar to the one he had seen placed in the box.

Having completed the presentation, the presenter informed the cameraperson that the presentation was complete. The cameraperson, who was blind to the test condition, filmed the subject until he decided that the subject was done searching. As in Experiment 1, the cameraperson considered that the subject was "done searching" if: (1) the subject walked more than 10 m away from the box, or (2) the subject was still within 10 m of the box, but at least 3 min had passed since the discovery of the food item. Consecutive trials with the same subject were repeated immediately, as soon as the subject had fully consumed the food from the first trial. The inter-trial interval was between 30 and 60 s. The order of the conditions was counterbalanced across subjects. We included in the analysis only subjects completing both conditions successfully.

4.1.4. Video analysis

Video records from Experiment 3 were coded in the same manner as those of previous experiments.

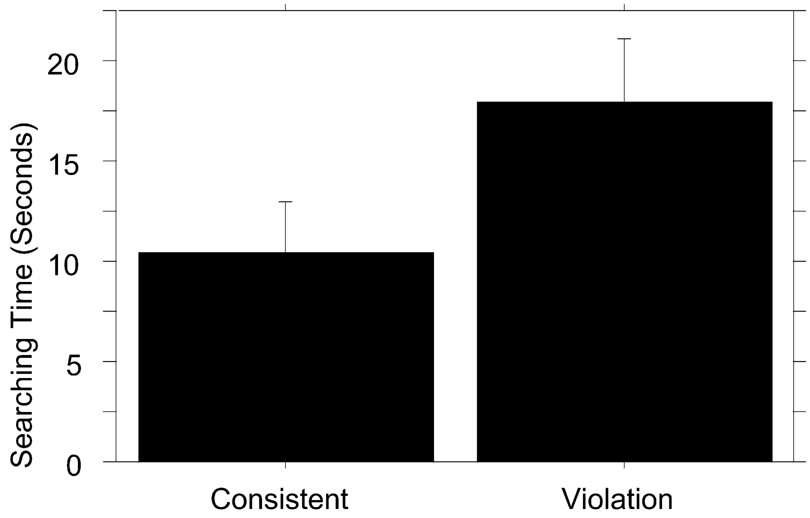


Fig. 6. Mean (±standard error) number of seconds subjects spent searching across consistent and violation conditions in Experiment 3.

4.2. Results

Subjects searched longer in the violation condition ($M = 17.99$ s) than in the consistent condition ($M = 10.54$ s; paired t-test: $t = 4.257$, $P = 0.001$, see Fig. 6). Paired sign tests revealed that 12 out of 13 subjects searched longer in the violation condition than in the consistent condition ($P = 0.003$). There was no effect of condition order (paired t-test: $t = 0.66$, $P = 0.52$).

4.3. Discussion

When rhesus macaques expect to find two objects in the box but find only one, they search longer than when they expect to find only one object and find one. This result suggests that rhesus macaques are able to enumerate two objects across time and space and use this information when searching for food objects. Like 12-month-old infants, they are able to use both spatiotemporal and property/kind information to individuate objects.

In addition to providing a test of spatiotemporal individuation, Experiment 3 provides evidence that rhesus macaques can distinguish between one object and two objects. As such, it adds to the growing body of evidence that rhesus macaques can enumerate small numbers of objects without training (Hauser et al., 1996, 2000; Sulkowski & Hauser, 2001). It also demonstrates that the searching time paradigm can be adapted to questions of number and may provide an elegant comparative method for investigating numerical representations across human infants and non-human primates.

Having demonstrated that rhesus macaques can use spatiotemporal information in the absence of property/kind information, we turn to yet another question about object individuation in the absence of linguistic abilities. Namely, in the absence of spatiotemporal information, what specific types of property and/or kind information are non-linguistic species able to use to individuate objects? The first two experiments demonstrate that macaques are able to use some combination of property and kind information to enumerate objects, but do not specify the features involved. Are rhesus macaques paying attention to specific features of the different objects (e.g. color, shape) and using these to individuate them? Or are they actually representing object kind information (e.g. *grape*ness) and using this to enumerate objects?

To begin to answer these questions, we examined whether or not rhesus macaques could use single property differences to individuate objects. To this end, we used a violation condition in which the food item found inside the box differed from the original item placed in the box on one critical featural dimension: it had either changed in shape or in color. We predicted that if rhesus macaques use these individual feature dimensions to individuate objects, then they should search longer on those individual featural change trials than on the corresponding control trials.

5. Experiment 4: changing the properties of shape and color

5.1. Method

5.1.1. Subjects

We tested 42 adult rhesus macaques from the Cayo Santiago population. Two subjects had been tested in a previous experiment. An additional 87 rhesus macaques were tested, but their data could not be used due to disinterest, interference, experimental error, and/or videocamera problems. Subjects were divided into two groups: the shape change group ($n = 21$) and the color change group ($n = 21$). Each subject was run on two conditions: a *consistent* and a *violation* condition.

5.1.2. Apparati and stimuli

We used the same plastic experimental box as in previous experiments. The food stimuli for the color change condition were normal white triangle-shaped apple chunks and dark blue triangle-shaped apple chunks (dyed with blue food coloring). The food stimuli for the shape change condition were triangle-shaped apple chunks and apple discs (10 cm in diameter). The two shapes were equal in volume (i.e. 1/8 of a whole apple).

5.1.3. Procedure

The presentation procedure for the color change condition was similar to that of Experiment 2 except for the following details (see Fig. 7). In this experiment, the box filled with leaves was already preloaded with one of the food items (e.g. white apple chunk). In the *violation condition*, the experimenter showed the subject that the box was full of leaves, taking care not to let him see the hidden apple chunk already inside. The experimenter then placed the box on the ground, removed a different colored food item (e.g. a blue apple chunk) from his waist pouch, presented this food item by waving it back and forth, and then placed it in the box. As the experimenter removed his hand from the box, he surreptitiously removed the food item he had just placed in the box using a closed fist and then

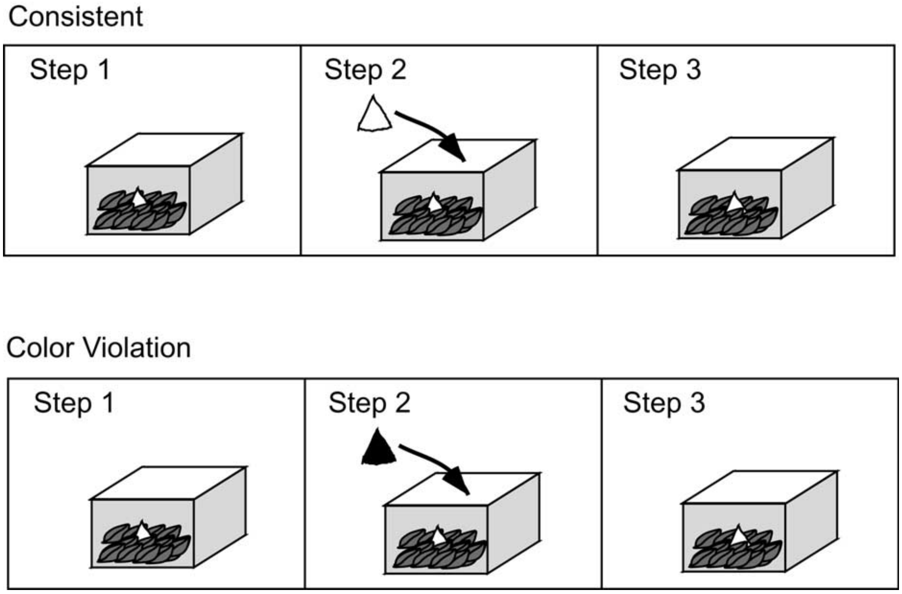
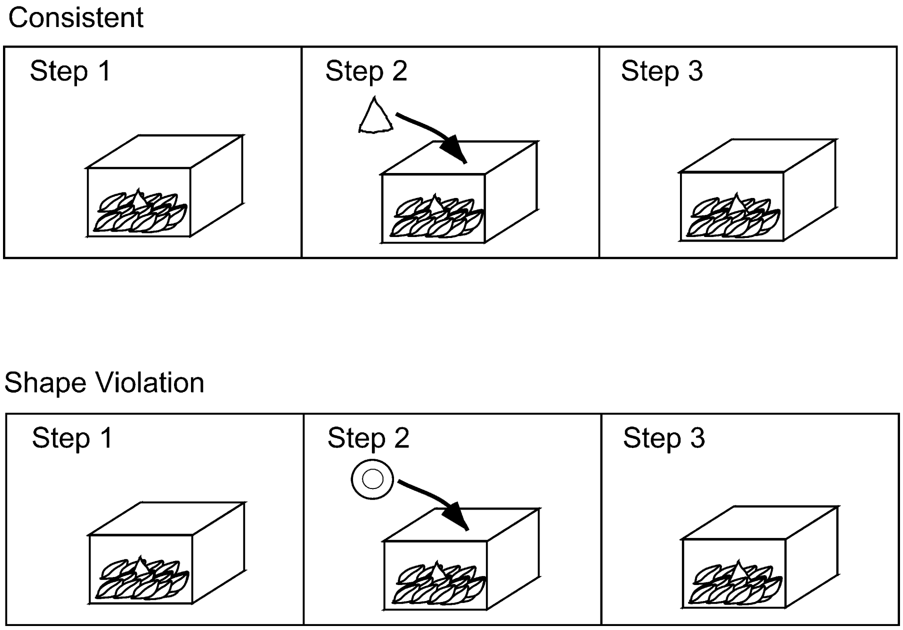


Fig. 7. Illustration of conditions used in the color change condition of Experiment 4.

walked away, thereby allowing the subject to search the box. When the subject approached the box, he found an apple chunk that differed in color from the one the experimenter had added to the box. In the *consistent condition*, in contrast, the experimenter pretended to add an apple chunk of the same color as the one hidden in the box. As such, when the subject approached the box, he found an apple chunk inside that was identical to the one he had seen placed.

Having completed the presentation, the presenter informed the cameraperson that the presentation was complete. As in Experiments 1 and 3, the cameraperson, who was blind to the test condition, continued filming the subject until he decided that the subject had finished searching. As in previous experiments, consecutive trials with the same subject were repeated immediately, as soon as the subject had fully consumed the food from the first session. The inter-trial interval was between 30 and 60 s. The color of the object hidden and the order of conditions were counterbalanced across subjects. We included in the final analysis only subjects completing both conditions successfully.

The presentation procedure for the shape change condition was identical to that of the color change condition (see Fig. 8) except that in the *violation condition*, the experimenter added a food item that differed in shape (e.g. apple disc) from the one that was originally preloaded into the box (e.g. a triangle-shaped apple chunk). Therefore, when the subject approached the box, he found an apple chunk that differed in shape from the one added to the box. As in the color change condition, the shape of the object hidden first and the order of conditions were counterbalanced across subjects and the final analysis included only subjects successfully completing both conditions.


Consistent

Shape Violation

Fig. 8. Illustration of conditions used in the shape change condition of Experiment 4.

5.2. Results

We performed a repeated measures ANOVA with feature (shape or color) as a between subjects factor and condition (consistent or violation) as a within subjects factor (see Fig. 9). There was no main effect of feature ($F(1,40) = 0.146$, $P = 0.70$). Subjects in the color and shape conditions did not differ in overall searching times. We did, however, observe a main effect of condition ($F(1,40) = 6.78$, $P = 0.01$). Subjects across all conditions searched longer during the violation condition ($M = 14.06$ s) than the consistent condition ($M = 10.06$ s). There was no effect of order ($F(1,40) = 2.22$, $P = 0.14$). There was also no interaction between feature and condition ($F(1,40) = 0.037$, $P = 0.85$); subjects in both conditions showed the same pattern of searching longer during the violation condition than in the consistent condition.

We performed paired t-tests to investigate the main effect of condition across specific features. Subjects in the color change test condition searched significantly longer in the violation condition than in the consistent condition ($t(20) = 2.27$, $P = 0.03$). This finding was confirmed with non-parametric tests as well (Wilcoxon Signed Rank: $Z = 2.10$, $P = 0.04$); more individuals looked longer at the violation color change test condition than the consistent condition. In the shape change condition, in contrast, although subjects searched longer in the violation condition than the consistent condition, this result failed to reach statistical significance with either parametric ($t(20) = 1.65$, $P = 0.11$) or non-parametric tests ($Z = 1.54$, $P = 0.12$).

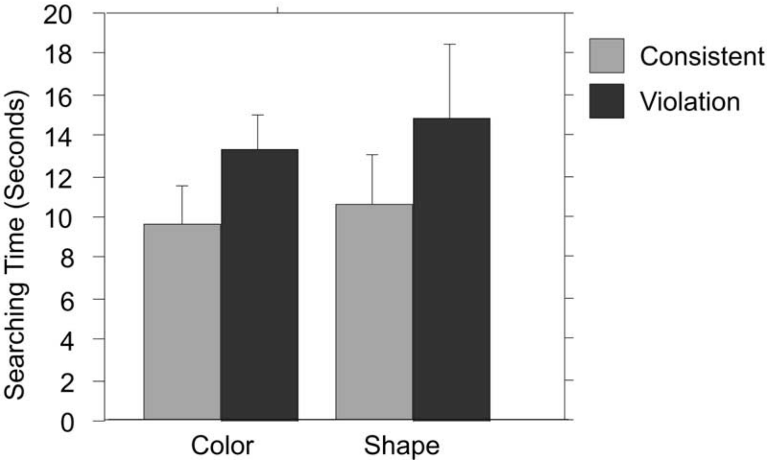


Fig. 9. Mean (±standard error) number of seconds subjects spent searching across consistent and violation conditions in color and shape change conditions in Experiment 4.

5.3. Discussion

The results of Experiment 4 suggest that rhesus macaques can use the property of color to identify a food object placed in a box. It remains unclear whether or not rhesus macaques can use the property of shape to do the same thing. Although rhesus macaques searched longer after shape violations, this result failed to reach the level of statistical significance. We see three possible explanations for these results. First, rhesus macaques may be able to use property information to individuate objects, but some properties might be more important to the process of individuation than others. Among cotton-top tamarins, for example, shape represents a critical feature in choosing among objects as tools, while color is irrelevant (Hauser, 1997; Hauser, Kralik, & Botto-Mahan, 1999). For rhesus macaques, the property of color may support individuation more readily than the property of shape, especially in the context of food (Santos et al., 2002; see below). Although this explanation explains the findings presented here, it is inconsistent with data on object individuation in human infants. Using an expectancy violation paradigm, several researchers have found that infants use shape to individuate objects before they use color (Leslie et al., 1998; Wilcox, 1999). These results suggest that, for infants at least, the property of shape is able to support individuation more easily than the property of color. One important difference between the present experiments on rhesus macaques and those conducted on human infants is that the former used food as stimuli whereas the latter involved artifacts. This difference leads to our next point.

The second possible explanation for our results is that rhesus macaques may have focused on the color of the apples placed into the box because of their past experience with the types of changes that food can undergo. Rhesus monkeys may find a change in an apple's color far more salient than a change in its shape simply because changes to a food's color in the natural world may be more unusual and/or more infrequent than changes to a food's shape.

Monkeys may simply be more likely to see changes in a food's shape than changes in its color and therefore may pay less attention to these changes. As such, a shift from a white apple piece to a blue apple piece may be more perceptually salient than a shift from a disc-shaped apple piece to a triangle-shaped apple piece. This alternative, however, rests on at least two assumptions: (1) rhesus see foods change in shape more often than they see foods change in color, and (2) a change from white to blue is more salient than a change from disc-shaped to triangular; we consider both assumptions somewhat tenuous. Just as rhesus in this population naturally experience changes in a food's shape (by eating it or breaking it), they just as naturally experience changes in a food's color (leaves and berries change color as they mature, fruits such as coconut have different colors on the inside and outside, etc.). More specifically, this assumption cannot be true for the specific stimuli we used in these experiments: apples. Apples are completely novel foods for rhesus of this population and thus they should have no specific experience with changes in an apple's shape or color. As such, neither feature should have an a priori salience to them based solely on their past experiences with apples. Furthermore, although blue colored foods are certainly novel with respect to other foods on the island, so are triangular-shaped food items.

The third and, we argue, most compelling explanation for our results is that rhesus macaques focus on kind information when individuating objects; we base our conclusion on the same kind of logic put forth by Xu and colleagues, using three different experimental procedures (Munakata et al., 2000; Uller et al., 1997; the current experiments), each providing converging evidence. If this explanation is correct, then when rhesus watch an apple disc placed into a box, they most likely represent the apple not as "a white 4 cm disc", but as "an *apple* piece". That is, rhesus macaques represent food objects not as collections of features, but as kinds (see Xu & Carey, 1996). If macaques represent these objects as members of different kinds, then some properties should be more important for categorization than others (see Keil, Smith, Simons, & Levin, 1998; Santos & Caramazza, in press; Santos, Hauser, & Spelke, in press). The properties that are salient for representing food kinds (e.g. substance properties like color and texture) differ from those that are salient for representing artifacts (e.g. form properties like shape; see Santos et al., 2001, in press). Curiously, the features that rhesus macaques use to individuate food objects in these experiments correspond to those features that are most salient for categorizing food kinds. In other experiments, rhesus macaques from the same population use the property of color, but not shape, to categorize novel food objects in a social facilitation task (Santos et al., 2001). It is possible, then, that rhesus macaques solve the color change individuation task by encoding the apples placed in the box as "blue food" versus "white food". If this account is correct, the pattern of data reported for Experiment 4 provides evidence that rhesus macaques use kind representations, as opposed to mere property information, for individuating food objects.

Unambiguous evidence for kind representations is difficult to come by in non-human animals, even though the results presented here provide the strongest evidence to date using spontaneous methods. One might argue, as explained above, that rhesus macaques selectively use color information because this feature is used to categorize *kinds* of foods. One could also argue, however, that rhesus macaques lack kind representations and selectively use color because it is most salient to them when they are categorizing foods. This problem applies as forcefully to the data on infants. The criteria for determining that infants are using kind information (as opposed to mere property information) is that they can individuate two objects with different labels (see Xu, 2000). In this way, a kind is defined as an object associated with a certain label. It is therefore somewhat circular to suggest that language is required for kind representations if kind representations are, by definition, representations of objects with different labels. What is needed, then, is a definition of a kind concept that does not involve a linguistic label. Such a definition might be based on non-property-based inductive inferences for different objects (see Gelman & Markman, 1986; Mandler & McDonough, 1993, 1996 for these kinds of inductive inference paradigms). If kind concepts are defined in this way, we can then examine how the emergence of language affects this understanding in a more rigorous way.

Although our experiments are modeled directly after previous paradigms used with human infants (see Uller et al., 2000; Van de Walle et al., 2000), we would like to point out an important difference between the method we used and that used by developmental psychologists. Unlike infancy reaching paradigms (see Uller et al., 2000; Van de Walle et al., 2000), our searching time paradigm measures not just how long the monkey spends reaching into the box, but also how long the monkey spends looking in and around the box. Incorporating both reaching and looking was critical because our subjects (unlike infants) clearly spent a large amount of time searching for the objects not only by reaching into the box but also by deliberately looking around for the objects in and around the box. As such, we felt that our “searching” measure must include both reaching and looking in order to reliably gauge subjects’ pursuit of and interest in the missing object. However, although our method provides a more comprehensive measure of searching, it does have one drawback, namely, it does not distinguish between a subject’s increased searching behavior and its increased looking for other reasons. As numerous violation of expectancy studies performed with this population can attest, rhesus macaques do look longer at unexpected events (Hauser et al., 1996; Munakata et al., 2000; Santos & Hauser, 2002; Santos et al., 2002). Therefore, our measure of searching includes the time an animal spends searching for missing objects, as well as the time subjects spend looking in response to various violations (which can include property violations, number violations, etc.). These two measures are confounded in our searching measure in a way that they are not in the infancy measures. Nonetheless, the experiments presented here still demonstrate robust and reliable patterns of searching that differ in a non-random fashion across conditions. It may well turn out that other methods yield more subtle differences across conditions, particularly a method that distinguishes between searching in the box and looking at the box. Nonetheless, developing such a method is beyond the scope of this paper and is most likely inappropriate for studies of free-ranging macaques.

Another potential problem with our method concerns the assumptions underlying our searching measure. As we stated in Section 1, we have argued that when monkeys search longer in inconsistent conditions, they do so because they are searching for missing food objects. In other words, we assume that monkeys search longer because they are actually searching for additional *objects*. An alternative explanation is that monkeys are searching longer not because of missing objects, but because of missing *properties* (i.e. the monkey is not looking for the missing grape, but for the missing grape-like features). This interpretation challenges the claim that monkeys are using kind representations to individuate objects in these experiments, and parallels some of the same issues raised in the infancy literature. Instead, this explanation implies that rhesus are searching longer merely because they recognize a mismatch in the types of properties they saw placed into the box and those they found inside later; they are detecting property violations, not numerical violations. To distinguish between these two interpretations, one must find evidence that subjects are searching longer in a given experiment because they are individuating objects and are therefore responding to numerical violations and not because they are simply detecting the properties of objects placed into the box and responding to property violations. Although we admit that our property/kind individuation experiment (Experiment 1) cannot unambiguously distinguish between these alternatives (at least in its current form), we propose one critical reason to conclude that subjects are in fact responding to numerical violations in this experiment. In Experiment 3, rhesus readily succeeded in a condition in which we contrasted consistent and inconsistent number outcomes. In this experiment, subjects search longer when two apples were added into a box and they found only one apple. This result suggests that, at the very least, longer searching *can* be due to numerical violations in the absence of property violations. We propose that similar numerical violations have resulted in longer searching in our other experiments. Future searching time experiments, however, should discern whether longer searching at one-object outcomes is due to violation of numerical expectations and not simply to surprise at property changes.

In Section 1, we discussed two lines of evidence against Xu's language hypothesis. The first of these lines of evidence, championed by Needham, Wilcox, and their colleagues, has established that infants in the first year of life can segregate and individuate objects using simple featural information in the absence of spatiotemporal cues (see Needham & Baillargeon, 2000 for review). In other words, infants are able to use property information to individuate two distinct objects before they have labels for those objects; whether or not this constitutes an explicit rejection of the claim that language is necessary for object kind discrimination is controversial, given the Xu and Carey (2000) counter-argument about the relationship between featural complexity and object kinds. In this paper, we provide a second line of evidence against Xu's language hypothesis. The four experiments reported here suggest that a species that lacks language may also be able to individuate objects in the absence of spatiotemporal information. Like those of Needham and Baillargeon, our results suggest that a population without the capacity for linguistic representations is able to form accurate expectations about objects in a situation that has been argued to require kind representations in human infants (Uller et al., 2000; Van de Walle et al., 2000). Although these data leave open the possibility that linguistic labels do play some role in the development of kind representations, they demonstrate that – contrary to Xu's original hypothesis – language cannot be required for such representations. Our results replicate the findings of earlier expectancy violation experiments using a new and possibly more ecologically valid task, and provide another important step in our understanding of object representations in the absence of language.

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References

Bogartz, R. S., Shinskey, J. L., & Speaker, C. J. (1997). Interpreting infant looking: the event set × event set design. *Developmental Psychology*, *33*, 408–422.

Carey, S. (1985). *Conceptual change in childhood.* Cambridge, MA: MIT Press.

Gelman, S. A., & Markman, E. M. (1986). Categories and induction in young children. *Cognition*, *23*, 183–208.

Haith, M. M. (1998). Who put the cog in infant cognition? Is rich interpretation too costly? *Infant Behavior & Development*, *21*, 167–179.

Hauser, M. D. (1997). Artifactual kinds and functional design features: what a primate understands without language. *Cognition*, *64*, 285–308.

Hauser, M. D. (2000). *Wild minds: what animals really think*. New York: Henry Hold.

Hauser, M., & Carey, S. (1998). Building a cognitive creature from a set of primitives: evolutionary and developmental insights. In D. D. Cummins & C. Allen (Eds.), *The evolution of mind* (pp. 51–106). New York: Oxford University Press.

Hauser, M. D., Carey, S., & Hauser, L. B. (2000). Spontaneous number representation in semi-free-ranging rhesus monkeys. *Proceedings of the Royal Society of London, Series B*, *267*, 829–833.

Hauser, M. D., Kralik, J., & Botto-Mahan, C. (1999). Problem solving and functional design features: experiments on cotton-top tamarins (*Saguinus oedipus*). *Animal Behaviour*, *57*, 565–582.

Hauser, M. D., MacNeilage, P., & Ware, M. (1996). Numerical representations in primates. *Proceedings of the National Academy of Sciences USA*, *93*, 1514–1517.

Keil, F. C. (1989). *Concepts, kinds, and cognitive development*. Cambridge, MA: MIT Press.

Keil, F. C., Smith, W. C., Simons, D. J., & Levin, D. T. (1998). Two dogmas of conceptual empiricism: implications for hybrid models of the structure of knowledge. *Cognition*, *60*, 143–171.

Leslie, A. M., Xu, F., Tremoulet, P. D., & Scholl, B. J. (1998). Indexing and the object concept: developing 'what' and 'where' systems. *Trends in Cognitive Sciences*, *2*, 10–18.

Mandler, J. M. (1992). How to build a baby II: conceptual primitives. *Psychological Review*, *99*, 587–604.

Mandler, J. M., & McDonough, L. (1993). Concept formation in infancy. *Cognitive Development*, *8*, 291–318.

Mandler, J. M., & McDonough, L. (1996). Drinking and driving don't mix: inductive generalization in infancy. *Cognition*, *59*, 307–335.

Munakata, Y., Santos, L. R., Spelke, E. S., Hauser, M. D., & O'Reilly, R. C. (2000). Visual representation in the wild: how rhesus monkeys parse objects. *Journal of Cognitive Neuroscience*, *13*, 44–58.

Needham, A. (1998). Infants' use of featural information in the segregation of stationary objects. *Infant Behavior & Development*, *21*, 47–75.

Needham, A. (1999). The role of shape in 4-month-old infants' segregation of adjacent objects. *Infant Behavior & Development*, *22*, 161–178.

Needham, A., & Baillargeon, R. (1997). Object segregation in 8-month-old infants. *Cognition*, *62*, 121–149.

Needham, A., & Baillargeon, R. (1998). Effects of prior experience on 4.5-month-old infants' object segregation. *Infant Behavior & Development*, *21*, 1–24.

Needham, A., & Baillargeon, R. (2000). Infants' use of featural and experiential information in segregating and individuating objects: a reply to Xu, Carey and Welch. *Cognition*, *74*, 255–284.

Rawlins, R. G., & Kessler, M. G. (1987). *The Cayo Santiago macaques: history, behavior, and biology*. Albany, NY: SUNY Press.

Santos, L. R., & Caramazza, A. (in press). The domain-specific hypothesis: a developmental and comparative perspective on category-specific deficits. In G. Humphreys & E. Forde (Eds.), Category specific in brain and mind. New York: Psychology Press.

Santos, L. R., & Hauser, M. D. (2002). Monkey see versus monkey do?: dissociations between looking and action in a non-human primate. *Developmental Science*, *5* (2), F1–F7.

Santos, L. R., Hauser, M. D., & Spelke, E. S. (2001). Representations of food kinds in the rhesus macaques (*Macaca mulatta*): an unexplored domain of knowledge. *Cognition*, *82*, 127–155.

Santos, L. R., Hauser, M. D., & Spelke, E. S. (in press). The representation of different domains of knowledge in human and non-human primates: artifactual and food kinds. In M. Beckoff, C. Allen, & G. Burghardt (Eds.), *The cognitive animal*. Cambridge, MA: MIT Press.

Santos, L. R., Miller, C. T., & Hauser, M. D. (2002). The features that guide them: distinguishing between functionally relevant and irrelevant features of artifacts in cotton-top tamarins (*Saguinus oedipus oedipus*) and rhesus macaques (*Macaca mulatta*), submitted for publication.

Spelke, E. S., Kestenbaum, R., Simons, D., & Wein, D. (1995). Spatio-temporal continuity, smoothness of motion, and object identity in infancy. *British Journal of Developmental Psychology*, *13*, 113–142.

Sulkowski, G. M., & Hauser, M. D. (2001). Can rhesus monkeys spontaneously subtract? *Cognition*, *79*, 239–262.

Tinklepaugh, E. (1928). An experimental study of representative factors in monkeys. *Journal of Comparative Psychology*, *13*, 207–224.

Uller, C., Leslie, A. M., & Carey, S. (2000). *Object individuation by 10- and 12-month-old infants in a reaching task*. Poster presented at the XIth biennial meeting of the International Society of Infant Studies, Brighton, UK.

Uller, C., Xu, F., Carey, S., & Hauser, M. D. (1997). Is language needed for constructing sortal concepts? A study with nonhuman primates. In E. Hughes (Ed.), *Proceedings of the 21st annual Boston University conference on language development* (pp. 665–677). Somerville, MA: Cascadilla Press.

Uller, M. C. (1996). *Origins of numerical concepts: a comparative study of human infants and non-humans primates*. Cambridge, MA: MIT Press.

Van de Walle, G. A., Carey, S., & Prevor, M. (2000). Bases for object individuation in infancy: evidence from manual search. *Journal of Cognition and Development*, *1*, 249–280.

Watanabe, M. (1996). Reward expectancy in primate prefrontal neurons. *Nature*, *382*, 629–632.

Wilcox, T. (1999). Object individuation: infants' use of shape, size, pattern, and color. *Cognition*, *72*, 125–166.

Wilcox, T., & Baillargeon, R. (1998). Object individuation in infancy: the use of featural information in reasoning about occlusion events. *Cognitive Psychology*, *37*, 97–155.

Wilcox, T., & Baillargeon, R. (1998). Object individuation in young infants: further evidence with an event-monitoring paradigm. *Developmental Science*, *1*, 127–142.

Williams, T. D., & Carey, S. (2000). *Development of object individuation in infant pigtail macaques*. Poster presented at the XIth biennial meeting of the International Society of Infant Studies, Brighton, UK.

Xu, F. (1999). Object individuation and object identity in infancy: the role of spatiotemporal information, object property information, and language. *Acta Psychologica*, *102*, 113–136.

Xu, F. (2000). *The emergence of kind concepts in infancy: a neo-Whorfian perspective*. Poster presented at the XIth biennial meeting of the International Society of Infant Studies, Brighton, UK.

Xu, F., & Carey, S. (1996). Infants' metaphysics: the case of numerical identity. *Cognitive Psychology*, *30*, 111–153.

Xu, F., & Carey, S. (2000). The emergence of kind concepts: a rejoinder to Needham and Baillargeon (2000). *Cognition*, *74*, 285–301.

Xu, F., Carey, S., & Quint, N. (1997). *Object individuation at 12 months: shape and other properties*. Poster presented at the biennial meeting of the Society for Research in Child Development, Washington, DC.

Xu, F., Carey, S., & Welch, J. (1999). Infants' ability to use object kind information for object individuation. *Cognition*, *70*, 137–166.