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Artifactual kinds and functional design features: what a primate understands without language

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Abstract

Of several domains of knowledge, humans appear to be born with an innately structured representational system for making sense of objects, what properties individuate them, how they move in space, and what causes them to move from one location to another. They also appear to make simple conceptual cuts between artifactual kinds and living kinds. The basis for this distinction seems to be a combination of crucial functional properties, together with a teleological (i.e., historical/intentional) stance, one that asks ‘What was this object designed for?’. Although non-human primates also appear to have considerable understanding of objects, and often use objects as tools, it is not clear whether they draw a distinction between artifactual and living kinds, and if so, what factors guide this distinction. As a step in addressing this problem, I present experiments on a small New World monkey, the cotton-top tamarin (*Saguinus oedipus oedipus*), designed to reveal their understanding of the functional properties of tools using a procedure associated with minimal training. Specifically, the experiments explored whether tamarins distinguish between relevant and irrelevant properties of a tool, and further, understand that some features can be transformed with little cost to functionality. The first experiment was a means-end task and involved using a cane-like object (a tool) to access a piece of food. In this experiment, there were always two choices: either the food was immediately accessible because it was located on the inside of the cane’s hook or less readily accessible because it was located on the outside of the hook. Most of the tamarins reached criterion on this task within a few sessions, consistently picking the cane with the most accessible food. Subsequent experiments (2–4) involved property changes (i.e., its color, texture, size and shape) that had either significant or relatively insignificant effects on the tool’s function. In general, the tamarins appeared tolerant of all property transformations as evidenced by the fact that they selected each object at least once. However, clear preferences also emerged suggesting that some properties had a more significant impact on the tool’s functionality. Thus, in head-to-head competitions, tools with color or texture changes were selectively preferred over tools with shape or size changes. This makes sense since color and texture do not effect the tool’s function, whereas shape and size do. The final experiments involved both novel and familiar objects that, based on their current configuration, could

readily be used as tools, in contrast with objects that required considerable manipulation to convert into a tool. Consistently, the tamarins preferred possible over convertible tools, and when two convertible tools were presented at the same time, they preferred the tool that required the fewest changes to the required motor response. Results suggest that the tamarins distinguish between relevant and irrelevant properties of a tool and this distinction is based on functionality, on having good design. This ability is especially surprising given the fact that tamarins do not naturally use tools, and infrequently come into contact with artifacts. Results are discussed in light of current theories concerning the representational foundations of natural kinds, and in particular, artifactual kinds. © 1997 Elsevier Science B.V.

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1. Introduction

An emerging view about concepts is that they are much more than a repository of features associated with particular objects and events in the world. Rather, concepts provide explanations for how and why things work (Armstrong et al., 1983; Gopnik and Wellman, 1994; Keil, 1994a,b; Smith, 1996; Keil et al., 1997). Of concern to developmentalists working on humans is how concepts are acquired and more specifically, whether certain conceptual domains are kickstarted by innately specified theories which then guide relevant experiences and conceptual refinements (Carey and Spelke, 1994; Wellman and Gelman, 1997). Numerous experiments suggest that there are domain-specific systems of knowledge for physics and psychology that are set in gear by theory-like algorithms (Leslie, 1994; Spelke, 1994; Gopnik and Meltzoff, 1997). More controversially, some would claim that comparable processes arise within the domain of biology (Carey, 1985, 1996; Keil, 1994a, 1995; Atran, 1996). Those interested in cognitive evolution have similar concerns, but see the specificity of domains of knowledge, and the conceptual representations that emerge, as a necessary consequence of natural selection acting on the mind to create evolved adaptations (Cosmides and Tooby, 1994; Pinker, 1994; Hauser, 1996). Although the logic of such evolutionary thinking is not in question, there is a continued need to examine, empirically, how domains of knowledge evolved, why some of our domains of knowledge are species-specific (i.e., unique to *Homo sapiens*) whereas others are shared with other species, and the extent to which the structure and content of concepts provides non-human animals with a system for explaining how the world works. The latter is critical if we wish to establish that within certain domains, non-human animals are not only capable of understanding that something is the case, but why it should be so. In this paper, I use work on non-human primates to inform how we think about such issues. In particular, I focus on physical knowledge of objects and the extent to which non-human primates are capable of understanding the critical functional properties of tools.

A number of non-human animals are capable of using objects in their environment as tools (for reviews, see McGrew, 1992; Vauclair, 1996). In some cases, one

object is slightly modified in order to gain access to another object as occurs when chimpanzees fish for termites by stripping the leaves off of a branch and then inserting the branch into a termite mound. In this case, as in all other cases of tool use, it is not clear what the individual has learned, although there is some evidence for causal understanding (Visalberghi and Limongelli, 1994, 1996; Visalberghi et al., 1995) and for making choices among a range of possible tools (e.g., Matsuzawa, 1996; Matsuzawa and Yamakoshi, 1996). Ideally, what one would like to know is: does the chimpanzee (or any other tool user) understand that not only branches, but any object that can fit into a termite mound might do the job? If they were given a choice between two sticks, one that was very straight and one that curved in and out, would they appreciate that the former is preferable because it is a more efficient tool? Are there certain featural transformations that would be irrelevant in terms of the tool's functionality (i.e., its design features) whereas other features would be relevant? At present, the literature on non-human animal tool use provides no clear answers to these questions, though some of the work by Visalberghi and colleagues, as well as Matsuzawa, suggests that capuchin monkeys and chimpanzees are relatively discriminating when it comes to selecting an appropriate tool for a task. Because the work on concept development and problem solving in human children provides some relevant theoretical guidance, I now briefly turn to some of these issues before presenting the empirical results from our experiments.

In an attempt to understand how representations of object kinds are acquired and modified, Keil (1989, 1994a,b, 1995) has conducted a series of insightful experiments with young children. The basic idea behind these experiments is quite simple: in assigning an object to a category, what featural transformations to the object will the child tolerate? Said differently, does the child have a notion of 'kind' or is the child's classification system guided by a cluster of properties? For example, if a raccoon undergoes an operation and has its fur replaced by that of a skunk, is it a raccoon or a skunk? Young children answer 'skunk' because they are driven by properties (e.g., color of the fur, smell) whereas older children answer 'raccoon' because they have developed the concept of a biological kind (e.g., what is, constitutionally or essentially, a raccoon). In contrast, if a typical beige touch tone phone has to be repaired, and its external 'shell' is replaced by a toy car, is it a phone or a toy car? In general, Keil finds that children are far more tolerant of changes to artifacts than they are to changes imposed on natural kinds, especially if they have some understanding, have a theory of, change and the mechanisms that underlie them. Moreover, they understand that both artifactual and natural kinds have components designed for a particular function, but recognize that such functional components play different roles for each object kind (see discussion in Bloom, 1996 and tool use experiments by Brown, 1990); for example, thorns on a rose bush serve a defensive function for the rose whereas thorns on a barbed wire fence serve a defensive function against intruders (i.e., they are not for the barbed wire fence).

If concepts provide explanatory power for organizing objects and events in the world, then at some level, they must be used to guide problem solving. When

problems are presented, they either have determinate or indeterminate outcomes, and in evaluating such situations, some features are relevant and some are irrelevant. In an elegant paper, Fay and Klahr (1996) explore these distinctions by presenting pre-school children with different sorts of problems. They argue that in evaluating a problem, individuals engage three processes. First, they search the problem environment, extracting information that is relevant to the task at hand. Second, they evaluate the problem and store the relevant details in a mental representation that classifies the situation as determinate or indeterminate. Third, they map the representation onto an appropriate response that is either verbal or non-verbal. What is important about this suite of processes is that they provide a useful way of decomposing problem solving tasks into cognitive pieces that ultimately are linked in adulthood, but that may emerge independently during development and evolution. Thus, for example, several studies in cognitive development have demonstrated, using the expectancy violation procedure (Spelke, 1985; Hauser and Carey, 1997), that young infants are capable of distinguishing between possible and impossible outcomes from physical events (Baillargeon, 1994, 1995; Spelke, 1994). It is not until much later in life that they can use such knowledge explicitly in tasks that involve, for example, a verbal response or targeted motor action (e.g., see Brown, 1990 for experiments on 18 month olds' understanding of tool use and the idea that cause-effect interactions among physical objects can only come about by means of contact, i.e., no action at a distance). In the words of Fay and Klahr, human infants appear capable of searching and evaluating, but only older children can map. If such cognitive dissociations occur developmentally, it is also possible that they occur during evolution.

Using the expectancy violation procedure, recent work on non-human primates has revealed that they have considerable knowledge of objects, the features that individuate them, the processes that cause them to move, and the trajectories they take when they move (Hauser et al., 1996, 1997; Hauser and Carey, 1997; Uller, 1997). What is not yet clear from these experiments is whether such knowledge can be used in tasks that require more explicit motor responses (e.g., targeted search) and whether their classification of objects derives from an assessment of properties or kinds. One study provides some insight, and is directly relevant to the experiments reported on below (Hauser et al., under review).

Cotton-top tamarins (*Saguinus oedipus oedipus*) were presented with a means-end task that involved comprehension of two abstract relational concepts (see Herrnstein, 1991; Ullman, 1996): On versus Off and Connected versus Disconnected. The task was simple, and represented a variant of one designed by Willatts (1984, 1990) for human infants; for brevity, I focus here on the tests of Connectedness. The tamarins were presented with a light blue tray, divided in two by a partition. On a typical trial, one side of the tray held a long, dark blue piece of cloth and on the end of the cloth, a small piece of food, colored white. On the other side of the tray, there were two pieces of dark blue cloth, separated by a narrow gap. A piece of food (also colored white) was placed on the end of the far cloth (from the tamarin's perspective). Following presentation, in which the tamarins could only see the objects but not touch them, they were allowed to choose between the two pieces of cloth. The

task: pull a piece of cloth as the means to acquiring food; only one choice was permitted per trial.

In the first condition of this experiment, only two parameters were varied: the position of the gap (near, far) and the relative position of the food on or off the cloth. The tamarins solved the problem without explicit training, and some individuals reached criterion within a few sessions. Subsequently, we set up experiments to probe what the tamarins learned from this task. Specifically, we were interested in assessing whether the tamarins learned something quite general and abstract about means-end tasks and connectedness, or whether they extracted a low level perceptual feature that would solve the problem. For example, they could easily solve the first condition of the experiment by avoiding the side with a dark blue (cloth)-light blue (tray)-dark blue (cloth) pattern. To test these hypotheses, all subsequent conditions involved changes in the color, shape, and size of the cloth and food, in addition to changes in the shape, size and position of the gap, and lastly, the degree to which the connection between two objects was functional (in the sense of a hook piercing a worm) versus functionless (in the sense of a hook touching the side of a worm). Accuracy on this task was not affected (i.e., did not significantly lower performance) by these perceptual features. Thus, the tamarins' understanding of this task went beyond: dark blue rectangular cloths and white food pellets on a light blue tray.

In terms of functionality, the tamarins also appeared to understand that some connections between objects are functional and others functionless. Thus, when given a choice between two pieces of cloth connected by a wooden dowel as opposed to pieces of chipped wood, the tamarins selected the wooden dowel; the chipped wood merely formed a physical path from one piece of cloth to the other, but the connection served no function in the means-end task. This suggests that the tamarins learned something about the cloth as a kind of tool, a kind that can assume quite variable properties (e.g., changes in color, shape, size).

To build on the results from the means-end cloth task, the following experiments were designed to address three specific questions: (1) If one particular object is used to solve a means-end task, can other objects be used to achieve comparable ends? (2) If other objects are accepted, what featural (property) changes or transformations are tolerated and do they relate to the object's functionality, what it appears to be designed for? (3) Given a choice between two objects that potentially function as tools, what factors guide the subject's selection? Are they guided by criteria for optimizing success in the means-end task?

To answer these questions, we used an approach that was comparable to the cloth tests described above. In particular, specific features were systematically manipulated, first on a univariate level and then on a multivariate level. Such manipulations allowed us to explore the extent to which subjects were using a relatively abstract concept to guide their choices as opposed to a simpler, feature-based decision rule. Furthermore, our initial experiment involved a limited number of unique exemplars and no explicit training. As such, we were able to observe relatively spontaneous decision processes in the absence of biases that may be imposed as a result of experimenter training.

2. Methods

2.1. Subjects

Experiments were run on a population of nine adult cotton-top tamarins, four males and five females. Table 1 presents a list of subjects. All individuals were born at the New England Regional Primate Center, Southborough, MA, USA and have been housed at the Primate Cognitive Neuroscience Laboratory at Harvard University since 1993. Cotton-top tamarins are omnivores, native to the rainforests of Columbia. Individuals typically live in monogamous breeding pairs, though it is not uncommon to observe both polygamous and polyandrous social groups (Rylands, 1996; Savage et al., 1996). Although tamarins can use their hands to extract exudate from trees or to process fruits, they have never been observed using tools in either the wild or in captivity.

Subjects are fed a diet of monkey chow, crickets, mealworms, yogurt, sunflower seeds, and peanuts together with ad libitum access to water; food is provided at the end of the day, once experiments have been completed. Weights are maintained at approximately 10–15% lower than is typical for captive cotton-top tamarins and thus, are closer to weights obtained for wild tamarins (personal communication, A. Savage).

All subjects tested had some experience running in experiments (Hauser et al., 1995, in preparation; Hauser, 1997; Hauser and Carey, 1997; Uller, 1997; Kralik and Hauser, in preparation). For example, three subjects had recently completed an experiment probing, through operant conditioning procedures, whether tamarins have the capacity to understand the abstract relational concept of ‘connectedness’ (Kralik and Hauser, in preparation). Three other subjects were being run on an operant task involving face perception (Weiss et al., in preparation). All subjects have been run in expectancy violation experiments focusing on numerical competence and object individuation (Hauser, 1997; Hauser and Carey, 1997; Uller, 1997). Importantly, seven out of nine subjects (Table 1) recently completed the cloth experiment (Hauser et al., under review) discussed in the introduction that, like

Table 1
Cotton-top tamarins tested in property/kind tool experiments

Subject ID	Group	Sex	Prior experience with means-end cloth test
Chomsky	L1	M	Yes
Bellugi	L1	F	Yes
Locke	L2	M	Yes
Markman	L2	F	No
Pinker	L3	M	Yes
Carey	L3	F	No
Quine	P	M	Yes
Millikan	P	F	Yes
Churchland	P	F	Yes

the experiment discussed below, required an understanding of a means-end task, the use of a tool, the comprehension of abstract-relational concepts, and the ability to determine meaningful from meaningless perceptual changes in the tool-like object. The two remaining subjects lacked such experience, and thus, were considered relatively naive with respect to means-end tasks and simple tool use.

2.2. *Test apparatus and general experimental design*

Test sessions involved the following steps. The target subject was removed from its home cage and transported in a plexiglass box to the experimental room. The subject was then transferred from the transport box to a test box. The test box consisted of a wire mesh platform, where subjects sat, and a V-shaped back that centered the subject with respect to the plexiglass (transparent) front panel. Centered in the middle of the front panel were two slits separated by a solid piece of transparent plexiglass. Each slit was wide enough for the tamarins to reach through and manipulate the selected experimental object, but too narrow for them to reach across and grab both objects at once (see below); as a result of this constraint, only one object could be selected in any given trial.

Once the subject was in place, a two-tiered stand was advanced. A light blue tray (consisting of two sides divided by a partition) holding the test objects was placed on the lower tier for 3–5 s. The tray was left in place until the subject saw each side clearly; at this level, it was not possible for the tamarins to reach through a slit and grab either the test object or food pellet. Having seen both test objects, the tray was removed from the lower tier and placed on the second tier; at no time during the presentation did the experimenter make eye contact with the subject, looking straight down at the floor throughout. Subjects were then allowed to reach out and select one test object. Only one selection was permitted per trial due to the physical dimensions of the front plexiglass panel. Subjects were not able to reach through both slits simultaneously, and grab both objects. Thus, if the trial involved a comparison between an accessible and an inaccessible food item (see experiment 1 below), and the side with the inaccessible food item was selected, then the trial was terminated.

All trials were set up out of view from the subject. The tamarins had no prior experience with the test objects and only obtained experience with each object by means of manipulating them during experimental sessions. Food pellets were only accessible by means of manipulating one of the test objects in relation to the pellet's placement (i.e., it was not possible for the tamarins to reach through and grab a pellet from the tray).

A total of four experiments (1–4) were run. In general terms, the task was the same for all four experiments: manipulate an object to gain access (means) to a 45 mg banana flavored food pellet (end). The objects were constructed out of Fimo®, a non-toxic clay. When Fimo® is baked in the oven and allowed to cool, it hardens and takes on a shiny smooth texture. All subjects ran each experiment. We did not have to train our subjects in this task since they spontaneously reached out to grab the test objects in each experiment.

3. Results

3.1. Experiment 1: design and results

Experiment 1 was a means-end task involving pairs of dark blue canes and small, white food pellets. The goal of this experiment was to provide the tamarins with experience using a single object; the only parameter to vary across trials, therefore, was the position of the pellet relative to the cane's hook. Because subjects were not trained to pull the canes, and because they received a limited set of tools and pellet positions, we hoped to gain greater insights into the abstractness of their conceptual representations and the extent to which early experience constrains subsequent performance. For example, the tamarins might only learn about blue canes and white pellets from experiment 1, rather than a more abstract understanding of objects as means to food.

The task involved pulling a cane to gain access to a pellet (Fig. 1). Each trial involved a choice between two identical canes, one with a pellet inside the hook and one on the outside. Although either cane could, in theory, provide access to the pellet, the optimal choice involved selecting the side with a pellet located on the inside of the hook. Pulling this cane straight back would bring the pellet close to the front of the test box in one shot. To access the other pellet required (1) lifting the cane up, rotating the hook approximately 180°, and then pulling straight back or, (2) pushing the hook portion up and over and then straight back. We assumed that the tamarins would search for the easiest solution and thus, pick the side with a pellet located inside the hook of the cane.

A total of 12 trials were run per test session. For trials 1–6, the pellet was most

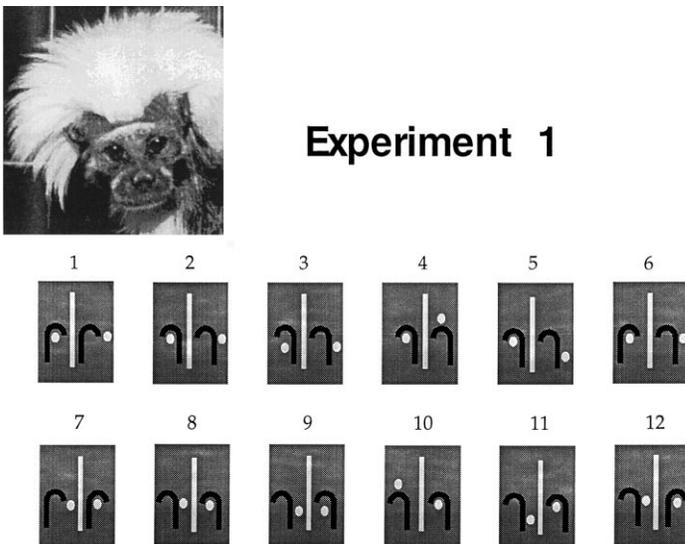


Fig. 1. Trials for experiment 1. The tray is indicated by the light gray rectangle, the partition by the thin white bar in the middle.

readily accessible by pulling the cane on the left side whereas for trials 7–12 (mirror reverse of 1–6), the pellet was accessible on the right side. To randomize the presentation of trials within sessions, we used a random number generator. Subjects were run on experiment 1 until they achieved an accuracy of 10 or more correct trials per session (i.e., >83%) on two consecutive sessions. A correct choice was defined as picking the cane with a pellet located on the inside of the hook.

Fig. 2 shows the learning curves for each subject in experiment 1. Some subjects reached criterion after 2–3 sessions whereas other subjects required as many as 10 sessions. As highlighted in Fig. 2, the two subjects who were completely naive with regard to the means-end task (Carey, Markman) achieved criterion at approximately the same pace as some of the subjects who had such experience (e.g., Millikan, Quine). In subsequent analyses, therefore, we made no distinction between subjects who were or who were not naive with respect to means-end tasks.

We set up experiment 1 to contrast a readily accessible food pellet (inside the hook) with a pellet that was more difficult to obtain (outside the hook). To repeat, the pellet located on the outside of the hook could be obtained if the tamarins either flipped the cane over (i.e., rotated the hook 180°) or lifted it up and over the pellet and then pulled straight back. In this sense, both canes provided potential access to the food pellet. When the tamarins selected the cane with a pellet located on the

Experiment 1: Sessions to Criterion

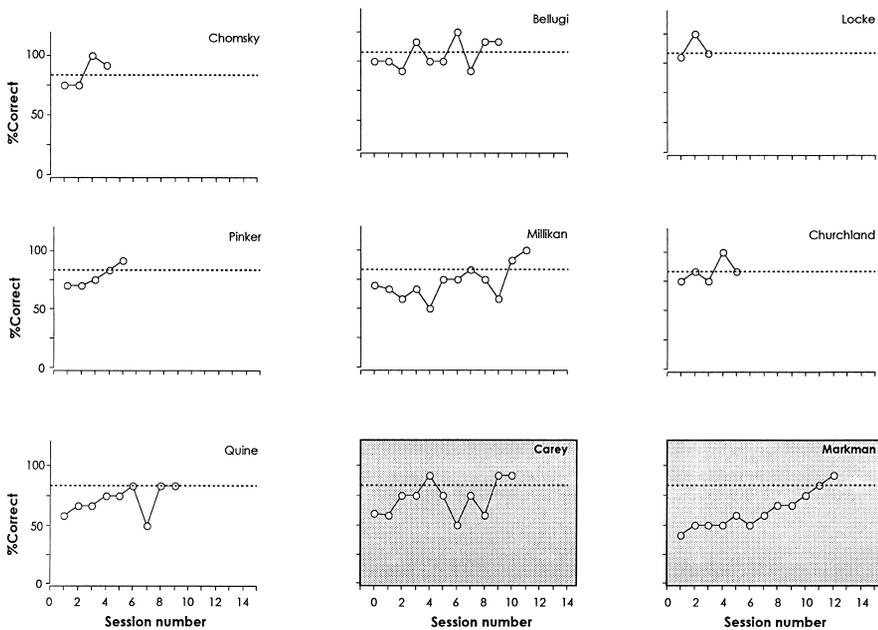


Fig. 2. Performance on experiment 1. Criterion is indicated by the dashed line at 85%. The two highlighted panels on the bottom row are for the two subjects (Carey, Markman) considered naive with regard to the means-end task. The y-axis represents the proportion of trials in which the subject picked the correct tool. The x-axis represents session number.

outside of the hook, there was no evidence that they were attempting to manipulate the cane to attain the pellet. That is, when they pulled on a cane their motor response was relatively stereotyped: they grabbed the base of the cane and pulled straight back.

The fact that subjects reached criterion quite quickly raises two points, each relevant to the design of experiments 2–4. First, the tamarins understand the means-end task of experiment 1. Although the test object was the same in each trial of experiment 1, individuals consistently favored the cane with a pellet located on the inside of the hook. In terms of tool efficiency, this is the most appropriate selection. The alternatives require far more complicated manipulations of the cane. Second, the task was designed to test whether the tamarins have access to the abstract relational concept, or in the words of the Gibsons (Gibson, 1966, 1979), an affordance, of ‘inside’. It is abstract because it is not tied to a particular type of object or objects. It is relational because an object that is tagged as inside holds a certain spatiotemporal relation to another object. At this stage of our test, however, there is no evidence that the tamarins were using the concept of ‘inside’ to guide their choice of canes.

To flesh out these two general points, we must ask more specific questions. What did the tamarins learn in this task? Did they learn something about dark blue canes or, did they learn something much more general and abstract? For example, do they understand that there are other possible tools that would be equally efficient? Have they really grasped the concept of ‘inside’? For experiment 1, it is possible that they solved the task by focusing on more concrete perceptual factors. For example, the tamarins could have solved the task by invoking the following algorithm: pick the side where the white pellet is closest to the concave portion of the blue curve. To address these questions, we designed experiments 2–4. Each experiment attempts to rule out a concrete perceptual account of the tamarins’ performance and, in addition, seeks information on the tamarins’ understanding of tools as kinds, their function and physical attributes.

3.2. *Experiment 2: design and results*

In experiment 2, we altered one physical feature of the putative tool and assessed both whether the tamarins would tolerate such changes (i.e., would they still consider these objects as functional in the means-end task?) and whether some changes were more salient in terms of the object’s functionality. More precisely, we were interested in understanding whether the tamarins would treat some featural changes as relevant to a putative tool’s functionality and other features as irrelevant.

Four features were manipulated: Color, Size, Texture and Shape (Table 2). Taking into account the constraints imposed by the test apparatus, the tamarin’s dexterity, and the size and shape of their hands, these featural manipulations can be tentatively ranked in terms of how they effect the object’s functionality. Thus, color changes are irrelevant. The cane works equally well when it is purple, red, green or yellow. Texture has a potentially more significant effect than color because it alters both how the object moves across the surface of the tray when pulled and

how easily the object can be grasped. Thus, for example, the cane with raised peaks moves less fluidly over the surface of the tray than either the original cane (smooth texture) or the new cane with perforations. Size, as set up in this experiment, has a significant effect on functionality. Both the longer and wider canes are more difficult to manipulate than the other canes. The longer cane is unwieldy because the hooked portion is quite a distance from its stem and as the cane is pulled in, the stem enters the test box and obstructs the tamarins' ability to maneuver. The wider cane is difficult to grasp, given the size of the tamarin's hand. Shape is likely to be the most significant alteration because it changes at least two components of the task. First, the tamarins can no longer use the relatively simple algorithm of 'pellet sitting in the concave portion of the hook', if this was in fact what they were using to solve the problem. This algorithm works for experiment 1 and with the other manipulations in experiment 2. Second, if the tamarins only learned about canes as putative tools from experiment 1, then they should have greater difficulty with a shape change than with all other changes.

In experiment 1, pellets located on the outside of the hook were not as readily accessible as pellets located on the inside of the hook. This setup forced the tamarins to choose carefully since an incorrect choice ended the trial without reinforcement. In experiment 2, the pellet was readily accessible on both sides of the tray (i.e., it was always located on the inside of a hook-like portion of the tool). Thus, even if the tamarins paid no attention to the featural details of the objects, and pulled randomly using the stereotyped motor response for experiment 1, they would be reinforced. For experiment 2, therefore, we were simply asking whether the tamarins had preferences for some objects over others or alternatively, whether they avoided some objects over others. To diminish the possibility that the tamarins would no longer attend to the differences between the two test objects presented within a trial, each session of experiment 2 was followed by a session of experiment 1.

Five subjects started with a Color versus Size comparison and after two sessions, switched to a Shape versus Texture comparison. The other four subjects started with Shape versus Texture and then switched to Color versus Size. As mentioned above, each session of experiment 2 was followed by a minimum of one session of experiment 1. Subjects returned to experiment 2 only after they reached criterion on experiment 1. Experiment 2 involved 12 trials, with the position of each tool appearing on the right and left sides; Fig. 3 shows only one position and not its mirror reverse.

Table 2
Experiment 2: single feature changes

Feature	Details
Color	Changed from original dark blue to (i) red versus (ii) purple.
Size	Changed from original size and width to (i) 1.5 times longer versus (ii) 1.5 times wider
Texture	Changed from smooth and solid to (i) perforated with holes versus (ii) raised with peaks
Shape	Changed from cane shape to (i) inverted V-shape versus (ii) hook at top bent back 90°

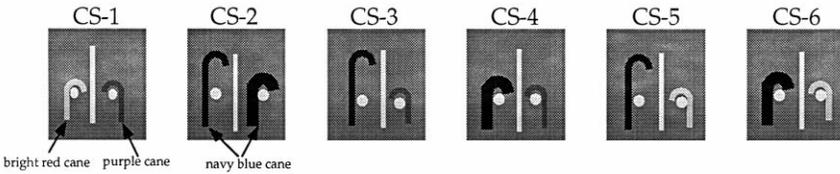
See Fig. 2 for drawings of object exemplars.

Each figure presents overall percentages by experiment and object pairing. For any given pairing, a higher percentage score indicates that this particular object was preferred or, that the object with a lower percentage score was avoided. To test for statistical significance among the major featural categories (i.e., Color versus Size, Texture versus Shape), scores for the first trial of each tool pairing of each experiment were used; although this reduces the sample size, it avoids the problem of pseudoreplication and further, removes potential experiential effects across trials of the same experiment.

Results from experiment 2 are presented in Fig. 4, contrasting preferences for test objects within and between featural categories. Within Color, there was no preference for purple (54%) over red (46%), even though purple is more similar to the original dark blue cane than red. Within Size, wide (72%) was preferred over long (28%); both width and length were 1.5 times greater than the original cane. In between-feature comparisons, both the red and purple canes were preferred (72%) over the long cane (28%). In contrast, no preferences emerged when the wide cane was paired with either the red (45% versus 55%) or purple cane (55% versus 45%). Putting this information together, tamarins were more likely to pick an object with a color change than an object with a size change on the first trial of each test ($\chi^2 = 19.6, P < 0.001$). Said somewhat differently, changes in color appeared

Experiment 2

Color/ Size



Shape/ Texture

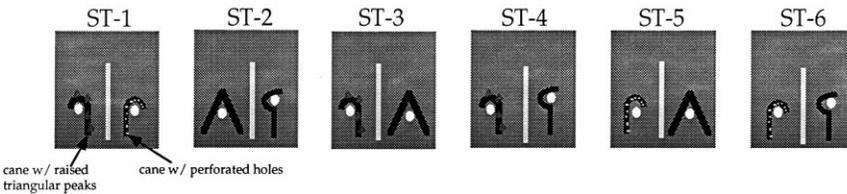


Fig. 3. Trials for experiment 2. The top row shows the tools and pairings for the Color/Size component of experiment 2. The bottom row shows the tools and pairings for the Shape/Texture component of experiment 2. For each pairing, the tools were presented once on the left and once on the right within a session.

less significant than changes in size with regard to the object’s functionality, though this effect was largely driven by the long cane.

Within Texture, subjects showed a slight preference for peaks (62%) over perforations (38%). Within Shape, subjects showed a strong preference for the triangle (93%) over the 90° hook (7%). For between feature comparisons, subjects preferred the textured peaks over the triangle (62% versus 38%) and 90° hook (85% versus 15%). There was no difference between the perforated texture (50%) and the triangle shape (50%), but a preference emerged for the perforated texture (73%) over the 90° hook (27%). Combining this information, subjects were more likely to pick an object associated with a texture change than an object associated with a shape change ($\chi^2 = 13.2, P < 0.001$). As for Color/Size, changes in Texture appeared less salient than changes in Shape with respect to the object’s functionality.

Although the tamarins exhibited preferences in experiment 2, what is perhaps most striking given their apparent lack of experience with tools is the fact that all of the objects were picked at least once by all subjects. Thus, in terms of the means-end task, changes in color, size, texture, and shape were all tolerated, at least within the range explored. Using some tools, however, proved more difficult with respect to pellet retrieval. Specifically, on some trials, subjects pulled a tool but failed to retrieve the pellet on their own. For color versus size, 11 out of 12 retrieval errors

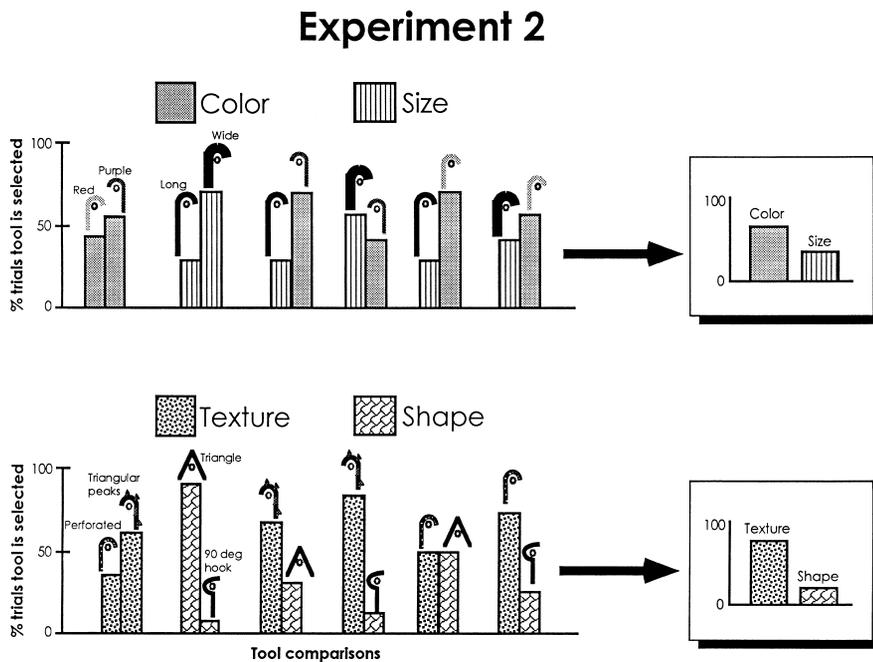


Fig. 4. Results from experiment 2, showing the proportion of trials in which subjects selected a tool, given specific pairings. On the right side of this figure, overall preferences for Color versus Size and for Texture versus Shape are presented.

occurred when subjects pulled the tool with an altered size. For shape versus texture, 11 out of 13 errors occurred when subjects pulled the tool with an altered shape.

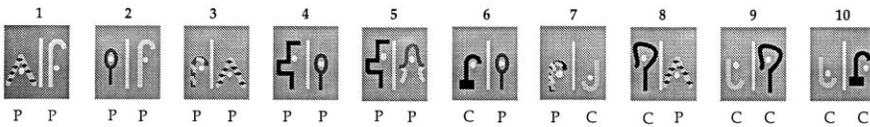
To further probe the level at which tamarins can use objects as tools, and specifically, as a means to food, we turn to experiments 3 and 4. These experiments were designed (1) to determine the tamarins' tolerance for changes in the physical properties of the putative tool (i.e., at what point do the tamarins reject an object as a tool?) and (2) to assess whether tamarins can convert an object into a functional tool if it is currently in a position, relative to the goal, that is inappropriate.

3.3. Experiment 3: design and results

Experiment 3 was divided into two sub-experiments in order to include as many pairwise comparisons as possible, while limiting the number of trials per session to 20; prior experience suggested that increasing the number of trials per session beyond 20 would cause a significant drop in performance. Thus, Fig. 5 shows only a sample of the trials presented. As in previous experiments, for all pairwise comparisons, each tool was presented on the right and left sides of the tray.

Experiment 3 introduced a set of new tools, varying in color, texture, shape, size, or some combination of these features (Fig. 5). Thus, for example, a new triangular object was introduced, with a new color (lime green) and new texture (small yellow spikes sticking out of a lime green triangular base). In addition, a new parameter was introduced: whether the current position of the tool provided access to the pellet by

Experiment 3



P = Possible tool (i.e., can be used with straight pull to access food)
 C = Convertible tool (i.e., cannot be used with straight pull to access food; tool position must be modified to access food)

Novel possible tools		Convertible tools	
	original blue, new shape		old shape, new combination of colors and texture
	lime green + yellow spikes new triangle shape		dayglo yellow, long cane
	purple with new shape		dayglo yellow + bright red, new shape
			hook portion sits vertically on stand, up off of tray
			ring portion of tool sits vertically, 90deg from horizontal stem
			hook is in the wrong position; novel light blue color

Fig. 5. Trials for experiment 3. This represents only a subset of all comparisons presented in experiment 3. All of the tools used in experiments 3.1 and 3.2 are illustrated, however. There were seven novel possible tools and three convertible tools. Under each trial (top), a 'P' is placed if the tool can be used with a straight pull whereas a 'C' is placed if the tool requires a novel set of motor actions to bring it into line with the pellet, making it accessible.

simply pulling straight back (familiar motor action, possible tool) or whether its position had to be altered and converted into a possible configuration for accessing the pellet (unfamiliar motor action, convertible tool). Thus, the trials within experiment 3 (both 3.1 and 3.2) involved three types of comparison: Possible versus Possible (P-P), Possible versus Convertible (P-C), and Convertible versus Convertible (C-C). P-P trials were like those in experiment 2 in that either choice yielded an immediately accessible (without significant changes in the original motor action) pellet. P-C trials involved a choice between an object that would yield a pellet without modifying previously implemented motor actions versus an object that required modification of motor actions and greater manipulation of the object to gain access to the pellet. C-C trials involved a choice of new objects requiring new manipulative actions. In P-C and C-C trials, therefore, picking the convertible object was less likely to lead to reinforcement, at least during the first few trials or sessions. We therefore expected the tamarins to show a preference for possible objects over convertible ones whenever these two were paired within a trial. Subjects received two sessions each of experiments 3.1 and 3.2. Overall, then, experiment 3 was designed to extend the range of variation in object properties far beyond those tested in experiments 1 and 2, to assess whether objects placed in a novel position with respect to functionality could be converted into an appropriate position, and to determine whether some objects would be rejected because they fell outside the range of tolerable variation for a putative tool in the current means-end task.

Fig. 6 shows the results of all paired comparisons. In general, and as highlighted in experiment 2, the tamarins were tolerant of almost all changes, picking all possible objects at least once. In fact, with only a few exceptions, there were no strong preferences within the category of possible objects, even though some of the featural changes were quite radical when contrasted with the original dark blue cane. The one object that was picked less than any other, when it was paired with another possible object, was the long yellow cane. Here, the color was novel, but the length was equal to the long dark blue cane presented in experiment 2. Interestingly, the tamarins' general bias against this object in P-P trials was reversed when it was paired against a convertible object (Fig. 6; experiment 3.1).

The most striking result from experiment 3 is the overwhelming preference for possible tools over convertible ones in P-C comparisons. This is revealed in Fig. 6 for each individual comparison, and is supported statistically by a Chi-square analysis of preferences on the first trial of each test of experiment 3 ($\chi^2 = 19.7$, $P < 0.001$). Of additional interest is the suggestion that in C-C trials, the tamarins selected the convertible tool that appeared to require the fewest or easiest changes in manipulation. Thus, for example, consider the comparison between the inverted light blue cane and the 90° ringed hook. The former requires grasping the base of the object, rotating it 180° to the north, and then pulling back; alternatively, it would be possible to grab the hook and use the tip as a hockey stick, slapping the pellet toward the front. In contrast, the ringed hook only requires a slight drop in the tip toward the tray so that it can be pulled straight back with the pellet.

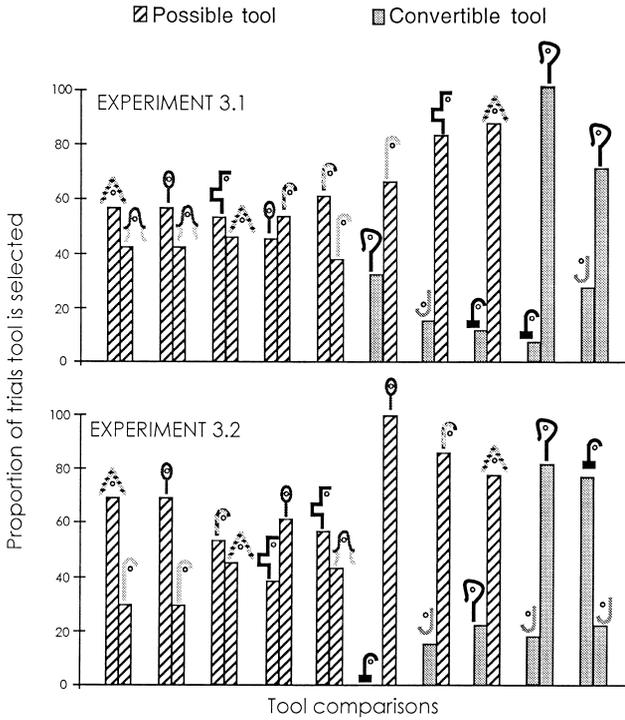


Fig. 6. Results from experiments 3.1 and 3.2, showing all pairwise comparisons. Preferences for tools considered ‘possible’ are indicated by striped bars whereas tools considered convertible are indicated by gray bars.

Although the tamarins did pull convertible tools, in no case did we find evidence that they were manipulating the tool into a possible position. In fact, it was extremely rare for a subject to pull on a convertible tool and obtain a pellet; the lack of reinforcement did not stop them from pulling such objects in an attempt to gain food. Our impression was that the tamarins’ failure to manipulate convertible tools into a possible position reflected their relatively poor dexterity and the physical constraints of the test apparatus.

3.4. Experiment 4: design and results

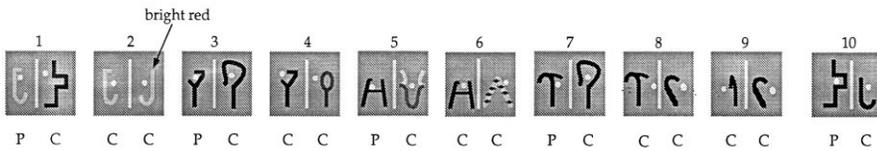
Experiment 4 introduced a new set of putative tools, both possible and convertible, and varying in color, size, shape and texture. Importantly, experiment 4 took objects that were familiar and possible tools in previous experiments, but turned them into convertible tools. Thus, for example, the old dark blue cane from experiment 1 was turned upside down in one case, with the hook located near the bottom of the tray, closer to the tamarins’ hands (see Fig. 7, trial 10); in another trial, the pellet was placed on the outside of the old green-yellow triangle as well as the closed loop on a stem (experiment 3). The idea here was to deter-

mine if familiarity would drive the tamarins' preferences or, whether a novel object placed in a more appropriate configuration would be favored over a familiar object placed in a novel, but inappropriate configuration. Again, in terms of functionality, novelty should be perceived as irrelevant; position of the object relative to the pellet is more relevant.

Fig. 7 shows only one position for each tool, but the same pairwise comparisons were also presented in their mirror reversed positions. Thus, each session of experiment 4 involved 20 trials and subjects received two sessions. As in experiment 3, this experiment also involved P-C and C-C comparisons; no P-P comparisons were presented.

Paralleling results from experiment 3, the tamarins consistently preferred possible over convertible tools, both at the individual level (Fig. 8) and when tested for statistical significance using data from first trial performance ($\chi^2 = 71.0, P < 0.001$). This effect was not due to a bias against new objects, for the tamarins picked possible new tools over familiar convertible ones. As in experiment 3, however, we rarely saw the tamarins take a potentially convertible tool and manipulate it into a position that allowed access to the pellet. This was even the case in some of the simpler convertible object setups. For example, in trials 8 and 9, the original dark blue cane was rotated -45° from its original position. To access the pellet, the tamarins would have to rotate the cane $+45^\circ$ and then pull straight back. They typically pulled straight back without manipulating the hooked portion of the cane, thereby missing the pellet. Again, the tamarins' inability to convert a tool into a possible position may reflect their poor dexterity and the constraints of the test apparatus.

Experiment 4



P = Possible tool (i.e., can be used with straight pull to access food)
 C = Convertible tool (i.e., cannot be used with straight pull to access food; tool position must be modified to access food)

Description of new tools

	Bright red cane, inverted, and with horizontal extension, making it a possible tool if pellet is beneath the extension		Old tool shape and color, but in unfamiliar position
	Right side of tool must be rotated counter-clockwise in order to access pellet		Tool must be pulled down and to lower right to access pellet
	Narrow cane, with hook facing up; hook must be rotated 90deg to the left and down to access pellet		Condition A cane, but side branch on upper right allows access to pellet

Fig. 7. Trials for experiment 4. Under each trial (top), a 'P' is placed if the tool can be used with a straight pull whereas a 'C' is placed if the tool requires a novel set of motor actions to bring it into line with the pellet, making it accessible.

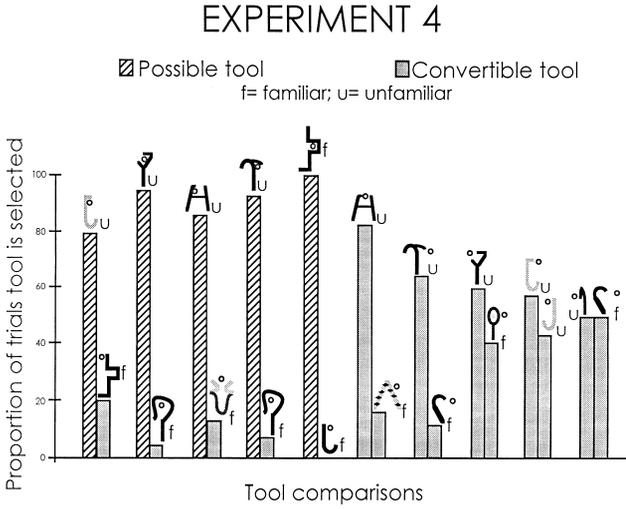


Fig. 8. Results from experiment 4 showing all pairwise comparisons. Preferences for tools considered 'possible' are indicated by striped bars whereas tools considered convertible are indicated by gray bars. If the tool appeared in an earlier experiment, an 'f' is placed next to the tool; if the tool is novel or unfamiliar, a 'u' is placed next to the tool.

Two points emerge. First, the tamarins are remarkably tolerant of featural changes in the tool. Second, if the change in the physical or configurational properties of the tool requires a novel motor routine for accessing the pellet, then the tamarins fail to access the pellet. This provides a window into the limitations of their tool using skills.

4. Discussion

'Seeing things as if their properties have purposes may be essential to any understanding of tool use, design, or modification, and such abilities may have clear origins in infancy... (S)ome sorts of properties may do more work for functional stances than for physical or intentional stances and vice versa'.

(Keil, 1995, p. 248).

This paper has explored the problem of object representation in a non-human primate, focusing specifically on their understanding of the functional properties of tools. In this discussion, I would like to return to Keil's (Keil, 1994b, 1995) work on object kinds, in addition to some of the conceptual issues that he and Bloom (1996) raise concerning the role of features and explanatory structures in organizing conceptual representations, specifically, artifactual kinds.

Keil's (1995) analysis of object kinds generates four points relevant to the results

presented in this report. I list these below in summary form, and then unpack them in greater detail in light of the tamarin data.

1. Defining a kind does not require highly correlated clusters of properties. Rather, kinds may be defined on the basis of a configuration of properties, each associated in a probabilistic fashion with members of the kind.
2. Certain property changes are critical in that they alter the functionality of the object and therefore, alter the kind.
3. ‘Functional things’ have properties with a specific purpose. Artifacts are considered as ‘functional things’.
4. Mechanisms must exist to connect explanatory/propositional structures with the data base of feature frequencies and correlations.

To evaluate the tamarin data, consider the task presented. A tray is advanced and the tamarins see two pieces of food, each placed next to an object. This step provides the tamarins with an opportunity to search, extract and then evaluate the relevant details of the task at hand. Given the fact that individuals spontaneously reached for the objects and manipulated them in the direction of the food, they appear to have grasped the essence of the problem: the object is a means to the food, and without the object, the food is inaccessible; they, in some sense, perceive the object as a ‘functional thing’. In the words of Fay and Klahr (1996), the tamarins have mapped the representation onto an appropriate response. We can derive these general conclusions from the tamarins’ performance in experiment 1, but we cannot make any more specific claims. Thus, we do not know which properties are significant, nor do we know whether the tamarins have developed a functional stance toward the object, understanding that the object is a kind of tool with specific design features. Unlike living kinds where properties have been designed for the organism (e.g., a deer’s antlers), the functional properties of the tool (e.g., the position of the cane’s hook relative to the pellet) have been designed (e.g., by a human experimenter) for an external agent (e.g., the tamarin), even though the tamarins need not understand any of this to solve the task. The subsequent conditions allow a more precise characterization of the representational system underlying the tamarins’ performance.

Experiment 2 involved systematic and parametric manipulations of the properties that are likely to have either significant or insignificant effects on the object’s functionality. The findings of Keil (1994a; 1995) and Brown (1990) with young children guided our selection of properties. Specifically, children consider color to be causally irrelevant for most artifactual kinds, whereas shape is important for assessing functionality (physical design). The tamarins’ performance in experiment 2 yielded similar patterns. Specifically, color and texture appeared irrelevant to the tool’s functionality, whereas size and shape were relevant. These conclusions are based on the fact that in paired comparisons, color was favored over size and texture was favored over shape. Nonetheless, even changes in shape and size were tolerated, as tamarins selected such tools on a number of trials and successfully obtained food. Returning to Keil’s points, no single property or cluster of properties appears to be necessary in defining the object as a tool with a particular function, although some properties are clearly more important than others, they carry different weightings.

Further, one cannot account for the tamarin's performance by invoking an argument based on typicality or prototypes. For example, when they were presented with the original blue cane from experiment 1, but in an altered position that made it a convertible rather than a possible tool, they preferred the unfamiliar, and in some cases, atypical tool that was in a possible position. The pattern of results presented here not only parallel those discussed by Keil from verbal responses, but also those reported by Brown (1990) using a similar paradigm of tool use. Specifically, Brown finds that children as young as 18 months attend to functional properties of tools (e.g., hooked end for attaining a goal) and ignore irrelevant properties (e.g., color). Moreover, when they are forced to use tools that violate their understanding of physical causality, they are incapable of overriding their response tendencies.

Experiments 3 and 4 were designed to extend the results from experiment 2, exploring more completely what the tamarins learned about the task, the nature of their explanatory structures, and the extent to which success on the task was dependent upon certain features. Based on their performance, it is clear that the tamarins did not form a simple one-to-one mapping between a single object and a single function. The tamarins readily pulled all new objects, even though they varied on a number of dimensions, some of which were highly relevant to the means-end task and thus, the object's functionality. More surprisingly, especially given their lack of experience (both under natural conditions and in our laboratory) with tools, the tamarins appeared to have access to quite subtle distinctions between objects on the basis of their relative efficiency as a tool. Thus, they preferentially selected possible over convertible tools, even when the possible tool was novel and the convertible tool was familiar, but placed in a new configuration relative to the pellet. The primary difference between possible and convertible was that the latter required a novel motor action that was often more difficult than the action required in experiment 1. Moreover, when two convertible tools were contrasted, the tamarins tended to select the tool requiring the smallest change in motor response.

Based on these results, it appears that the tamarins have a better understanding of means-end/cause-effect relationships than the capuchins tested by Visalberghi and colleagues (reviewed in Visalberghi and Limongelli, 1996). Visalberghi and Limongelli (1996) conclude their work by stating that 'unlike children and at least some of the chimpanzees, capuchins do not 'know' why one tool is effective and another is not'. (p. 75). Our comparative claim, however, must be treated cautiously due to the different methodologies employed. If this species difference is real, it presents a fundamental paradox given the exceptional tool using abilities of capuchins in the wild and their general absence in tamarins. Significantly more work is needed before we can make sense of this apparent paradox.

In summary, the tamarins' performance reveals the following insights into their conceptual representations, and their knowledge of the functional properties of tools. The objects used in the means-end task were perceived as having design features suitable for the task at hand: to help access the food pellet. It is, of course, possible that the tamarins perceive such objects as having other potential purposes, but these experiments do not address this possibility. For a given purpose, some properties of the object are clearly more important than others, and this is relevant to

the point that some properties of tools have specific purposes whereas others do not. Thus, color is an irrelevant property of the tools used in this study, and changes in color did not effect performance. In contrast, shape changes are highly relevant, especially when such changes are evaluated relative to the position of the pellet. For example, when the hook of the cane is at the top and the pellet is on the inside of the hook, then this tool is functionally well designed for the task at hand; a straight pull on the stem readily brings the pellet closer. In contrast, when this same cane is inverted, placing the hook on the bottom, the tool is less well designed. Either the subject has to use the straight end to pull the pellet closer (this is difficult because there is no hook and thus, it is harder to control the pellet's movement) or, must flip the cane over so that the hook is on top, a difficult maneuver given the physical constraints of the test apparatus and the tamarins' dexterity.

Given that the tamarins understand some means-end relationships, can appreciate that more than one object may serve a similar function, and that some properties of a tool are causally relevant to the task at hand whereas other properties are irrelevant, are we licensed to conclude that tamarins have access to an artifactual kind representation? Certainly not if we adhere to some of the theoretical distinctions recently articulated by Keil (1994a,b, 1995) and Bloom (1996). For instance, Bloom argues that part of what it means to have the concept of an artifactual kind is this:

'We infer that a novel entity has been successfully created with the intention to be a member of artifact kind X – and thus is a member of artifact kind X – if its current appearance and potential use are best explained as resulting from the intention to create a member of artifact kind X'. (p. 17)

Assume for the moment that Bloom's characterization is correct. We have no evidence from the tamarins' performance that they make an inference about the creator's intention to craft an appropriate tool. But perhaps Bloom's definition is too restrictive. It certainly places an exceptionally strong bias toward species with language, who can query the creator and find out about his or her intention. Perhaps, then, we need to focus on the possibility that prior to having a concept of an artifactual kind that is linguistically laden, or at least enriched by language, there is a more primitive, non-linguistic concept of artifactual kind, one shared by human infants and non-human primates. The representational properties or content of this concept of artifactual kind would hold in the absence any understanding of the creator's intent.

Given the task presented, we are licensed to claim that the tamarins are capable of distinguishing between objects that have functional and non-functional (or, perhaps more appropriately, less optimal) design features. In this sense, they have a functional concept of artifacts. We do not know, however, whether they see such tools as falling within a particular artifactual kind X. Nor do our data allow us to address a second conceptual point raised by Bloom and Keil: because artifacts have particular design features, we naturally form intuitions about which features can be removed or broken, while nonetheless thinking that the object continues to hold its membership in the specific artifactual kind. Thus, if we take a wrist watch and remove the minute hand, we nonetheless conceive of it as a watch, though a slightly less useful one. The

minute hand plays a functional role and for telling minutes within the hour, a critical role. But removing the feature does not cause the object to lose its membership in the artifactual kind ‘watch’. Moreover, we can replace the minute hand and bring the object back to its full status as a ‘watch’ that tells hours and minutes.

To address some of these more difficult conceptual issues, other experiments are necessary. For instance, to determine whether the tamarins are bound to the particular stimulus situation, and to further assess whether they are capable of picking among an array of possible tool types, one could set up the following design. First, place a pellet on a tray, out of reach from the tamarin. Inside the tamarin’s test box, provide a tool kit of sorts, an array of possible tools for the job. This type of setup is indeterminate (in contrast with the quite determinate setup presented in the current experiment). It is quite like Kohler’s experiments where chimpanzees attempted to reach a hanging banana by using boxes and sticks, and Visalberghi’s work with capuchins where individuals attempted to extract food from inside of a tube. By altering the tool kit and the context in which they are presented with the opportunity to obtain food that is out of reach, we can begin to refine the class of objects that fall within a particular functional tool category. Second, one could train the tamarins to use a tool with complex design features, multiple parts that serve particular functions. In the next phase of the experiment, selectively remove specific parts of the tool that are either relevant or irrelevant to the task. Pair these manipulated tools and assess both which tools they select, and their reaction times to make a choice. The tamarins’ performance can then be used to determine which features are most salient and which manipulated tools are most similar to the original kind. Such experiments would provide further information on the range of features that can be removed or broken while preserving the essence of the tool’s functionality. Perhaps more importantly, they will enable us to assess the extent to which representing kinds depends on language (e.g., Bloom, 1996; Xu and Carey, 1996; Gopnik and Meltzoff, 1997), or can develop within the child, and evolve within a non-human species, in the absence of language.

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