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What Is Challenging About Tool Use? The Capuchin's Perspective

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Our fascination with the use of tools by nonhuman animals reflects a profound appreciation of the importance of tools to our own species. There is no doubt that the use of tools has empowered humans to diversify their way of life and to exploit resources not available to other primates. The paleontological and archaeological records show that changes in tools throughout human history reflect an accumulating mastery of physical relations and knowledge of natural processes. The tools themselves provide a record of human workmanship, and, from the earliest periods of human history, one of the best records from which to infer the behavior of our ancestors. Moreover, using tools is linked in our minds to intelligence; the emergence of tools in human history is thought to reflect the evolution of human intelligence.

Apart from the issue of intelligence, animals using tools interest biologists because tool use is a means by which an individual can expand available resources. For example, chimpanzees (*Pan troglodytes*) can open certain kinds of nuts only by cracking them with a stone. These nuts are a rich food source for the animals. Similarly, using a cactus needle, the woodpecker finch (*Cactospiza pallida*) can obtain prey not otherwise accessible. Although it is often an assumption, using a tool to solve an ecologically important problem (such as obtaining food or constructing shelter) is generally thought to confer an advantage over solving the same problem by some other means without using a tool, usually because the tool confers some mechanical advantage or some protection to the user.

We all understand what we mean by the word "tool" and by the phrase "using a tool." However, as is often the case for words and phrases used in everyday speech, these terms are actually too vague for scientific purposes. To determine whether and under what circumstances other species use tools, we need a more precise definition. Beck (1980) offered a widely accepted functional definition of tool use in his book *Animal Tool Behavior*, which is still the most complete catalog of tool use in animals. Beck states that "tool use is the external employment of an unattached environmental object to alter more efficiently the form, position, or condition of another object, another organism, or the user itself when the user holds or carries the tool during or just prior to use and is responsible for the proper orientation of the tool" (p. 10). To distinguish exploratory behaviors from tool use, we need to make a further distinction that must be inferred from the animal's behavior. Tool use requires that the agent pursue a goal. Exploration can lead to fortuitous discovery of how to use an object as a tool, but it is the purposeful repetition of that sequence of actions to reach a goal that is recognized as tool use.

As Beck (1980) shows convincingly, tool use is widely distributed across the animal kingdom; it is clearly not restricted to primates. However, it is thought that tool use is more flexible in format and more varied in function in primates than in other orders (Tomasello & Call, 1997). In the wild, tool use is widespread among chimpanzees, observed less often in orangutans (*Pongo pygmaeus*), and even less often in the other great apes (gorillas, *Gorilla gorilla*, and bonobos *Pan paniscus*), and capuchins (genus *Cebus*). Only wild chimpanzees use tools habitually, in varied formats, and for diverse purposes. However, all of these species use tools spontaneously and readily in captivity in flexible and diverse ways. Many other species of nonhuman primates occasionally use objects as tools (e.g., *Macaca tonkeana*: Ueno & Fujita, 1998; *Macaca fascicularis*: Zuberbühler, Gygax, Harley, & Kummer, 1996; *Macaca silenus*: Westergaard, 1988; *Papio papio*: Beck, 1973; see Beck, 1980, for review). But none are habitual users of tools, although they can easily be trained to use tools (*Macaca fuscata:* Hihara, Obayashi, Tanaka, & Iriki, 2003). Clearly, use of an object as a tool is challenging for all primates and an unusual accomplishment for most.

For many years, we have studied tool use and other features of manipulative behavior and problem solving in tufted capuchin monkeys (*Cebus apella*), the most adept and frequent users of tools among monkeys. In this chapter, we use capuchins as a vehicle to discuss tool use in nonhuman primates. After providing some background on capuchins and an overview of the forms and contexts of tool use commonly observed in this genus, we review experimental studies focusing on the number and kind of relations among object, substrate, and actions required to use an object to achieve a goal. This section is framed in terms of a particular view of tool use that we believe holds promise for a broad understanding of the phenomenon as a particular kind of perceptual-motor challenge.

To the best of our knowledge, capuchins learn to use tools in much the same way that other species do. Understanding how they learn to use tools, and the aspects of using tools that challenge them, gives us a new understanding of tool use in our own species as well as other species of nonhuman animals. Finally, to better understand why captive capuchins readily use tools, but capuchins in the wild rarely do so, we discuss the behavioral and environmental factors that promote and constrain the occurrence of tool use in these monkeys.

CAPUCHIN MONKEYS

Capuchin monkeys have been popular subjects for research in the laboratory as well as in the field (see Fragaszy, Visalberghi, & Fedigan, 2004, for a review). They are robustly built monkeys weighing between 2.5 and 5 kg. Capuchins are named for the distinctive caps on their crowns that appear in various colors and shapes in different species. They have an unusual life history: capuchins live an anomalously long time (up to 55 years in captivity), and they have a long period of maternal care and immaturity. A large ratio of brain size to body size also distinguishes capuchins from other monkey species. Capuchins live in groups ranging from around 10 to more than 40 individuals that contain one or more adult males, several adult females, and immatures. In general, each group contains a clearly dominant male and female. Although group members can be assigned to different dominance classes, social relations are characterized by a high degree of tolerance among individuals.

Capuchins are very widely distributed in Central and South America, ranging from Honduras to the north of Argentina and from Peru to the Atlantic coast of Brazil. Such a wide distribution is possible because they can thrive in a variety of habitats. They spend most of their time in trees. However, in response to local conditions, they may also spend time feeding on the ground (including raiding crops), drinking, playing, or moving across open ground between patches of forest.

Capuchins are omnivores. They eat mostly fruits but include varying portions of other vegetable items (leaves and shoots, flowers, buds, etc.), invertebrates (mollusks, insects, worms, etc.), and vertebrates (birds and their eggs, small mammals, lizards, etc.) in their diet. Many other South American monkeys eat the same items as capuchins, but what distinguishes the latter is their destructive manner of foraging. Capuchins are renowned as extractive foragers, meaning that they exploit hidden and encased foods. Their foraging behavior is distinctive for its inclusion of a large variety of strenuous actions (e.g., dig, rip, bite, bang, grab, break; see figure 27.1) as well as dexterous and precise ones (e.g., pull or pick with precision grip, scoop, open by peeling).

One particular form of strenuous foraging activity typifies wild capuchins: breaking open hard-shelled fruits, nuts, and invertebrates. *C. apella* repeatedly bang the shelled item against a tree

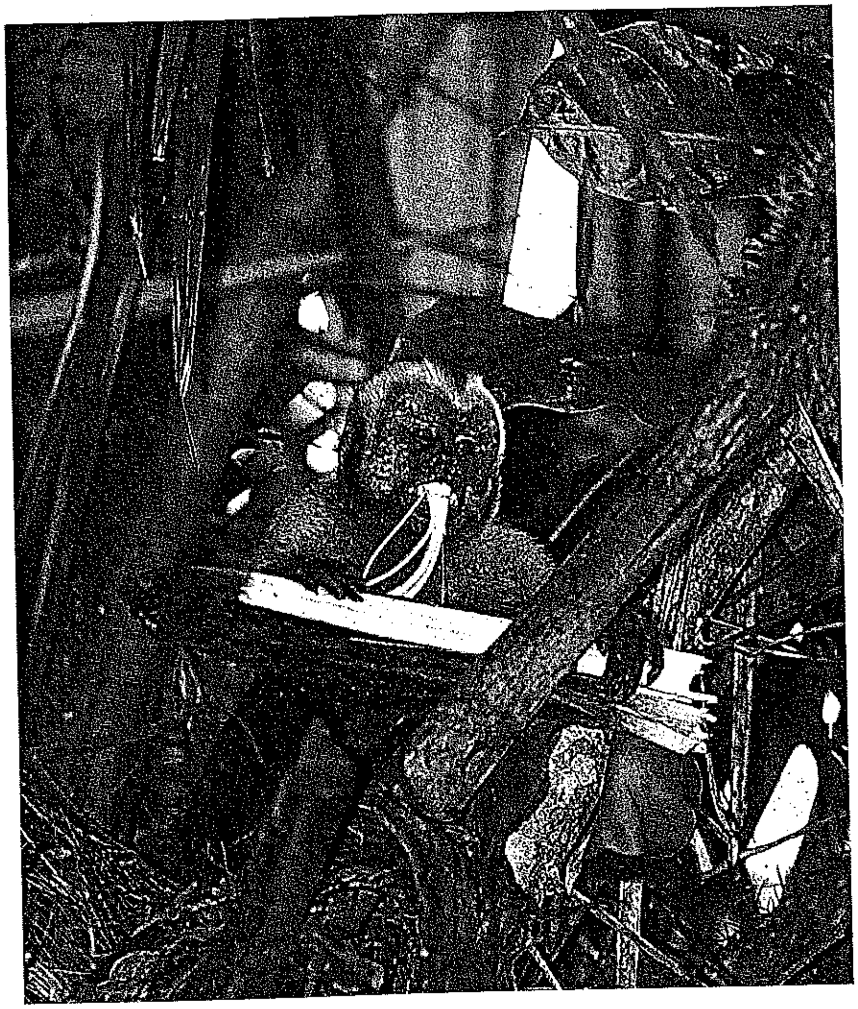

Figure 27.1. Manu National Park, Peru. An adult male *C. apella* strips pieces from a branch using strong arms and teeth. (Photograph courtesy of Charles Janson.)

trunk or other hard surface until cracks appear in the shell. Then, they peel or remove the cracked rind with the teeth and hands or bang the nut or shell again until the husk breaks and the flesh or kernels can be extracted.

Capuchins are comparable to other species of monkeys in their achievements in tasks commonly used to assess memorial, attentional, and conceptual abilities (e.g., Piagetian sensorimotor tasks, various discrimination, matching, and conceptual learning tasks, as well as social cognition tasks; Adams-Curtis, 1990; Anderson, 1996; Antinucci, 1989; D'Amato & Salmon, 1984; De Lillo & Visalberghi, 1994; see Tomasello & Call, 1997, and Fragaszy, Fedigan, & Visalberghi, 2004, for a comparative review). However, their engagement with objects is unique. Captive capuchins of all ages devote considerable attention, time, and energy to manipulating objects; moreover, they frequently combine objects and surfaces in actions (e.g., bang objects on surfaces and poke objects into surfaces), leading to fortuitous spontaneous discoveries and innovations.

HISTORICAL OVERVIEW OF TOOL USE REPORTS

The Complete Capuchin (Fragaszy, Fedigan, et al., 2004, chap. 10) contains the most updated and exhaustive information on the tool using skills of capuchins. The use of tools has been observed mainly in captive capuchins; the first report dates back about 500 years. The Spanish naturalist Gonzalo Fernández de Oviedo y Valdés (de Oviedo, 1526/1996, cited by Urbani, 1998) was the first to describe a capuchin monkey cracking open a nut with a tool. Hundreds of years later, Erasmus Darwin, the grandfather of the more famous Charles Darwin, observed this same behavior in a park in London (Darwin, 1794). A century later, naturalists and psychologists began to report serendipitous observations as well as systematic studies of captive capuchins using tools (e.g., Klüver, 1933, 1937; Nolte, 1958; Romanes, 1883/1977; Watson, 1908; for further details, see Beck, 1980; Fragaszy, Fedigan, et al., 2004; Visalberghi, 1990). At this point, it became clear that these South American monkeys were capable of using many different tools to reach many different goals (sticks to rake/push/insert, hard objects to crack open nuts, etc.).

According to Hill (1960), Buffon writes that Dampiér (1697) provided the first report of tool use by wild capuchins (living on the island of Gorgona off the coast of Colombia) cracking open mollusks by banging them on the rocks or using a stone as a tool to smash the shells. Note that according to Beck's definition (1980), only the latter case can be considered tool use. However, Dampier merely wrote that the monkeys ate mollusks by digging them out of the shells. Unless different editions of the book contain different information, the earlier references to Dampier reporting tool use were apparently in error. In other words, Dampier did not report that he saw wild capuchins using tools. Although there are second-hand reports of capuchins using pounding tools (e.g., Hernández-Camacho & Cooper, 1976), Fernandes (1991) published the first report of direct observation of tool use by wild capuchins. Fernandes described, 300 years later, what Buffon and Hill erroneously attributed to Dampier: a wild capuchin using a broken oyster shell to strike oysters still attached to the substrate, successfully breaking them open. Another instance of tool use by wild *C. capucinus* was carefully documented by Boinski (1988); she observed a male killing a snake by hitting it with a branch obtained from nearby vegetation.

In a photograph report that appeared in the popular press, Oxford (2003) documented a group of wild *C. apella* in the "cerrado" habitat of Brazil that feed routinely on the nuts of the Attalea palm. He photographed these monkeys opening the hard nuts by first placing them on a large stone and then pounding them with stones that often weighed more than a kilogram. Prompted by his astonishing photos, we conducted an exploratory investigation in this same area (Fragaszy, Izar, Visalberghi, Ottoni, & Gomes de Oliveira, 2004). Direct observation of several instances of tool use by wild capuchin monkeys (male and female) convinced us that the phenomenon was indeed a legitimate discovery. In surveying the surrounding area, we found indirect physical evidence that monkeys cracked nuts on numerous rock outcrops, boulders, logs, and even the tops of mesas. The abundance of shell remains and depressions in the anvil surface at numerous anvil sites indicate that nut-cracking activity is common and long enduring. The presence of abundant anvil sites, limited alternative food resources, the abundance of palms, and the fact that the palms in this region produce fruit at ground level all likely contribute to the monkeys' routine exploitation of palm nuts via cracking them with stones. In our opinion, ecologically and behaviorally, capuchins' nut-cracking appears to parallel nut-cracking observed in wild chimpanzees. Further systematic long-term studies are needed.

In the last two decades of the last century, a surge of interest in capuchins' tool use developed that continues to the present. This increased interest was partly inspired by Parker and Gibson's (1977, 1979) argument that higher forms of intelligence evolved as an adaptation for extracting embedded food resources. Pursuing this idea, some researchers investigated the development of tool-using behaviors in young individuals as well as the achievements of adults within a Piagetian framework (Chevalier-Skolnikoff, 1989, 1990; K. R. Gibson, 1990; Natale, 1989; Parker & Potì, 1990). Others (e.g., Anderson, Fragaszy, Visalberghi, & Westergaard—see table 27.1 for references) undertook studies to clarify (1) how behavior, morphology, and cognition contribute to the emergence of tool use, (2) the range of capuchins' tool use, (3) the extent to which social influences affect individuals learning to use objects as tools, (4) the flexibility of tool use with varying objects and surfaces, and (5) what this flexibility means about underlying comprehension of the task. Recently, reports of tool use by wild or semifree capuchins carried out in the capuchins' natural habitats have appeared (e.g., Jalles-Filho, da Cunha, & Salm, 2001; Ottoni & Mannu, 2001; Rocha, dos Reis, & Sekiama,

Table 27.1 Recent Studies on Tool Use in Capuchins, Chronologically Ordered

Task	Relational Category[a]	Specific Aim(s) of the Study	No. of Tool Users/No. Total[b]	Species	Source
Studies in Captivity[c]					
Nut cracking	First dynamic	Selection among differently effective tools	1/6	*C. apella*	Antinucci & Visalberghi, 1986
Nut cracking	First dynamic	Acquisition of the behavior and social learning	2/42	*C. apella*	Visalberghi, 1987
Dipping	First static	Acquisition of the behavior and social learning	6/9	*C. apella*	Westergaard & Fragaszy, 1987a
Sponging	First static		9/9		
Stick directed to a wound	First static	Serendipitious observation	n.a.	*C. apella*	Westergaard & Fragaszy, 1987b
Stick directed to a wound	First static	Serendipitious observation	n.a.	*C. apella*	Ritchie & Fragaszy, 1988
Raking/digging/probing	Ambiguous description	Observational study	n.a./12	*C. apella* *C. albifrons*	Chevalier-Skolnikoff, 1989
Nut cracking	First static	Social influences on tool use acquisition	5/20	*C. apella*	Fragaszy & Visalberghi, 1989
Stick to push	First static		5/20		
Stick to rake	First dynamic	Sensorimotor intelligence	3	*C. apella*	Natale, 1989
Stick to push a reward out of a tube	First dynamic	Appreciation of how the tool should be modified	3/4	*C. apella*	Visalberghi & Trinca, 1989
Nut cracking	First dynamic	Benefits in terms of time and success due to the use of tools	5/6	*C. apella*	Anderson, 1990
Stick to rake	First dynamic	Sensorimotor intelligence	3/5	*C. apella*	Parker & Potì, 1998
		Developmental	1		
Sticks to push a reward out of a tube	First dynamic	Selection of the appropriate tool	4	*C. apella*	Visalberghi, 1993
Nut cracking and probing	First static	Sequential use of tools (tool-set)	3/9	*C. apella*	Westergaard & Suomi, 1993
	First static				
Probing	First static	Selection of the appropriate tool	2	*C. apella*	Anderson & Henneman, 1994
Dipping	First static	Tool acquisition in juveniles and influence of the context	3juv/9juv	*C. apella*	Fragaszy, Fedigan, et al., 1994
Nut cracking	First static		3juv/9juv		
Stick to push a reward out of a tube	Second simult.	Understanding of cause-effect relations	4	*C. apella*	Visalberghi & Limongelli, 1994
Aimed throwing	First static	Modeling early hominid technology	4	*C. apella*	Westergaard & Suomi, 1994a
Stone flaking	First dynamic	Production of flakes	6/11	*C. apella*	Westergaard & Suomi, 1994b
Stones as cutting tools	First static	Stones as cutting tools	3/15		
Bone modification due to the use of tools	First static	Modeling early hominid technology	5/10	*C. apella*	Westergaard & Suomi, 1994c

(continued)

Table 27.1 (*Continued*)

Task	Relational Category[a]	Specific Aim(s) of the Study	No. of Tool Users/No. Total[b]	Species	Source
Nut cracking	First static	Use and modification of bone tools	3/9	*C. apella*	Westergaard & Suomi, 1994d
Bone fragments as cutting tools	First static		3/9		
Stick to displace a reward out of a tube	First dynamic	Comparison with apes	6	*C. apella*	Visalberghi et al., 1995
Dipping	First static	Modeling East Asian hominid bamboo technology	5/18	*C. apella*	Westergaard & Suomi, 1995a
Cutting	First static		6/18		
Digging tools	First static	Modeling hominid subsistence technology	4/10	*C. apella*	Westergaard & Suomi, 1995b
Stone throwing	First static	Modeling hominid throwing capabilities	4	*C. apella*	Westergaard & Suomi, 1995c
Pestle use	First static	Use of different objects as pestle	10/18	*C. apella*	Westergaard et al., 1995
Nut cracking	First static	Modeling hominid metal-tool technology	5/14	*C. apella*	Westergaard et al., 1996
Cutting	First static		5/14		
Stones as cutting tools	First static	Transfer of tools and food	3/11	*C. apella*	Westergaard & Suomi, 1997
Ant gathering	First static	Use of sticks to extract ants	7/14	*C. apella*	Westergaard et al., 1997
Stones as cutting tools	First static	Use of a tool-set	3/14		
Nut cracking	First static	Use of color chips to request tools	1	*C .apella*	Westergaard, Chavanne, et al., 1998
Dipping	First static				
Dipping	First static	Role of sex and age on tool use acquisition	21/36	*C. apella*	Westergaard, Lundquist, et al., 1998
		Factors associated with tool use and modification	31/61		
Container for water	First static	Serendipitious observation	1/11	*C. olivaceus*	Urbani, 1999
Sponging	Zero		1/11		
Stick as cane	NA		1/11		
Bait for fishing	First static	Observational study	4/6	*C. apella*	Mendes et al., 2000
Cracking open a baited box	First static	Modeling hominids' behavioral evolution and the transport of tools	8/13	*C. apella*	Jalles-Filho et al., 2001
Transport tools to the box			1/13		
Transport tools to the nuts and nut cracking	First dynamic		7/8		
Dipping	First static	Influence of task location of tool use	2/4	*C. olivaceus*	Dubois et al., 2001
Tool choice, obstacles, and traps	First dynamic and second simult.	Selection of the appropriate tool and understanding of cause-effect relations	4	*C. apella*	Fujita et al., 2003

Table 27.1 *(Continued)*

Task	Relational Category[a]	Specific Aim(s) of the Study	Condition	No. of Tool Users/No. Total[b]	Species	Source
Studies in Semifree and Wild Conditions[d]						
Throwing, probing	NA[e]	Observational study	W	NA/21	*C. capucinus*	Chevalier-Skolnikoff, 1990
Pounding to open oysters	First static	Serendipitious observation	W	NA	*C. apella*	Fernandes, 1991
Exploratory probing	First static	Serendipitious observation	W	NA	*C. capucinus*	Garber & Paciulli, 1997
Nut cracking	? Second sequential	Serendipitious	W	NA	*C. apella*	Langguth & Alonso, 1997
Nut cracking for inside larvae	Second sequential	Use of suitable pounding tools and anvils	S-F	no data/44	*C. apella*	Rocha et al., 1998
Dipping	First static	Selection and modification of tools	S-F	3/11	*C. apella*	Lavallee, 1999
Nut cracking	Second sequential	Search of suitable anvil and pounding tools	S-F	15/18	*C. apella*	Ottoni & Mannu, 2001
Leaves to absorb liquid	Zero	Serendipitious observation	W	NA	*C. albifrons*	Phillips, 1998
Branches to kill a snake	First static	Serendipitious observation	W	NA	*C. capucinus*	Boinski, 1988
Nut cracking[f]	? Second sequential	Observational study	W	NA	*C. apella*	Boinski et al., 2001
Stick to push	First dynamic	Acquisition of tool use by providing a tool task	W	0/15	*C. capucinus*	Garber & Brown, 2004
Nut cracking	Second sequential	Use of pounding tools and anvils	W	Several	*C. apella*	Oxford, 2003; Fragaszy, Izar, et al., 2004

[a]Relational categories are defined in table 27.2 according to the number (zero, first, or second order) and type of relations (static and dynamic) embodied in the task. We include a few cases reported in the literature as tool use involving a zero order relation that do not fit our criterion of tool use.

[b]Number of individuals using tools and total number of individuals tested. When there is only one value, it means that the study focussed only on those subjects. NA = not applicable, meaning that the information is not provided by the author(s).

[c]Captivity includes cages, outdoor enclosures, and small islands.

[d]In semifree ranging (S-F) conditions, the animals have access to large areas from which they obtain a substantial part of their food. W = wild.

[e]In our view, the instances described are not cases of tool use. Most of them refer to explorative behaviors and to dropping branches.

[f]Boinski et al., 2001, did not actually see the capsule of the *Couratari oblongifolia* open or the capuchin bring its content to the mouth.

Note: From *The Complete Capuchin*, by D. Fragaszy, L. Fedigan, and E. Visalberghi, 2004, Cambridge: Cambridge University Press. Updated with permission of the publisher.

1998), and, as mentioned, we have observed wild capuchin monkeys cracking open palm nuts using stones and anvils (Fragaszy, Izar, et al., 2004). Table 27.1 provides a list of published reports on tool use in capuchins from 1980, the vast majority of which (about two-thirds) refer to studies carried out in captivity. Instead of reviewing the above studies (for this, we direct interested readers to Fragaszy, Fedigan, et al., 2004), we describe only a few of them to illustrate the types of tool-using problems that capuchins master readily and the types that are more challenging for them.

A PERCEPTION-ACTION VIEW OF TOOL USE

Before we review research reports, we need to present and explain our particular treatment of tool use. The definition of tool use from Beck (1980) that we quoted at the opening of the chapter is sufficient to identify tool use across a broad spectrum of species and contexts, as it was intended to do. However, this definition still leaves ambiguous the status of some actions. Consider the case where an individual rubs a substance on the body (called "anointing" in monkeys; e.g., Baker, 1996), presumably because the astringent substance feels good on the skin (and also because it likely provides insecticidal or antibacterial protection; Valderrama, Robinson, Attygalle, & Eisner, 2000). In this case, the actor, to paraphrase Beck's definition, uses a material (an unattached environmental object) to alter the condition of its skin while the user holds or carries the material during use and the user is responsible for the proper orientation of the material. However, several elements are not clear: for example, whether rubbing something on the body counts as orienting a material. Given this ambiguity, we do not classify anointing as tool use.

Beck's functional definition presents a further problem for us: Namely, it is meant only to distinguish tool use from other categories of action. But, identifying an action as tool use does not help to evaluate the relative complexity of the action; thus, it does not help to establish whether or why some forms of tool use are more challenging than others. For this purpose, we need a principled psychological framework of tool use.

We can think about tool use in terms of the relations among objects, surfaces, effectors, and movements that must be recognized or produced to achieve a goal.[1] This framework was first explicated by Lockman (2000) in a discussion of the origins of tool use in human infancy through exploratory action with objects and surfaces. In this framework, the actor, through common exploratory actions in the species-typical behavioral repertoire (Lockman refers to these as "perception-action routines"), (a) discovers the properties of objects and surfaces, and the consequences of combining them in various ways, (b) learns to recognize and manage the mobile spatial frames of reference that govern the relation of body, objects, and surfaces to each other, and (c) practices modulating actions to achieve particular consequences. Thus, combinatorial exploration leads to tool use.

An important element in this framework is that the actor produces information through action that guides subsequent activity, and action and perception occur in inextricably linked cycles. This insight applies to all action, as explicated by J. J. Gibson (1966, 1979; see E. J. Gibson & Pick, 2000). In this view, the actor must produce at least one needed relation between one object and another object or a surface in order for the action to qualify as tool use. Merely recognizing the appropriate relation, but not producing it, is not tool use.

To make this point clearer, consider the following example. A dog attending closely to a bicycle or to a stone is using neither the bicycle nor the stone as a tool. These objects become tools only when they are used for reaching a goal (traveling efficiently or cracking open a nut) and only when the actor is responsible for producing the relevant relation. Even if the dog has gone on runs with its owner riding the bicycle or received nuts after its owner cracked them, so that it anticipates a fast run or bits of nuts when these objects are present, the dog is not yet a tool user. Similarly, preferential attention toward one of two (or more) objects or choice of an object (Fujita, Kuroshima, & Asai, 2003; Hauser, 1997; Povinelli, 2000; Santos, Miller, & Hauser, 2003) may inform us about the actor's recognition of spatial relations that are relevant for tool use, but attention and choice are not tool use.

TOOL USE IN CAPUCHINS

To be conservative, we focus on cases in which capuchins use objects to achieve a tangible goal (thus ruling out banging to make noise and anointing the body with material with no clear immediate goal, among other actions). Moreover, we add to the definition of tool use given here (using an object as a functional extension of the body to act on another object or surface) the requirement that the actor itself produce a relation between the tool and another object or surface, and not simply use a preexisting relation (labeled as zero-order relations in table 27.2). This definition excludes some situations that others commonly include as examples of tool use, such as pulling in a cane where the curve of the cane already surrounds a piece of food when the actor arrives on the scene. In our scheme, the monkey itself has to place the cane in relation to the food (producing a first-order relation) for the action to be classified as tool use.

An animal may not use a tool consistently in all contexts; it may use a tool to solve one task but be unable to use it to solve another. What determines the difficulty of a tool-using task? According to the perception-action framework, the number and kind of relations among objects, surfaces, and movements that must be recognized or produced to achieve a goal determine the complexity of a tool-using task (see table 27.2).

Table 27.2 Relations Produced Through Action With an Object That Are Evident in Capuchins' Use of Tools

Relational Category	Definition	Examples
Zero Order		
	Act on one object; action on second object occurs by default.	Pull in a cane positioned with food inside the hook and the straight part of the cane within reach. Pull in cloth with food on the cloth.
First Order		
Static first-order relations	Acting with an object on a fixed surface (or on a fixed object) to reach the goal.	Probe into an opening with a stick ("dip"). Pound a stone on a nut fixed on a surface.
Dynamic first-order relations	Acting with an object A in relation to an object B that moves. Because action with A alters the state of B, B must be monitored as action progresses.	Push food out of a tube with a stick. Pull in an object with a stick when they are not already positioned so that pulling is effective. Pound a loose nut with a stone.
Second Order		
Sequential second-order relations	Acting with an object A in relation to object B following placement of object B in relation to a third object C (surface or object). In this case, one static relation between B and C and then one dynamic relation between A and B are produced.	Pound a stone against a nut placed on a second stone.
Simultaneous second-order relations	Acting with an object A in relation to object B while maintaining B in relation to C (surface or object). In this case two dynamic relations (between A and B, and between B and C) are coordinated simultaneously.	Push food through tube with a stick while avoiding a hole. Pull food with a rake across a surface with a hole. Pound a stone against a nut on an anvil surface while holding the nut (to prevent the nut from falling off the anvil).

Note: In our view, an action involving a zero-order relation is not tool use; tool use requires producing a first-order relation. Order refers to the number of relations between objects and surfaces that are required to reach the goal, and not to the number of actions in a sequence.

We recognize two types of spatial relations here: static and dynamic. Static relations are produced once, such as placing a nut on a specific surface. Dynamic relations must be maintained through time, such as holding a nut on an inclined surface or keeping an object behind the blade of a hoe while sweeping it laterally. Other thing being equal, a dynamic relation is more difficult to achieve than a static relation, because it requires continuous monitoring. The boundary between static and dynamic relations may not always be clear (for example, the case of a nut placed on an inclined stone), but it is still useful, we think, to keep this dimension of action in mind when thinking about a particular tool problem.

First-Order Problems (Single Relations)

Captive capuchins are often successful in tasks where they must produce a single static spatial relation. Probing into an opening with a stick or pounding a nut or other object fixed to a surface (see figure 27.2, top left and right) are examples of actions embodying static first-order relations. Dipping and banging are very common actions performed frequently by all capuchins. Actions producing dynamic single relations are also fairly common, such as pushing or pulling an object with a stick (figure 27.2, bottom left). Pounding a loose nut with a stone can involve a static relation if the nut remains where it is placed without support (see figure 27.2, bottom right) or a dynamic relation if the object slips unless supported.

A dipping/probing task is a good example of a tool-using task involving a single static relation that has been used many times with captive capuchins (see figure 27.2, top left). In this task, a container is filled with a viscous food (e.g., syrup, applesauce, yogurt) or ants (Westergaard, Lundquist, Kuhn, & Suomi, 1997) that can be retrieved through an opening that is too small for a capuchin's hand. The container is fixed to a rigid surface and suitable objects (stick, straw, dowels, and branches from which smaller pieces can be used) are presented. Capuchins master this task before their first birthday (Westergaard & Fragaszy, 1987a; Westergaard, Lundquist, Haynie, Kuhn, & Suomi, 1998) or shortly thereafter (Fragaszy, Vitale, & Ritchie, 1994).

In a variation of this task, capuchins struck an acetate film with sharp-edged stones and cut an opening into a closed food container (Westergaard & Suomi, 1994b). When sticks to probe with are not readily available near the apparatus, capuchins collect them from somewhere out of view and bring them to the work site (Fragaszy & Visalberghi, 1989; Lavallee, 1999; Visalberghi, 1987). Planning is implied by the collection of tools distant from the work site (see also Jalles-Filho et al., 2001).

Once capuchins have learned to dip for food, they do not forget how to do this, even after several years. For example, two capuchins that learned to dip for syrup, dipped years later when given similar opportunities, although the setting was completely different (from indoor to semifree conditions) (Lavallee, 1999). However, applying a strategy successfully adopted in the past is not necessarily efficient for the task at hand. Figure 27.3 shows a female tufted capuchin that years before had used sticks to dip for syrup. Now, she has an opportunity to work for a new food item, a walnut. She is holding a straw and touching the shell of the walnut with it. Clearly, dipping will not work in this context. In this case, the monkey will have to abandon the remembered action—object combination and learn new ones. It is evident from this example that capuchins do not always appreciate the appropriate elements of a task in the same way as an adult human observer.

SECOND-ORDER PROBLEMS (TWO RELATIONS)

Inserting a stick into an opening is a fairly probable action for capuchins, as their success in dipping tasks suggests (see earlier). Capuchin monkeys also readily discover that after they insert a stick into a horizontal tube, they can push food out of the tube using a stick (figure 27.4). Pushing food through a tube requires producing one static relation (inserting the stick into the tube) and then one dynamic relation (a sustained push on the food with the stick).

Visalberghi and Trinca (1989) used a transparent tube, which allowed the experimenter and subject alike to view the food inside and to see the tool entering the tube, to study the tool-using behavior of four tufted capuchin monkeys. The monkeys mastered this problem within 101 min without any training or demonstrations. This general finding has been replicated with other capuchins and other primate species (for a review, see Visalberghi, 2000).

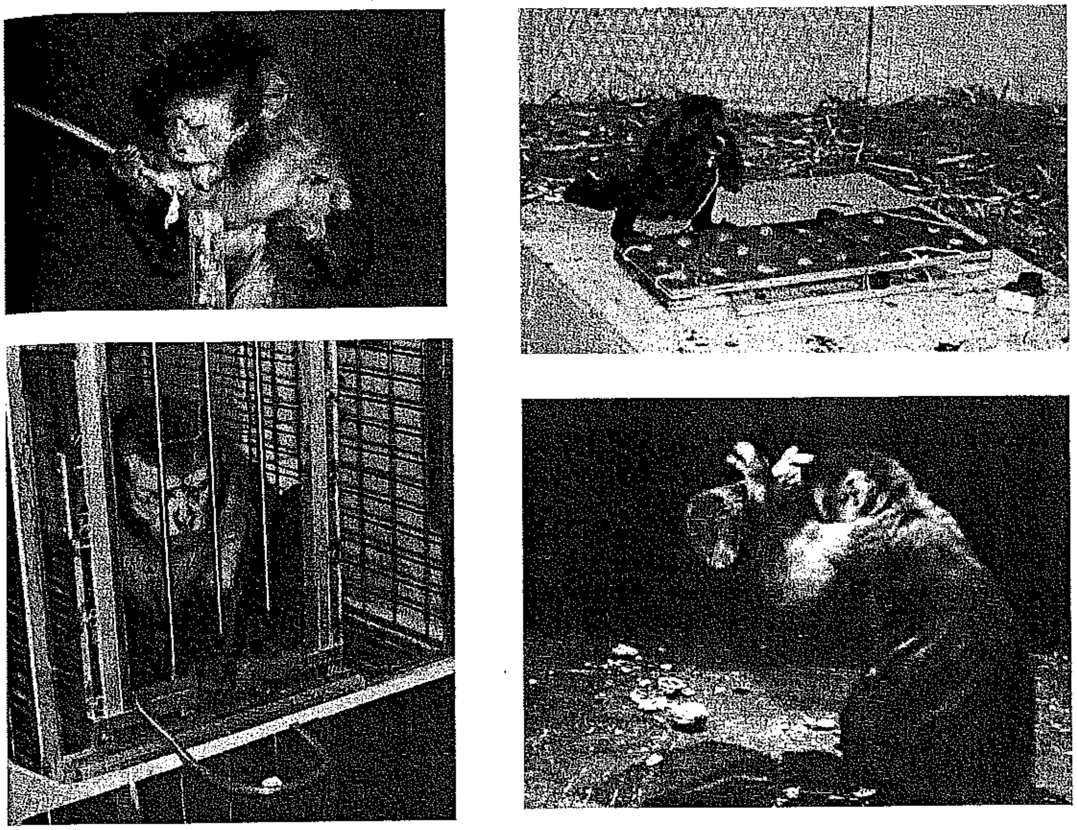

Figure 27.2. *Top left,* Adult female tufted capuchin dips for applesauce while holding her newborn infant in one arm. She holds the stick with a power grip. (Photograph courtesy of Elisabetta Visalberghi.) This is an example of producing a static first-order relation; see table 27.2. *Bottom left,* Tufted capuchins use a C-shaped tool to retrieve a reward. Once the monkey has placed the hook around the food, the task becomes easy, but the monkey must still monitor that the food remains within the hook of the tool as it slides across the surface. This task involves producing a dynamic first-order relation. (Photograph courtesy of S. Cummins-Sebree.) *Top right,* Juvenile uses a metal object to crack open a walnut glued in the wooden board. (Photograph courtesy of Elisabetta Visalberghi.) This is an example of producing a static first-order relation. *Bottom right,* Adult male effectively cracks open a nut by striking it with a log, demonstrating skillful use of a tool (from video by Elisabetta Visalberghi). This involves a static first-order relation if the nut remains stationary during the cracking process. If the nut must be supported to prevent it from moving (not shown), this is an additional, dynamic relation that the actor must produce.

The four monkeys tested by Visalberghi and Trinca (1989) subsequently encountered the same tube apparatus in three new conditions in which the tools had to be modified before use or used in succession (see figure 27.4). In one condition, the object (a bundle of thin canes held together by tape) was too large in diameter to fit into the tube. In another condition, the stick had thin pieces of dowel, inserted transversely at each end, so that the ends of the stick could not enter the tube. To insert the stick into the tube, the dowel had to be pulled out or broken off. In the third condition, the sticks were so short that two of them had to be inserted one behind the other inside the tube in order to move the food far enough for the monkey to reach it. The capuchins succeeded under all conditions within a few minutes. Despite their success, they made many attempts to use the original object without modifying it and to use parts of the object (e.g., the tape, a splinter; see figure 27.4) that did not have the necessary properties (e.g., rigidity, length) to displace the food from the tube. Over the 10 trials in each

Figure 27.3. An adult female tufted capuchin, proficient in using straw for dipping syrup, touches a nut glued on a wooden board with a straw, using the same action that she used previously to retrieve syrup from a closed container. She ignores the adjacent hard objects (one shown in the foreground) that could be used effectively to crack open nuts. Striking a nut glued in place would be producing a first-order static relation. (Photograph courtesy of Elisabetta Visalberghi.)

condition, the number of errors produced by each monkey and the nature of their errors decreased only slightly. After an interval of 5 years, when these same capuchins encountered these objects and the tube again for a filming session, they made the same kinds of errors (Visalberghi & Limongelli, 1992). These findings indicate that the monkeys did not quickly learn what properties of the objects, surfaces, and actions were most important for success, and they were willing to produce multiple actions in sequences in attempts to solve the problem.

In another experiment, the same four capuchins were given a choice among four different objects to use to push food out of the tube (Visalberghi, 1993). Three of the objects could not be inserted or would not reach the food (one was too thick, one was too short, and one had a transverse block at one end that prevented its insertion), whereas the fourth was the appropriate diameter and length. Although they made a few wrong choices throughout the 16 test trials, all the capuchins selected the correct tool far more often than would be expected by chance. Similarly, Anderson and Henneman (1994) found that capuchins selected an appropriate object for dipping from among an array of appropriate and inappropriate objects. It appears that recognizing an appropriate object to insert is easier for monkeys than modifying an object appropriately beforehand.

Cracking open a nut sometimes requires managing two spatial relations in succession. For example, if the nut is loose and most of the ground surface is relatively soft but hard objects are present, the monkey can use one hard object as an anvil and another to pound. Positioning the nut on a specific hard surface (an anvil) is the first spatial relation; pounding the nut with a hard object is the second. The monkey must often hold the nut in place to make sure that it stays on the anvil as it is struck, adding a dynamic element to the first of the two relations.

Capuchins, in semifree conditions, crack nuts placed on an anvil from about 2 years of age (Ottoni & Mannu, 2001; Resende & Ottoni, 2002; Rocha et al., 1998). And, as noted, in Piauí (Brazil), wild *C. apella libidinosus* (or *Cebus libidinosus* according to the more recent classification of the genus by Groves, 2001; Rylands, Schneider, Mittermeier, Groves, & Rodriguez-Luna, 2000;

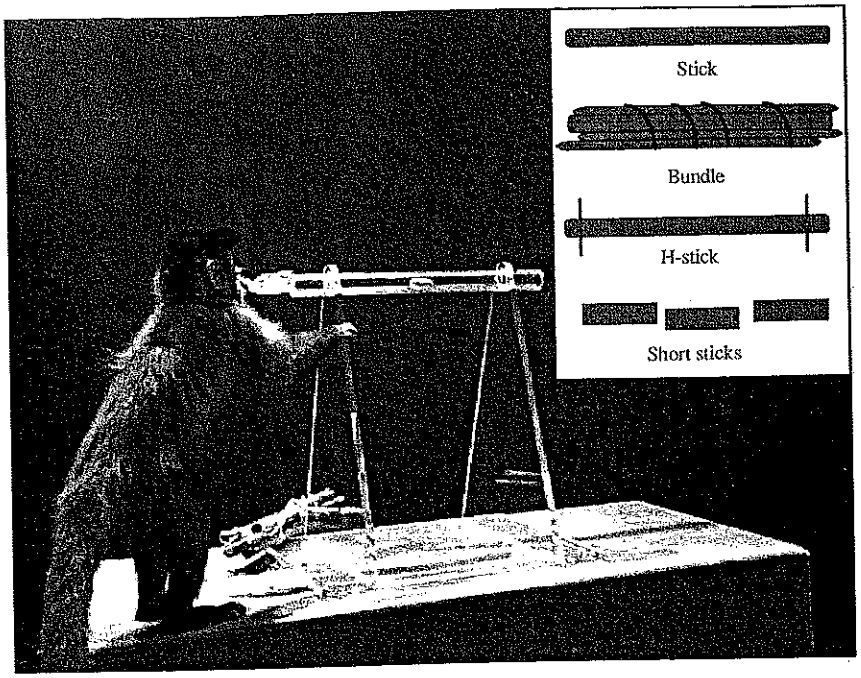

Figure 27.4. The tube task consists of a transparent horizontal tube baited in the center with a food treat. Pushing food through a tube requires producing one static relation (inserting the stick into the tube) and then one dynamic relation (a sustained push on the food with the stick). The objects provided to the subject that can be used as tools are shown in the *top right* of the figure. (From *top* to *bottom*) A stick that can be used to push the treat out of the tube. A bundle consisting of several reeds firmly held together by tape; the diameter of the intact bundle is too large to fit into the tube. The H-stick consisting of a dowel with two smaller sticks placed transversally near the end; the transverse sticks block the insertion of the dowel into the tube. Short sticks at least two of which must be inserted into the tube one behind the other to displace the reward. (Drawing by S. Marta.) The capuchin in the figure has dismantled the bundle of reeds (visible at her feet) and is inserting the tape, not a reed, into the tube. Errors of this type (selecting inappropriate objects as tools) are common in capuchin monkeys. (Photograph courtesy of Elisabetta Visalberghi.)

see also Fragaszy, Fedigan, et al., 2004) routinely open hard nuts with tools (Fragaszy, Izar, et al., 2004). This appears to be a very promising setting in which to study tool use in wild capuchins, as Matsuzawa and colleagues have done with wild chimpanzees (Inoue-Nakamura & Matsuzawa, 1997; Matsuzawa, 1994; Matsuzawa et al., 2001).

It is clear that capuchins are capable of solving a variety of different tasks requiring first- and second-order relations, more so than monkeys of other genera tested so far. However, in most studies with captive capuchins, not all individuals were successful at any particular task (e.g., Westergaard et al., 1998). Some individuals ignored the task, whereas others, although they explored the context, did not solve the task, even if they had many opportunities to watch others using an object and obtaining food. In contrast, many of the wild tufted capuchin monkeys observed by Fragaszy, Izar, et al. (2004) cracked open nuts (Marino Gomes de Oliveira, personal communication), and all individuals except infants cracked nuts in Ottoni and Mannu's (2001) study.

Several factors may account for more consistent use of tools to obtain food by individuals in seminatural or natural groups than in captive groups. More frequent exposure to the task over a longer period of time, exposure to the task from an early age, richer social context, and greater motivation in obtaining food are some of the more obvious ones (see Fragaszy & Visalberghi, 2004, for discussion of variables that affect learning in social settings). In most of the laboratory studies, the tool task is presented for a limited duration and a limited number of times, sometimes with few or no companions present, and the monkeys are typically well nourished and fully adult when they first encounter the task. In a natural setting, the task (embedded food to open) is present daily for weeks or months, for year after year. All individuals have repeated opportunity and a strong interest in obtaining the food, and materials are distributed in space and cannot be monopolized by any single individual. In other words, whereas the experimental data reflect cross-sectional testing, field observations reflect longitudinal exposure.

Moving Objects Across Irregular Surfaces: An Extreme Challenge for Capuchins

Visalberghi and Limongelli (1994) presented a variation of the tube task, the trap-tube task, to four capuchin monkeys already proficient in pushing food out of a tube. The apparatus consists of a transparent tube with a hole in the center and a "trap" underneath the hole (figure 27.5). The experimenter placed the reward on one side of the hole. To get the food, the capuchin had to insert the stick into the tube (first relation) and push the food (second relation) away from the trap (third relation). The monkey could avoid the trap while retrieving the reward by taking into account the outcome of its action with the stick on the movement of the food (toward or away from the trap). Once the stick is inserted into the tube, avoiding moving the food over the trap embodies two dynamic relations: one that the monkey must produce (between the stick and the food) and one that it must recognize beforehand (between the movement of the food over the trap and the food falling into the trap).

The four capuchins were tested for 140 trials. Three of them succeeded at only chance levels, whereas the fourth (3 years old) succeeded on 86% of trials in the second half of the experiment. Careful observation of this monkey's performance revealed that she adopted a distance-based rule: She looked inside the tube from either end and only then did she insert the stick into the opening farthest from the reward (Visalberghi & Limongelli, 1994). However, when the tube was modified so that one "arm" was longer than the other, as shown in figure 27.6, the distance rule became counterproductive. When the trap was not centered, inserting the stick into the side of the tube from which the reward was farther away led to failure. As expected from the use of a distance rule, when the trap was not centered, the monkey's rate of success fell significantly below chance level (Limongelli, Boysen, & Visalberghi, 1995).

A distance-based strategy seems odd to us. As adult humans, we anticipate or we imagine the effect of pushing the food with the stick and (simultaneously) the fate of the food when it moves above a hole. Thus, the position of the food with respect to the trap is integral to how we decide to push the food. The four capuchins probably anticipated that pushing with the stick causes the food to move, but they did not simultaneously recognize that the food will fall into the hole when they push it toward the hole. The behavior of the three monkeys that never scored better than chance with the trap tube supports this view. This view is also supported the thorough analysis of the behavior of the fourth monkey who discovered an effective strategy based on a spatial relation instead of one based on the recognition beforehand of the relation between the movement of the food over the trap and the food falling into the trap.

When the trap tube was presented to five chimpanzees, two solved it at above-chance level (Limongelli et al., 1995), but their strategy was not based on the same distance rule as was used by the successful capuchin, Roberta (see Experiment 2, in Limongelli et al., 1995). It is possible that these two apes might have understood the relevant relation between the food and the hole, as do children above 3 years of age (Visalberghi & Limongelli, 1996; Want & Harris, 2001). However, Reaux and Povinelli (2000) found that several chimpanzees behaved like Roberta; they solved the task by inserting the stick into the end of the tube farthest from the food. When they encountered the tube with the trap rotated 180 degrees vertically (so that the reward cannot fall into it and be lost), they continued to use the same distance rule. Therefore, identifying the second spatial relation in the trap problem is not easy for either apes or capuchins, even though they can see the hole and the food and see that, when they push the food into the hole, it falls into the trap.

To better understand what makes the trap tube difficult for capuchins and chimpanzees, we should consider whether they perceive the hole in the tube and whether they anticipate the path of motion of the food when it enters the hole. Would

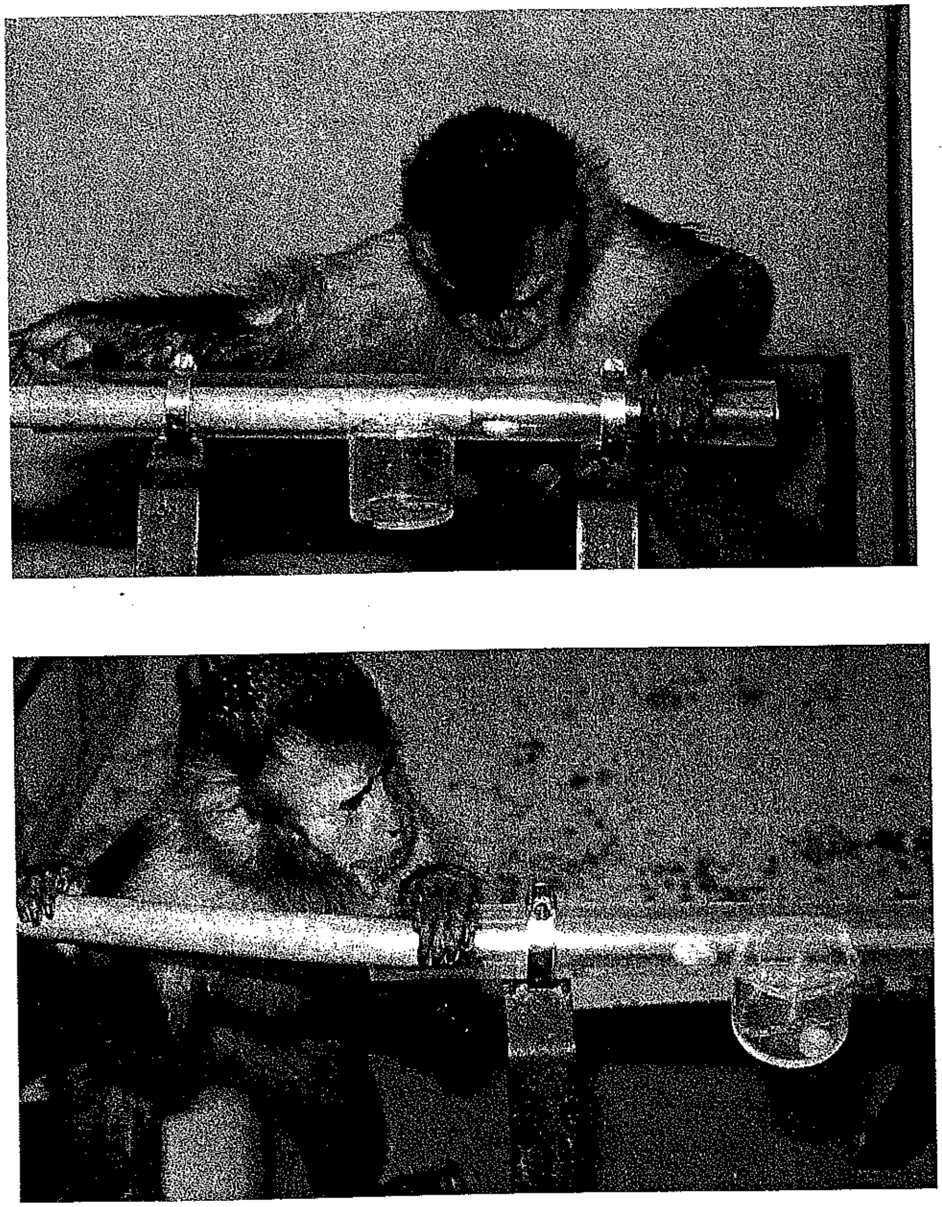

Figure 27.5. Trap-tube is a transparent tube with a hole in the center and a trap underneath it. The *upper panel* shows an example of correct insertion of the stick; the reward is on the right side of the trap. Note how delicately the monkey (Roberta) moves the stick with the fingertips of her right hand while at the same time monitoring the slow movement of the reward. The *lower panel* shows an example of insertion of the stick in the wrong side of the tube. Note that the reward, lost on a previous trial by Roberta, is already inside the trap. (Photographs courtesy of Elisabetta Visalberghi.)

they eventually learn to solve this problem effectively if they generated more or different kinds of feedback from their own actions concerning objects moving across surfaces? Experiments to test these hypotheses have begun.

Cummins (1999) investigated the ability of four capuchin monkeys to deal with two kinds of aberrations of a surface (a barrier and a hole) while using a hoe to retrieve a piece of food (figure 27.7). When the hoe struck the hole, the monkey could

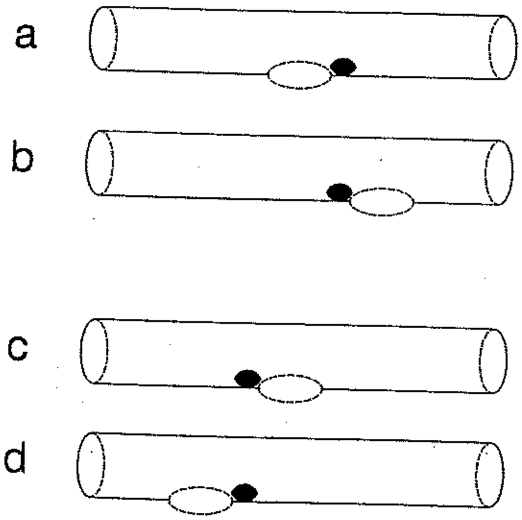

Figure 27.6. Control tests presented to Roberta, the only capuchin that solved the trap-tube task above chance level. These tubes were used to test whether Roberta was using a distance strategy to solve the trap-tube task. When the reward falls into the hole, it is lost to the monkey. The figure shows the possible locations of the reward at the beginning of each trial. In *a* and *c*, the hole is centered; in *b* and *d* the food is in the same position as in *a* and *c* but the hole is displaced from the middle part of the tube. Note that in *a* and *b* the reward is closer to the opening on the right and farther from the opening to the left and that in *c* and *d* the reward is closer to the opening on the left and farther from the opening to the right. Roberta did not solve the problem when it was presented as in *b* and *d*. (Redrawn by S. Marta from Limongelli et al., 1995.)

see and feel the blade of the hoe falling into it. When the hoe struck the barrier, the monkey could see that the hoe was partly occluded and could feel the impediment to movement. In this task, capuchins detected barriers on surfaces more readily than holes and they moved an object past a barrier more successfully than past a hole. In subsequent testing, the monkeys avoided moving a reward toward a hole placed anywhere on a surface. They also readily moved the reward across a location where, on a previous trial, the hole had been (Cummins-Sebree & Fragaszy, 2005). In other words, their successful performance was not based on the spatial rule of avoiding the area where a hole sometimes appears. These results suggest that feedback from action is very important for learning; when capuchin monkeys had enough of the right kinds of experience, they learned to use one object to move another object past a hole, just as they learned to move an object past a barrier.

The four capuchins tested by Fujita et al. (2003) used cane tools effectively to pull in food across a smooth surface but failed when they encountered new situations involving obstacles and traps. The fact that these same subjects were proficient in tasks requiring a choice between cane tools of varying shape, size, color, or material led Fujita et al. to argue that capuchins are able to appreciate relationships between items (namely, tool and reward), but they have difficulty mastering relationships among items (namely, tool, food, and a constraining environmental feature, such as a trap).

Visalberghi and Néel (2003) provide an example where experience acting on objects resulted in excellent discrimination by capuchin monkeys in a different kind of task. In terms of time and energy, opening an embedded food is a costly activity. Therefore, it is important for the monkey to determine, before opening it, whether a particular shell is empty or full. Visalberghi and Néel permitted the monkeys to choose one of two visually identical nuts to open. The nuts were hung on the side of the cage with string; the monkey could take one and the other was immediately removed. One of the nuts was empty (worthless); the other was full (valuable). Before making their choice, the capuchins lifted the nuts (presumably to judge their weight) and tapped the shells (presumably to listen). The monkeys could discriminate between nuts differing by as little as 2 to 3 gm, a 21 to 30% difference in weight. Either tapping or lifting was sufficient for accurate discrimination between the full and empty nuts. By their action, the monkeys produced information about the nuts that permitted them to make informed choices.

We suggest that the same processes apply to behavior in tool-using situations. Tool users act to produce information about objects and surfaces that guide further action. To the extent that the context permits effective production of salient information from their own action, capuchins are likely to master the problem.

The notion that individuals act to produce relevant perceptual information, and that this information guides further action and further learning, opens a new avenue for investigating how and when monkeys will master using objects as tools.

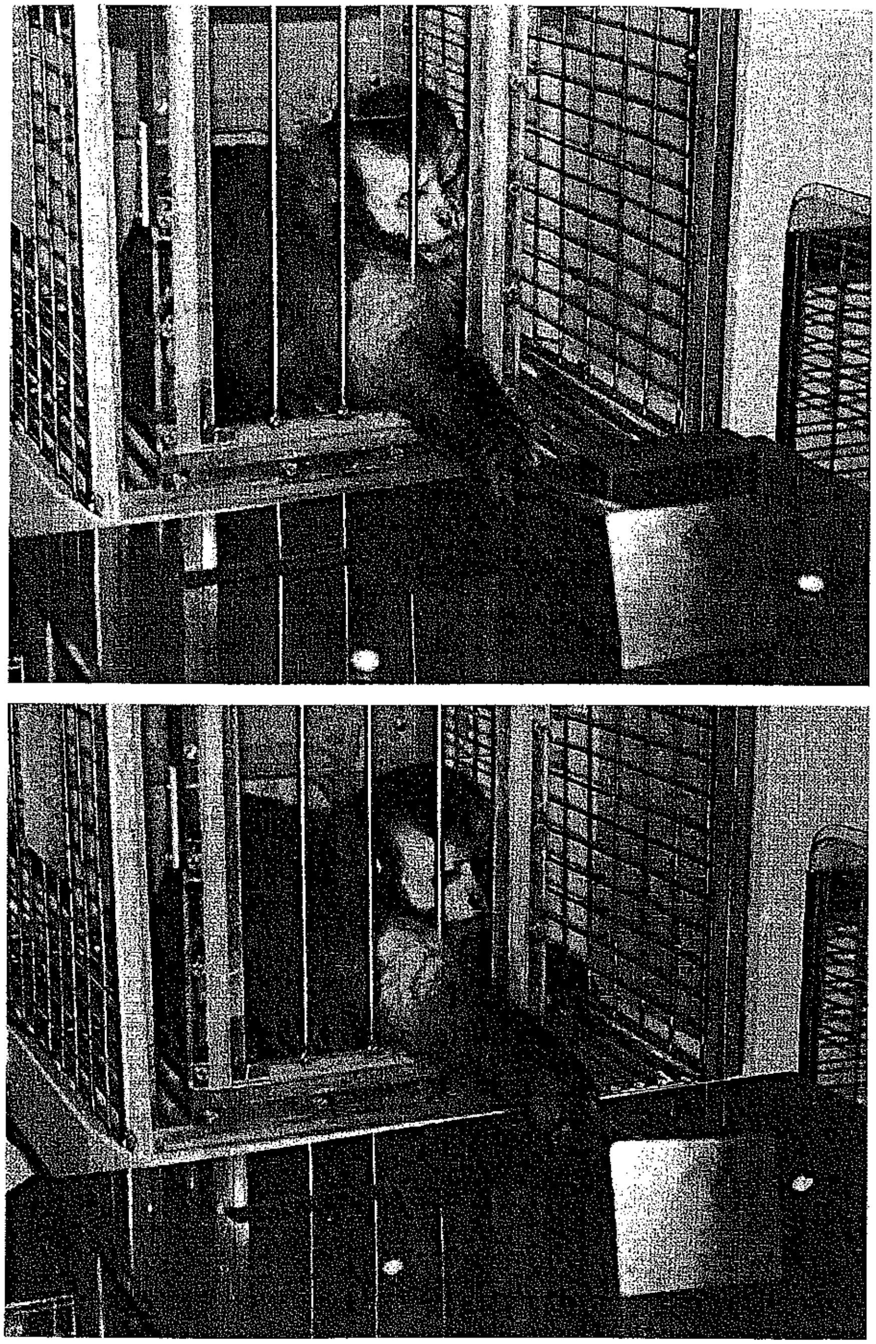

Figure 27.7. A capuchin monkey faces the choice of retrieving one of the two pieces of food with a hoe. Success depends on the type of surface the food must traverse. In the *lower panel,* the monkey is moving the hoe to collect a piece of food by sliding it across a solid, smooth surface (the surface on the monkey's left; on the right side of the picture) instead of trying to collect the piece of food placed behind a hole (the dark rectangle on the surface to the monkey's right; on the left side of the picture); in the *upper panel,* the monkey moves the food around the barrier (the raised block on the right) rather than toward the hole on the left. Coping with moving food past the hole posed a greater challenge to the monkeys than coping with moving food around the barrier. (Photographs courtesy of S. Cummins-Sebree.)

We anticipate an active program of research to investigate these ideas.

Behavioral and Environmental Factors Promoting and Constraining Tool Use

Captive capuchins' impressive achievements in using tools contrast sharply with the scarcity of reports of tool use by wild capuchins. What aspects of capuchins' behavior and ecology might result in the discovery of how to use an object as a tool? And conversely, what can constrain or prevent capuchins from using tools, or prevent the scientist from noticing it? Considering these questions may help us understand why captive and wild monkeys differ in tool use and may suggest new ways to look for tool use in wild capuchins.

Like other monkeys, capuchins possess sensory, anatomical, and behavioral characteristics that enable them to use objects as tools (e.g., they have grasping hands and stereoscopic vision, they coordinate vision and prehension, and they manipulate objects dexterously). In addition to these characteristics, as mentioned earlier in this chapter, capuchins possess behavioral characteristics that are less widely shared with other primates and that are particularly relevant to using objects as tools. Both wild and captive capuchins reliably and spontaneously combine objects with substrates and with other objects by pounding and rubbing; they also insert their hands and objects in holes and crevices (Boinski, Quatrone, & Swartz 2001; Fragaszy, 1986; Fragaszy & Adams-Curtis, 1991; Janson & Boinski, 1992; Panger, 1998). These actions are sufficient to support the discovery of tool use by captive capuchins (Visalberghi, 1987). When captive capuchins encounter objects they consider benign, whether novel or familiar, they quickly approach, explore, and manipulate them enthusiastically. Interest in objects, even familiar ones, persists over time (Visalberghi, 1988; Westergaard & Fragaszy, 1985). On encountering an interesting set of objects or an interesting substrate with loose objects available, and with the time and security to investigate, a capuchin monkey will reliably produce actions with objects on surfaces. This form of activity is more likely when the monkey is on the ground, so that the object does not fall out of reach when the monkey drops it (as would occur if the monkey is in a tree), when a substrate to bang the object against is easily within reach, and when the monkey itself is at no risk of falling.

These optimal conditions are less likely to be present for wild capuchins (Visalberghi, 1993), which do not respond as enthusiastically to novel objects as do captive monkeys (Visalberghi, Janson, & Agostini, 2003). Capuchins' arboreal lifestyle limits their opportunities to manipulate objects and makes the use of objects as tools more challenging. When in the trees, capuchins' hands are more often needed for support, loose objects that could be used as tools are less available and are less easily set aside and retrieved, and stable, strong, and appropriately shaped supporting substrates are less available than on the ground. Although arboreality may limit opportunities, it does not preclude tool use as both chimpanzees and orangutans do sometimes use tools in trees (Boesch & Boesch-Achermann, 2000; van Schaik, 2003; van Schaik, Fox, & Sitompul, 1996). Finally, capuchins have not yet been studied extensively in the wild and activities carried out high in the forest canopy are more difficult for terrestrial humans to view than activities occurring on the ground (but see later). All of these points may account for the rarity of observations of tool use in wild capuchins.

Let us now consider the circumstances under which wild capuchins should be expected to use tools. Tool using would provide an alternative feeding strategy when other important resources are scarce. For example, the exploitation of nuts and the pith of oil palms (*Elais guineensis*) by wild chimpanzees in Bossou (Guinea, West Africa) is strongly negatively correlated with the availability of fruit (Yamakoshi, 1998). Visalberghi (1997) argued that the general disposition to act with objects that leads capuchins to use tools for exploiting embedded food resources is more likely when readily available foods are scarce or undesirable. In addition, using a tool is more likely when direct pounding or biting does not suffice (Visalberghi & Vitale, 1990). Thus, we should expect to find capuchins using tools when seasonal reductions in fruit availability are particularly harsh and an embedded food that is difficult to open is abundant or highly desirable due to its nutritional value, or when the diversity of foods is consistently low and an embedded food is an important staple item in the diet.

Evidence supporting this view is slowly accumulating. The few reports of wild capuchins using tools are all cases in which easily obtained food was scarce or abundant food was very difficult to obtain. Fernandes (1991, p. 530) argues that the ability to open oysters by using a tool allowed capuchins to be "the only permanent primate resident" in the mangrove swamp he surveyed. There is strong, but indirect evidence (remains of Syagrus nuts on and near stones on the ground in areas where tufted capuchin monkeys ranged) that, during a period of severe drought, wild *C. apella* used stones to pound open nuts (Langguth & Alonso, 1997). We expect that, as we look more widely at wild capuchins in areas where they search for encased foods on the ground, we may find additional populations of monkeys using stones as tools to pound open hard foods.

In short, the strong motivation imposed by harsh ecological conditions, a certain degree of terrestriality, and the ready availability of stones and hard surfaces on which to place the embedded food to be pounded all favor the emergence of using tools to open hard foods. Tool use, in turn, may give capuchins a chance to inhabit otherwise inhospitable areas and to deal with seasonal changes in food availability.

CONCLUDING REMARKS

Tool use among nonhuman animals will certainly remain of interest to behavioral scientists for many reasons for years to come. Nevertheless, in part because it is of interest to so many communities for diverse reasons, there is more discussion about tool use than research on the topic; indeed, we find the literature on tool use, as a whole, to be theory poor.

For most of the twentieth century, studies of tool use in animals were descriptive or documentary. Documentary studies will remain important (i.e., reports of new discoveries from the field that individuals of a particular species use an object as a tool, such as van Schaik & Knott, 2001, for orangutans; Hunt, 1996, and Weir, Chappell, & Kacelnik, 2002, for New Caledonian crows). However, we have entered a new millenium and it is time to face a new challenge. The challenge for the field of comparative cognition that we are now in a position to address is understanding the origins and mechanisms that support the use of tools in diverse species. This task requires theoretically driven empirica, and particularly experimental investigations. There is no comprehensive "theory of tool use" to guide us. Instead, theoretical treatments of tool use, particularly by nonhuman primates, have included adaptations of Piagetian theory by Parker and colleagues (Parker & Gibson, 1977; Parker, Langer, & McKinney, 2000; Parker & Potì, 1990) and Antinucci (1989), innate knowledge and causal comprehension theory by Visalberghi and Tomasello (1998) and Povinelli (2000), and hierarchical ordering theories by Greenfield (1991) and Matsuzawa (2001).

We have proposed using perception-action theory, offered some examples of research with capuchin monkeys based on this theory, and applied it post-hoc to previous studies with capuchins (see table 27.1). This theory seems to us to offer promising new directions for comparative research. We suggest that theoretical diversity is a healthy state for the field at this time; we look forward to continuing experimental work guided by several theoretical orientations.

Where should research on tool use in capuchins go in the near future? Three directions seem to us to be very promising. First, descriptive studies of tool use and other forms of combinatorial behavior by wild capuchins (e.g., Boinski et al., 2001; Panger, 1998) will continue to be enormously important to our understanding of developmental processes and functional consequences of these activities.

Second, we look forward to the start of experimental studies on tool use at field sites where this is permissible. Ottoni and colleagues (Ottoni & Mannu, 2001; Resende & Ottoni, 2002) have begun such a line of work. A site where capuchins are provisioned and provided with opportunities to use tools could create a natural laboratory of the kind that Matsuzawa and colleagues have done at Bossou (Inoue-Nakumura & Matsuzawa, 1997; Matsuzawa et al., 2001). Natural laboratories provide opportunities for many kinds of longitudinal, developmental, and experimental studies, such as investigating how animals cope with altered conditions (new kinds of nuts or tools, altered abundance or distribution, etc.). Moreover, naturally occurring phenomena, such as immigration of skillful individuals into groups whose members do not use tools in the same manner, can tell us about the contribution of social context to skill development in a natural setting. Overall, the more comparable data we have obtained on wild capuchins and wild chimpanzees, the more powerful will be our comparisons of these two tool-using genera. We are now beginning to collect such data.

Third, we look forward to experimental studies in the laboratory using perception-action theory to examine how capuchins detect, produce, and modulate spatial relations among objects. In general, this theory directs our attention to the physical and perceptual challenges of using objects as tools. One can ask, for example, how monkeys progress from banging a hard object erratically on a nut and the surface surrounding the nut, to carefully modulated, accurate strikes that break the nut efficiently. Or, one can ask what features of the repertoire contribute to initial discoveries of useful relational properties, how easily the monkeys learn to detect and produce appropriate spatial relations, and so forth. We know virtually nothing about these topics at present for any nonhuman species. We are particularly interested in the possibility that producing and sustaining dynamic and static relations pose differential challenges to the monkeys. One of the advantages of this line of investigation is that it leads naturally to links with neuroscience, biomechanics, morphology, and related fields in the life sciences.

A final thought: Seeking compatible explanations for behavioral phenomena at multiple levels (mechanism, function, development, and evolution) invigorates the field of animal behavior (Kamil, 1998). Comparative cognition would do well to follow the model of the larger field of animal behavior and work to maintain multiple levels of explanation and multiple links with other fields. Researchers interested in tool use in nonhuman species should keep this in mind.

Acknowledgments This work was supported by grants from the Italian Ministry of Education, University and Research (MIUR/FIRB) to Elisabetta Visalberghi and from the National Science Foundation to Dorothy Fragaszy. The authors thank J. Lockman, H. Takeshita, and S. Itakura for discussions about the model of tool use presented in table 27.1.

Notes

1. This view of tool use is similar in many respects to those presented by Greenfield (1991).

2. Hauser (1997) tested cotton-top tamarins (*Saguinus oedipus*) in a choice paradigm (previously adopted by Brown, 1990, to test human infants), and Povinelli (2000) used the same paradigm with chimpanzees. In these studies, the subject had to choose between objects to retrieve a reward. The choice, not the actual use of the object as tool, was the dependent variable used to evaluate the monkeys' representation of the functionally relevant features of a tool. Santos and co-workers (in press) used looking time to test whether tamarins and rhesus (*Macaca mulatta*) distinguished between relevant and irrelevant features of a tool. In Hauser and Santos's studies, macaques and tamarins reliably distinguished relevant and irrelevant features of objects that could be used to pull in food. As mentioned earlier, we consider the two variables of choice and looking time to indicate something about the subjects' interest in objects or events but not about tool use per se.

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