CHAPTER

39

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

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In *Comparative Cognition: Experimental Explorations of Animal Intelligence.* (2012) T. R. Zentall and E. A. Wasserman (Eds.): Oxford University Press, pp. 777-799.

Abstract

Capuchin monkeys (genus *Cebus*) are the most adept and frequent users of tools among monkeys. This chapter uses 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 discuss these studies focusing on the number and kind of relations among object, substrate, and actions with an object that capuchins used to achieve a goal. 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 a new understanding of tool use in our own species as well as other species of nonhuman animals.

Keywords: tool use, capuchin monkeys, learning, action-perception theory, stone tool use

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. Shumaker, Walkup and Beck (2011) state that "tool use is the external employment of an unattached or manipulable attached environmental object to alter more efficiently the form, position, or condition of another object, another organism, or the user itself when the user holds and directly manipulates the tool during or prior to use and is responsible for the proper and effective orientation of the tool" (p. 5). 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 Shumaker et al. (2011) and Bentley-Condit and Smith (2010) show convincingly, tool use is widely distributed across the animal kingdom; it is clearly not restricted to primates. However, it is thought by some researchers that tool use is more flexible in format and more varied in function in primates than in other orders (Bentley-Condit & Smith, 2010; Tomasello & Call, 1997). In wild great apes, tool use is widespread among chimpanzees but is observed less often in orangutans (*Pongo pygmaeus*) and even less often in the other great apes (gorillas, *Gorilla gorilla*, and bonobos, *Pan paniscus*). Wild chimpanzees use tools habitually, in many varied formats across their geographical distribution, and for diverse purposes. However, all species of great apes use tools spontaneously in captivity in flexible and diverse ways. Captive lesser apes (gibbons and siamangs, in the family *Hylobatidae*) have occasionally been reported to use tools as well. Several species of monkeys occasionally spontaneously use objects as tools in captivity, and several research programs involve training monkeys to use tools (for example, Japanese macaques, *Macaca fuscata*, Hihara, Obayashi, Tanaka, & Iriki, 2003; see Anderson, 2006; Bentley-Condit & Smith, 2010; Humle & Fragaszy, 2010; and Shumaker et al., 2011, for reviews). Prosimians have also been reported to use tools in several ways (reviewed in Shumaker et al., 2011). However, only two species of monkeys use tools habitually in natural circumstances (*Macaca fascicularis*: Gumert et al. 2009; Malaivjitnond et al., 2007; *Cebus libidinosus:* Ferreira, Emidio, & Jersalinksy 2010; Spagnoletti et al., 2011; see also Ottoni & Izar, 2008). 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* and *Cebus libidinosus*; hereafter, capuchins), 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 discuss our studies of tool use in these monkeys, focusing on the number and kind of relations among object, substrate, and actions with an object they used 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.

Capuchin Monkeys, Genus *Cebus*

Capuchins are robustly built monkeys that have been popular subjects for research in the laboratory as well as in the field (see Fragaszy, Visalberghi, & Fedigan, 2004a, for a review). 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, especially towards infants and young juveniles.

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 on the ground feeding (including raiding crops and excavating tubers), 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, tubers, etc.), invertebrates (mollusks, insects, worms, etc.), and vertebrates (birds and their eggs, small mammals, lizards, snakes, etc.) in their diet. Many other South American monkeys eat many of 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) 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.

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; see Fragaszy et al., 2004a, and Tomasello & Call, 1997, for 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 et al., 2004a, Chapter 10) contains exhaustive information on the tool-using skills of capuchins through the 20th century. The first report of tool use in captive capuchins 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 et al., 2004a; 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.).

Dampier (1697) observed wild capuchins using a stone as a tool to open mollusks. Though erroneously reported as tool use, what Dampier actually saw did not involve the use of percussive tools. (Fragaszy et al., 2004a). The first observation of a wild capuchin using a broken oyster shell to strike oysters attached to the substrate, successfully opening them, was reported by Fernandes (1991). Boinski (1988) carefully documented how a male wild *Cebus capucinus* killed a snake by hitting it with a branch obtained from nearby vegetation. But only in the present millennium has habitual tool use in wild capuchins been discovered in northeastern Brazil, as described in the last paragraphs of this section.

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 in primates 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 & Poti, 1990). Others (e.g., Anderson, Fragaszy, Visalberghi, & Westergaard—see Table 39.1 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. Naturalistic observations of tool use by capuchins living in semi-free conditions were also carried out (e.g.,; Jalles-Filho, da Cunha, & Salm, 2001; Ottoni & Mannu, 2001; Rocha, dos Reis, & Sekiama, 1998). However, until very few years ago, captive capuchins' impressive achievements in using tools sharply contrasted with the scarcity of reports of tool use by wild capuchins. Published reports we found concerned inferred cases (e.g., Langguth & Alonso, 1997) or serendipitously observed cases (e.g., Boinski, 1988; Fernandes, 1991; for further details see Fragaszy et al., 2004a). This state of affairs changed in 2004, when two research teams reported repeated use of tools in two populations of wild bearded capuchin monkeys (*Cebus libidinosus*) in northeastern Brazil (Fragaszy, Izar, Visalberghi, Ottoni, & de Oliveira, 2004b; Moura & Lee, 2004), and reports followed soon after of percussive tool use in other populations of *Cebus libidinosus* (Ferreira, Emidio, & Jerusalinsky, 2010; Waga, Dacier, Pinha, & Tavares, 2006) and in *Cebus xanthosternos* (Canale, Guidorizzi, Kierulff, & Gatto, 2009; see also Ottoni & Izar, 2008), and a report of termite-fishing in *Cebus flavius* (Souto, Bione, Bastos, Bezerra, Fragaszy, & Schiel, 2011), all in northeastern Brazil.

Fragaszy et al. (2004b) observed several individuals cracking open palm nuts using stones and anvils in Fazenda Boa Vista (hereafter FBV, State of Piauí; Fig. 39.1); since then the research team working at FBV has documented habitual nut-cracking in two capuchin groups (Spagnoletti, Visalberghi, Ottoni, Izar, & Fragaszy, 2011) and inferred nut-cracking for several other groups in the vicinity of FBV (up to 15 km) on the basis of physical remains at anvil sites (hammer stones, nut shells, pitted surface of the anvil; Visalberghi, Fragaszy, Izar, & Spagnoletti, unpublished data; see Visalberghi, Fragaszy, Ottoni, Izar, de Oliveira, & Andrade, 2007, for a description of how anvil sites are documented). Four hundred km away, in the Serra da Capivara National Park, capuchins use stones to access embedded food by percussion and by scraping, and sticks to probe for honey and to flush vertebrate prey (Ottoni & Mannu, 2001; Mannu & Ottoni, 2009). The capuchins observed by Mannu and Ottoni (2009) sometimes used tools sequentially (e.g., one stone to excavate soil and a second to strike the embedded plant tuber) and seemed to have a broader toolkit (i.e., a set of objects used as tools) than wild capuchin monkeys elsewhere. Captive capuchins studied by Westergaard and Suomi (1993, 1994b, reviewed in Westergaard, 1999) also used two tools sequentially (a stone to crack a nut, and then a stick to pry out pieces of nut kernel), and even used two tools concurrently (a hammer stone with a chisel stone to breach an acetate seal capping a container with food). Klüver (1933, 1937) also reported several instances in which his captive subject used tools sequentially to solve problems. We have not yet observed wild capuchins using two tools concurrently.

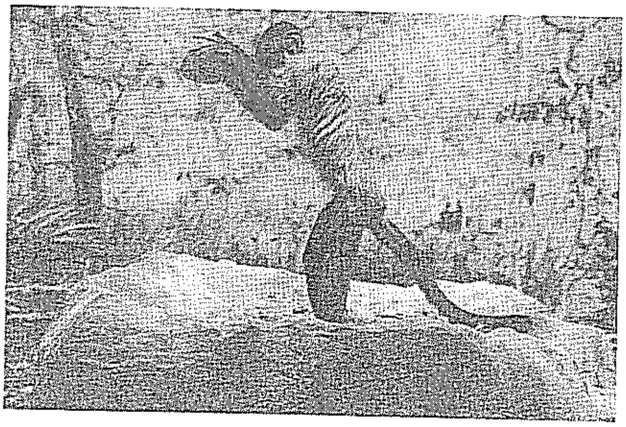

Fig. 39.1 Fazenda Boa Vista (Piauí, Brazil). A young male lifts a hammer stone to crack a palm nut (visible on the stone anvil) (photo by Elisabetta Visalberghi).

We now have compelling evidence that capuchins at FBV routinely use hammer stones weighing on average 1 kg to crack a variety of encased foods, particularly palm nuts (Spagnoletti et al., 2011; Visalberghi et al., 2007). The capuchins hold the hammer stone with both hands in a bipedal stance and use postures and movements reminiscent of human weightlifters to lift the stone and strike the nut (Liu et al., 2009a). Most species of palm nuts exploited by capuchins are very resistant to cracking; for example, the peak force at failure for piassava nuts (tentatively identified as *Orbignya* sp.) is similar to that of Panda nuts, the hardest nuts cracked with tools by chimpanzees (Boesch & Boesch-Achermann, 2000; Visalberghi et al., 2008).

Stones large enough to use as hammers are scarce in the landscape at FBV (Visalberghi et al., 2009a). Visalberghi et al. (2007) predicted that capuchins transport stones of suitable weight and composition to anvil sites to use as tools. Systematic observations of the behavior of two wild groups as well as recent field experiments confirmed these predictions (Spagnoletti et al., 2011; Visalberghi et al., 2009b). To crack nuts, capuchins given a choice of stones select the heavier, harder stones; when choosing between stones of equivalent strong composition, they prefer the heavier stone (Fragaszy, Pickering, Liu, Izar, Ottoni, & Visalberghi, 2010a) even when that stone has a smaller volume than other potential hammer stones (Visalberghi et al., 2009b). Typically the monkeys collected the food item and then the stone and carried both to the anvil in one trip (Fig. 39.2). In one study, the most proficient monkey required just over 6 strikes to open a single nut; the least proficient that cracked open a nut required more than 75 strikes to open one nut (Fragaszy et al., 2010a).

For many archaeologists and anthropologists, chimpanzees have become the referent for modeling early hominins (Sayers & Lovejoy, 2008). However, wild bearded capuchin monkeys, a species that separated from the human lineage about 35 million years ago, also habitually use tools, whereas great apes other than chimpanzees rarely do. Nut-cracking

Fig. 39.2 Fazenda Boa Vista (Piauí, Brazil). An adult male transports a large stone and two palm nuts to an anvil using a bipedal gait (photograph by Elisabetta Visalberghi).

behavior in capuchin monkeys is of particular interest in this regard because capuchins can serve to demonstrate convergences in behavior reflecting ecological foundations for the character of interest (in this case, percussive tool use). A rigorous comparison of tool use in capuchins with tool use in chimpanzees and humans, extant and extinct, contributes to the exploration of the origins and evolution of human behavior (Haslam, Hernandez-Aguilar, Ling, Carvalho, de la Torre, DeStefano, Du, Foley, Hardy, Harris, Marchant, Matsuzawa, McGrew, Mercader, Mora, Petraglia, Roche, Visalberghi & Warren, 2009).

A Perception-Action View of Tool Use

Table 39.1 provides a list of published reports on tool use in capuchins from 1980 to 2009, the vast majority of which refer to studies carried out in captivity. Instead of reviewing these studies (for this, we direct interested readers to Fragaszy et al., 2004a), 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.

Before we review research reports, we need to present and explain our particular treatment of tool use. The definition of tool use from Shumaker et al. (2011) 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 perhaps because it likely provides insecticidal or antibacterial protection; Valderrama, Robinson, Attygalle, & Eisner, 2000). In this case, the actor, to paraphrase Shumaker et al.'s definition, uses a material (an unattached environmental object) to alter the condition of its skin while the user holds or directly manipulates the material during use and the user is responsible for the effective orientation of the material. However, several elements are not clear: for example, whether rubbing something on the body counts as orienting a material, nor is the effect of the action clear. Given this ambiguity, we do not classify anointing as tool use.

Shumaker et al.'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.

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). Thus, combinatorial exploration leads to tool use. 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

Table 39.1 **Recent studies on tool use in capuchins, chronologically ordered. Updated from Fragaszy, D., Fedigan, L., and Visalberghi, E. (2004). The Complete Capuchin. Cambridge: Cambridge University Press, (with permission of the Publisher).**

(a) Studies in captivity[a]

Task	Relational Category[b]	Aim(s) of the Study	N Tool Users/N tot[c]	Species	Source
Nut cracking	1st dynamic	Selection among differently effective tools	1/6	*C. apella*	Antinucci and Visalberghi (1986)
Nut cracking	1st dynamic	Acquisition of the behavior and social learning	2/42	*C. apella*	Visalberghi (1987)
Dipping Sponging	1st static 1st static	Acquisition of the behavior and social learning	6/9 9/9	*C. apella*	Westergaard and Fragaszy (1987a)
Stick directed to a wound	1st static	Serendipitous observation	n.a.	*C. apella*	Westergaard and Fragaszy (1987b)
Stick directed to a wound	1st static	Serendipitous observation	n.a.	*C. apella*	Ritchie and Fragaszy (1988)
Raking/digging/ probing	ambiguous description	Serendipitous observations	n.a./12	*C. apella* *C. albifrons*	Chevalier-Skolnikoff (1989)
Nut cracking Stick to push	1st static 1st static	Social influences on tool use acquisition	5/20 5/20	*C. apella*	Fragaszy and Visalberghi (1989)
Stick to rake	1st dynamic	Sensorimotor intelligence	3	*C. apella*	Natale (1989)
Stick to push a reward out of a tube	1st dynamic	Appreciation of how the tool should be modified	3/4	*C. apella*	Visalberghi and Trinca (1989)
Nut cracking	1st dynamic	Benefits in terms of time and success due to the use of tools	5/6	*C. apella*	Anderson (1990)
Stick to rake	1st dynamic	Sensorimotor intelligence Developmental	3/5 1	*C. apella*	Parker and Potì (1990)
Sticks to push a reward out of a tube	1st dynamic	Selection of the appropriate tool	4	*C. apella*	Visalberghi (1993)
Nut cracking and probing	1st static 1st static	Sequential use of tools (tool-set)	3/9	*C. apella*	Westergaard and Suomi (1993)
Probing	1st static	Selection of the appropriate tool	2	*C. apella*	Anderson and Henneman (1994)

Dipping Nut cracking	1st static 1st static	Tool acquisition in juveniles and influence of the context	3juv/9juv 3juv/9juv	*C. apella*	Fragaszy et al. (1994)
Stick to push a reward out of a tube	2nd simult.	Understanding of cause effects relations	4	*C. apella*	Visalberghi and Limongelli (1994)
Stone flaking Stones as cutting tools	1st dynamic 1st static	Production of flakes Stones as cutting tools	6/11 3/15	*C. apella*	Westergaard and Suomi (1994a)
Nut cracking Bone fragments as cutting tools	1st static 1st static	The use and modification of bone tools	3/9 3/9	*C. apella*	Westergaard and Suomi (1994b)
Bone modification due to the use of tools	1st static	Modeling early hominid technology	5/10	*C. apella*	Westergaard and Suomi (1994c)
Aimed throwing	1st static	Modeling early hominid technology	4	*C. apella*	Westergaard and Suomi (1994d)
Stick to displace a reward out of a tube	1st dynamic	Comparison with apes	6	*C. apella*	Visalberghi et al. (1995)
Digging tools	1st static	Modeling hominid subsistence technology	4/10	*C. apella*	Westergaard and Suomi (1995a)
Stone throwing	1st static	Modeling hominid throwing capabilities	4	*C. apella*	Westergaard and Suomi (1995b)
Dipping Cutting	1st static 1st static	Modeling East Asian hominid bamboo technology	5/18 6/18	*C. apella*	Westergaard and Suomi (1995c)
Pestle use	1st static	Use of different objects as pestle	10/18	*C. apella*	Westergaard et al. (1995)
Nut cracking Cutting	1st static 1st static	Modeling hominid metal-tool technology	5/14 5/14	*C. apella*	Westergaard et al. (1996)
Stones as cutting tools	1st static	Transfer of tools and food	3/11	*C. apella*	Westergaard and Suomi (1997)
Ant gathering Stones as cutting tools	1st static 1st static	Use of sticks to extract ants Use of a tool-set	7/14 3/14	*C. apella*	Westergaard et al. (1997)
Nut cracking Dipping	1st static 1st static	Use of color chips to request tools	1	*C .apella*	Westergaard et al. (1998a)
Dipping	1st static	Role of sex and age on tool use acquisition Factors associated with tools use and modification	21/36 31/61	*C. apella*	Westergaard et al. (1998b)
Container for water Sponging Stick as cane	1st static zero n.a.	Serendipitous observation	1/11 1/11 1/11	*C. olivaceus*	Urbani (1999)

(*Continued*)

Table 39.1 Recent studies on tool use in capuchins, chronologically ordered. Updated from Fragaszy, D., Fedigan, L., and Visalberghi, E. (2004). The Complete Capuchin. Cambridge: Cambridge University Press, (with permission of the Publisher) (Continued).

(a) Studies in captivity[a]

Task	Relational Category[b]	Aim(s) of the Study	N Tool Users/N tot[c]	Species	Source
Bait for fishing	1st static	Observational study	4 /6	*C. apella*	Mendes et al. (2000)
Cracking open a baited box Transport tools to the box Transport tools to the nuts and nut cracking	1st static 1st dynamic	Modeling hominids behavioral evolution and the transport of tools	8/13 1/13 7/8	*C. apella*	Jalles-Filho et al. (2001)
Dipping	1st static	Influence of task location of tool use	2/4	*C. olivaceus*	Dubois et al. (2001)
Tool choice, obstacles and traps	1st dynamic & 2nd simult.	Selection of the appropriate tool and understanding of cause effects relations	4	*C. apella*	Fujita et al. (2003)
Raking food out of reach	1st dynamic	Factors affecting tool use	13/58	*C. apella*	Byrne and Suomi (2004)
Dipping Pounding	1st static 1st static	Transport of dipping and pounding tools	n.a.	*C. apella*	Cleveland et al. (2004)
Throwing	1st dynamic	Discrimination of functional throwing tools	n.a.	*C. apella*	Evans and Westergaard (2004)
Probing	1st static	Value attribution to tools during exchanges with humans	n.a.	*C. apella*	Westergaard et al. (2004)
Choosing vs. using tools	1st dynamic	Using sticks to get food out of reach	6/6	*C. apella*	Cummins-Sebree and Fragaszy (2005)
Dipping	1st static	Delay gratification in a tool task	n.a.	*C. apella*	Evans and Westergaard (2006)
Dipping	1st static	Social influences on tool use	8/8	*C. apella*	Flemming et al. (2006)
Nut cracking	1st static	Tool selection	1/1	*C. apella sp.*	Jalles-Filho et al. (2007)
Pounding and probing	1st static	Possible manufacture by pounding of a stick to probe	1/6	*Cebus sp.*	Bortolini and Bicca-Marques (2007)
Nut cracking	1st static	Tool selection based on weight	4/4	*C. apella*	Schrauf et al. (2008)
Use of a tool to poke and to lever	1st dynamic	Learning tool use from humans by mother-reared and human- reared capuchins	n.a.	*C. apella*	Fredman and Whiten (2008)

(b) Studies in semi-free (s-f) and wild (w) conditions[d].

Task	Relational Category	Specific aim(s) of the Study	Cond.	N Tool Users/N tot	Species	Source
Throwing, probing	n.a.[c]	Observational study	w	n.a. /21	*C. capucinus*	Chevalier-Skolnikoff (1990)
Pounding to open oysters	1st static	Serendipitous observation	w	n.a.	*C. apella*	Fernandes (1991)
Exploratory probing	1st static	Serendipitous observation	w	n.a.	*C. capucinus*	Garber and Paciulli (1997)
Use of pounding tools to crack palm nuts	2nd sequential	Indirect evidence from physical traces	w	n.a.	*C. apella*	Langguth and Alonso (1997)
Use of pounding tools to crack palm nuts	2nd sequential	Use of suitable pounding tools and anvils [Experiment]	s-f	no data/44	*C. apella*	Rocha et al. (1998)
Leaves to absorb liquid	Zero	Serendipitous observation	w	n.a.	*C. albifrons*	Phillips (1998)
Branches to kill a snake	1st static	Serendipitous observation	w	n.a.	*C .capucinus*	Boinski (1988)
Dipping	1st static	Selection and modification of tools (Experiment)	s-f	3/11	*C. apella*	Lavallee (1999)
Use of pounding tool[f]	2nd sequential	Observational study	w	n.a.	*C. apella*	Boinski et al. (2001)
Use of pounding tools to crack palm nuts	2nd sequential	Observational study	s-f	15/18	*C. apella*	Ottoni and Mannu (2001)
Stick to push	1st dynamic	Acquisition of tool use	w	0/15	*C. capucinus*	Garber and Brown (2004)
Use of pounding tools to crack palm nuts	2nd sequential	Use of pounding tools and anvils	w	4/10	*C. libidinosus*	Fragaszy et al. (2004b)
Use of pounding tools Digging Probing	2nd seq. 1st static 1st static	Ecological study; serendipitous observations of stone tool use	w	No data/10	*C. libidinosus*	Moura and Lee, (2004)
Use of pounding tools to crack palm nuts	2nd sequential	Social aspects of nut cracking	s-f	12/20	*C. apella*	Ottoni et al., (2005)
Use of pounding tools to crack palm nuts and other foods	2nd sequential	Observational study to document tool use	w	5/27	*C. libidinosus*	Waga et al. (2006)
Use of pounding tools to crack palm nuts	2nd sequential	Ontogeny of nut cracking	s-f	n.a.	*C. apella*	Resende et al. (2008)

(*Continued*)

(b) Studies in semi-free (s-f) and wild (w) conditions[d]. (Continued)

Task	Relational category	Specific aim(s) of the study	Cond.	N tool users/N tot	Species	Source
Use of pounding tools and anvils	2nd sequential	Observational study, interviews, and inference from physical traces to document tool use	w	n.a.	*C. xanthosternos* *C. libidinosus*	Canale et al. (2009)
Use of tools to pound Use of tools to pound dig Use of tools to pound probe	2nd seq. 1st static 1st static	Tool-kit: Use of sticks to probe and as weapons and of stones for different purposes	w	No data/64	*C. libidinosus*	Mannu and Ottoni, (2009)
Use of pounding tools to crack palm nuts and other foods	2nd sequential	Normative use of pounding tools and anvils across a year	w	22/28	*C. libidinosus*	Spagnoletti (2009)
Use of pounding tools to crack palm nuts	2nd sequential	Kinematics and energetics of nut-cracking	w	n.a.	*C. libidinosus*	Liu et al. (2009a)
Selection of pounding tools to crack palm nuts	2nd sequential	Decision rules for selection of pounding tools	w	n.a.	*C. libidinosus*	Visalberghi et al. (2009b)
Selection of pounding tools to crack palm nuts	2nd sequential	Use of pounding tools and anvils	w	n.a.	*C. libidinosus*	Visalberghi et al. (2009a)
Use of pounding tools to crack palm nuts	2nd sequential	Efficiency of nut-cracking	w	n.a.	*C. libidinosus*	Fragaszy et al. (2010a)
Selection of pounding tools to crack palm nuts	2nd sequential	Use of pounding tools and anvils	w	n.a.	*C. libidinosus*	Fragaszy et al. (2010b)
Use of pounding tools to crack palm nuts	2nd sequential	Ontogeny of nut-cracking	w	n.a.	*C. libidinosus*	Liu et al. (2009b)

[a] Captivity includes cages, outdoor enclosures and small islands.
[b] Relational categories are defined in Table 2 according to the number (zero, 1st or 2nd order) and, for 1st order relations, the type of relation (static or dynamic) embodied in the task. We include a few cases reported in the literature as tool use that involve a zero-order relation, and thus that do not reach our criterion for tool use. All reported 2nd order relations are sequential (rather than concurrent). Due to space limitations, we do not report the static/dynamic dimension for each relation in each case. Many concern cracking nuts with a stone, an action that begins with one static relation (placing a nut on an anvil, then releasing it) followed by a second static relation (striking the [stationary] nut with the stone).
[c] Number of individuals using tools and total number of individuals tested. When there is only one value, it means that the study focused only on those subjects. n.a. = not applicable, meaning that the information is not provided by the Author(s), or the subjects participated because they were tool users or learning to use tools.
[d] In semi-free ranging conditions the animals are provisioned and cannot leave an enclosure but can obtain some portion of their diet through foraging on natural resources.
[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. This behavior was not observed again.

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 may inform us about the actor's recognition of object properties or spatial relations that are relevant for tool use (Fujita, Kuroshima, & Asai, 2003), but attention or choice is not tool use (see Cummins-Sebree & Fragaszy, 2005, for a discussion of this issue).

Tool Use by 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 (labeled a first-order relation in Table 39.2), rather than simply use a preexisting relation (labeled a zero-order relation in Table 39.2). 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

Table 39.2 Relations produced through action with an object that are evident in capuchins' use of tools. In our view, an action involving a zero-order relation is not tool use. 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.

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. Since 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).

classified as tool use. St Amant and Horton (2008) make a similar suggestion—that is, that one sense of tool use involves altering a target object by mechanical means.

An animal may not use a tool consistently in all contexts; it may use a tool to solve one task but not 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 39.2). For a thorough discussion of this framework, see Fragaszy and Cummins-Sebree (2005).

We recognize two types of spatial relations here: static and dynamic. Static relations are produced once, by a discrete action, such as placing a nut on a surface followed by releasing the grip. Dynamic relations must be maintained through time and across space, such as keeping an object behind the blade of a hoe while sweeping the hoe laterally to move the object across a surface. Other things being equal, producing an effective dynamic relation is more effortful than producing an effective static relation, because the dynamic relation requires continuous monitoring. The boundary between static and dynamic relations may not always be clear (for example, the case of a nut held in place on an inclined surface), 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 (Fig. 39.3, top left and top right) are examples

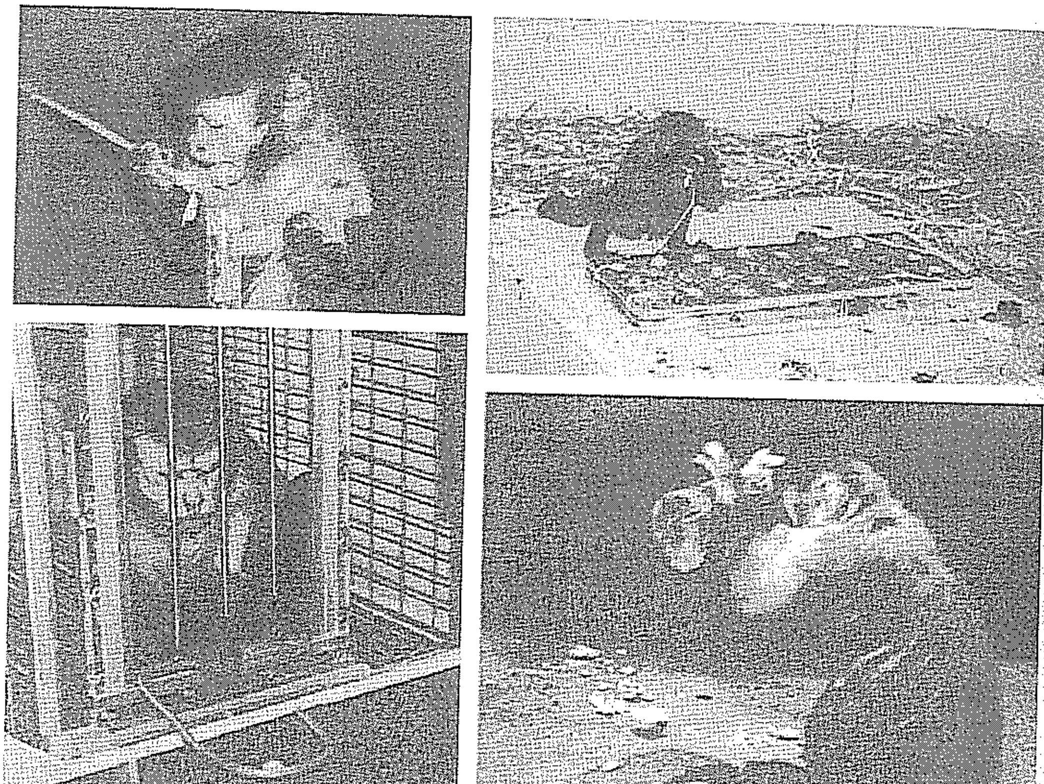

Fig. 39.3 *Top left*: Adult female tufted capuchin dips for applesauce while holding her newborn infant in one arm. She holds the stick with a power grip. (Photograph by Elisabetta Visalberghi.) This is an example of producing a static first-order relation; see Table 39.2. *Bottom left*: Tufted capuchins 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 into the wooden board. (Photograph by 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 of 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.

of actions embodying static first-order relations. Dipping and banging are 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 (Fig. 39.3, bottom left). Pounding a loose nut with a stone can involve a static relation if the nut remains where it is placed without support (Fig. 39.3, 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 (Fig. 39.3, 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). 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 semi-free conditions) (Lavallee, 1999). However, applying a strategy successfully adopted in the past is not necessarily efficient for the task at hand. Figure 39.4 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.

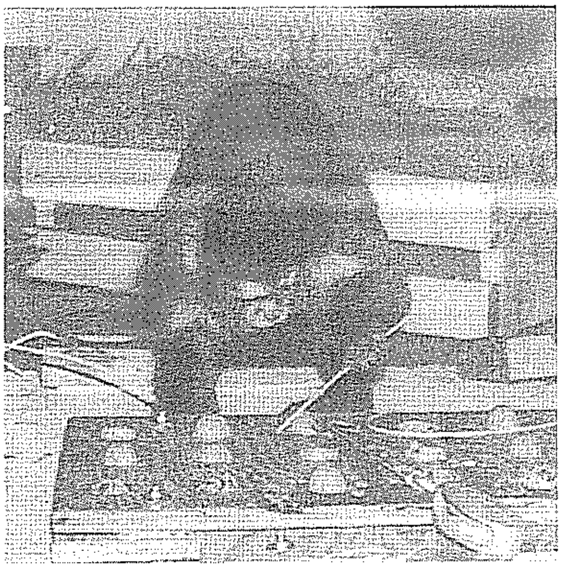

Fig. 39.4 An adult female tufted capuchin, proficient in using a straw for dipping syrup, touches a nut glued onto a wooden board with a straw, using the same action she used previously to retrieve syrup from a closed container. She ignores the adjacent hard objects (one shown in the foreground) that could be used effectively to crack open nuts. Striking a nut glued in place would be producing a first-order static relation (photograph by Elisabetta Visalberghi).

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 (Fig. 39.5). 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 in a couple of hours without any training or demonstrations and subsequently encountered the same tube apparatus in three new conditions in which the tools had to be modified before use or used in succession (Fig. 39.5). 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; Fig. 39.5) that did not have the necessary properties (e.g., rigidity, length) to displace the food from the tube. Over the 10 trials in each 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.

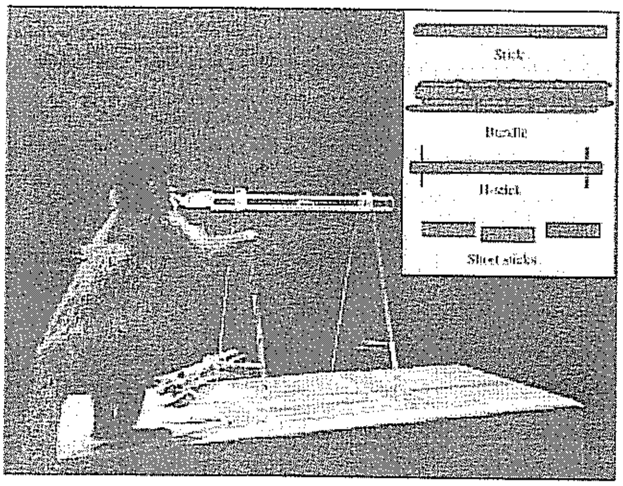

Fig. 39.5 The tube task consists of a transparent horizontal tube baited in the center with a food treat. Pushing food through a tube requires producing one static relation (inserting the stick into the tube) and then one dynamic relation (a sustained push on the food with the stick). The capuchin in 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 (trying to use inappropriate objects as tools) are common in capuchin monkeys. (Photograph by Elisabetta Visalberghi.) 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: (1) a stick that can be used to push the treat out of the tube; (2) 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; (3) the H-stick, consisting of a dowel with two smaller sticks placed transversely near the end; the transverse sticks block the insertion of the dowel into the tube; (4) 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).

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 consistently modifying an object appropriately beforehand.

Unless the nut is on a hard substrate, cracking open a nut 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 must position the nut on one hard object and use another object to pound the nut. Positioning the nut on a specific hard surface (an anvil) is the first spatial relation that must be produced; pounding the nut with a hard object is the second. It appears that young capuchins learning to crack nuts do not produce these two actions with equal probability. Striking a surface or another object with a stone is a common action from the first year of life. In contrast, placing and releasing an object (so that it may then be struck) appears less commonly through the second year of life (Resende, Ottoni, & Fragaszy, 2008). Partly for this reason, capuchins do not crack nuts placed on an anvil until about 2 years of age or later (Liu et al., 2009b; Resende et al., 2008; Rocha et al., 1998). Note that the probabilities of performing the two essential actions for nut-cracking, placing the nut and striking it with a stone, are quite different in young chimpanzees and young capuchin monkeys. Young chimpanzees readily place objects on a surface and then release their grasp, but they do not often strike one object with another. Capuchins show the reverse pattern, striking readily but placing and releasing less often. Thus, producing different kinds of spatial relations with objects is differentially challenging to the two species. An individual must master producing these two relations in the correct sequence to become efficient at cracking nuts, but producing the correct actions by themselves is the first challenge.

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 (especially adult females) 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, virtually all adult capuchins at our field site in Brazil crack open nuts with hammer and anvil (Spagnoletti et al. 2011). Similarly, all individuals except infants cracked nuts in Ottoni and Mannu's (2001) study of capuchins living in a large park.

Several factors may account for more consistent use of tools to obtain food by individuals in semi-free or wild 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 et al., 2004a, 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 cannot be monopolized by any single individual all the time. 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 (Fig. 39.6). 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).

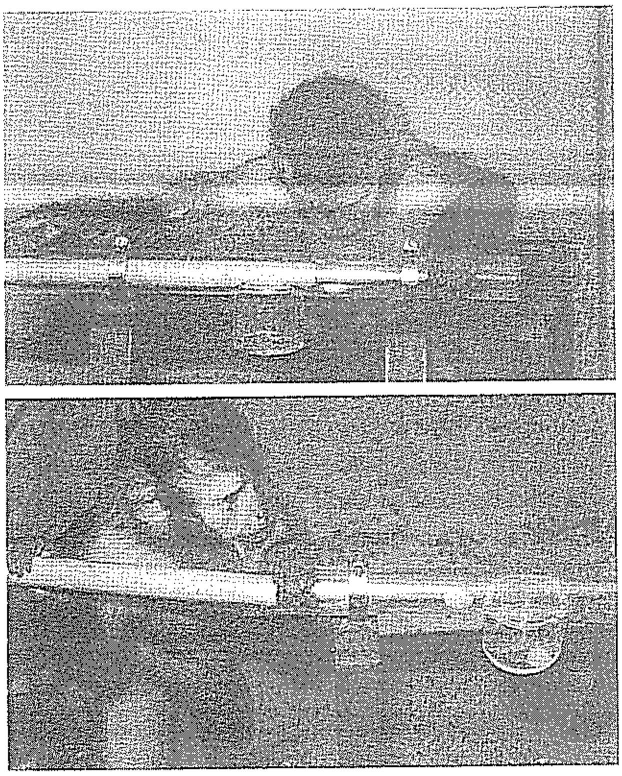

Fig. 39.6 Trap tube is a transparent tube with a hole in the center and a trap underneath it. The upper panel shows an example of correct insertion of the stick; the reward is on the right side of the trap. Note how delicately the monkey (Roberta) moves the stick with the fingertips of her right hand 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 by Elisabetta Visalberghi).

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 (Fig. 39.7), the distance rule became counterproductive. When the trap was not centered, inserting the stick into the

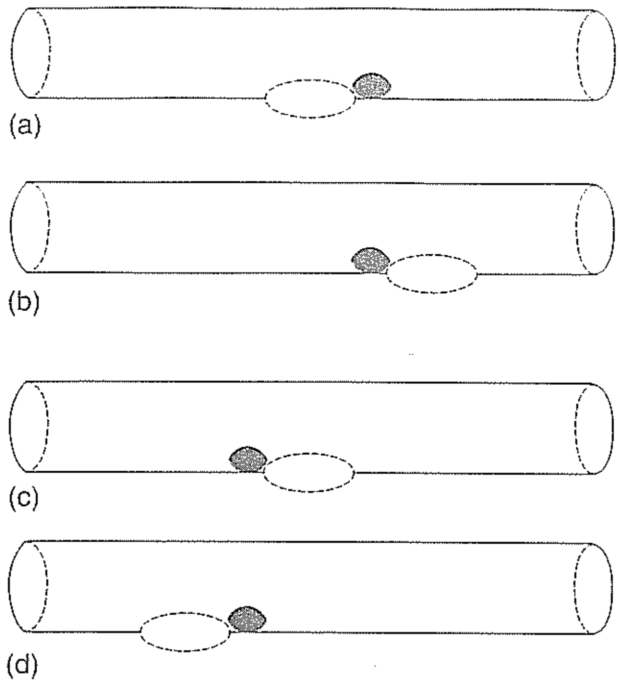

Fig. 39.7 Control tests presented to Roberta, the only capuchin that solved the trap-tube task at above-chance level. These tubes were used to test whether Roberta was using a distance strategy to solve the trap-tube task. When the reward falls into the hole, it is lost to the monkey. The figure shows 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 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).

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 by 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, using the tool and identifying the second spatial relation in the trap problem is not easy for either apes or capuchins. Mulcahy and Call (2006) and Seed, Call, Emery and Clayton (2009) demonstrated that the performance of chimpanzees in trap tasks is strongly affected by the manner in which the task is presented. Overall, the data suggest that chimpanzees, like capuchins, do not readily manage the trap relation in an object-movement task.

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. Convergent evidence that capuchin monkeys do not expect an object to fall into a gap comes from experiments reported by Fragaszy and Cummins-Sebree (1999). One or more capuchin monkeys (of four tested) that viewed a ball rolling could correctly predict its endpoint when it traveled across a continuous surface or when a barrier appeared, but none of them predicted its endpoint when the line of travel passed over a gap. Would they eventually learn to solve this problem if they generated more or different kinds of feedback from their own actions concerning objects moving across surfaces? Experiments suggest that they would.

Fragaszy and Cummins-Sebree (2005) investigated the ability of four capuchin monkeys to deal with two kinds of surface constraints (a barrier and a hole) while using a hoe to retrieve a piece of food

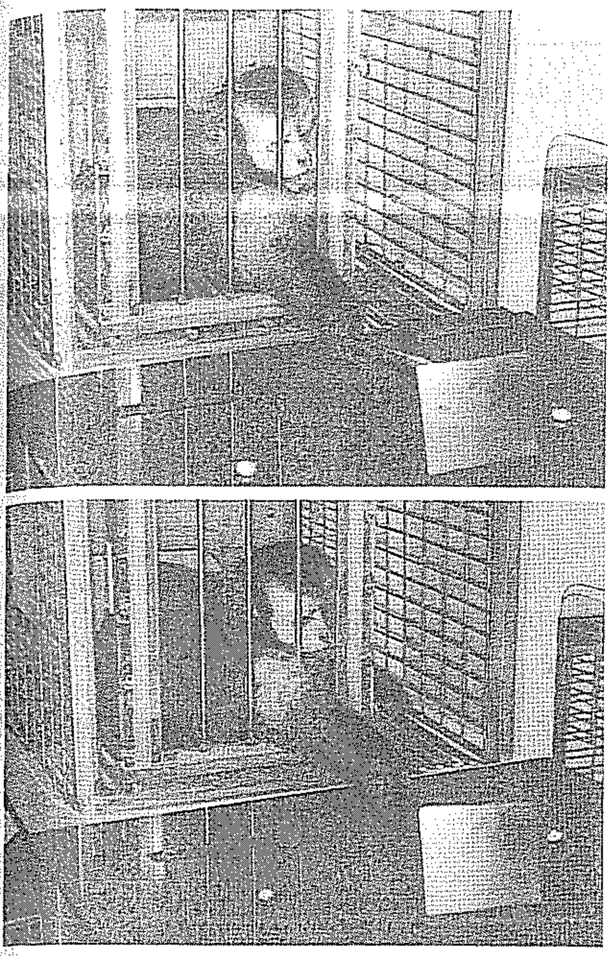

Fig. 39.8 A capuchin monkey facing the choice of retrieving one of two pieces of food with a hoe. In the lower panel, the monkey is moving the hoe to collect a piece of food by sliding it across a solid, smooth surface (the surface on the monkey's left; on the right side of the picture) instead of trying 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. Moving food past the hole posed a greater challenge to the monkeys than moving food around the barrier. They more frequently lost the food by knocking it into the hole than by losing control of it in other situations, and they learned to choose the food on the side with no hole (photographs courtesy of S. Cummins-Sebree).

(Fig. 39.8). When the hoe struck the hole, the monkey could 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, Kuroshima and Asai (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 two items (namely, tool and food), but they have difficulty mastering relationships among three items (namely, tool, food, and a constraining environmental feature, such as a hole in the surface—i.e., 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, such as a nut in an intact shell, 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 walnuts 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 contained the full kernel (valuable). Before making their choice, the capuchins lifted the nuts (presumably to judge their weight) and tapped the shells (presumably to listen or to feel the vibration). 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 actions, the monkeys produced information about the nuts that permitted them to make informed choices.

To the extent that the context permits effective production of salient information from their own action, capuchins are likely to master the problem in tool-using situations as well. Tool users act to produce information about objects and surfaces that guide further action. Both captive and wild capuchins select percussors according to weight and gain information about weight or density both by moving/lifting the objects or by tapping them; listening to the sound is a good indication of an object's density (Schrauf & Visalberghi, 2008; Visalberghi et al., 2009b). The proposition that individuals act to produce relevant perceptual information, and that this information guides further action (as proposed by Gibson 1966), opens a new avenue for investigating how and when monkeys will master using objects as tools. We anticipate an active program of research to investigate these ideas.

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 theoretically driven research on the topic; indeed, we find the literature on tool use, as a whole, to be theory-poor.

For most of the 20th century, studies of tool use in animals were descriptive or documentary. We are now in a position to address the challenge of understanding the origins and mechanisms that support the use of tools in diverse species. This task requires theoretically driven empirical 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 et al. (Parker & Gibson, 1977; Parker, Langer, & McKinney, 2000) 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 Gibsonian perception-action theory, and applied it *post hoc* to previous studies with captive capuchins and prospectively in recent experiments with wild capuchins (see Table 39.1). This theory seems to us to offer promising new directions for comparative research (see Fragaszy & Cummins-Sebree, 2005). 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; Mannu & Ottoni, 2009; Panger, 1998; Souto et al., 2011) will continue to be enormously important to our understanding of the functional consequences of these activities.

Second, field experiments are proving valuable. For example, we have conducted studies at FBV (Piauí, Brazil) where wild capuchins are provided with opportunities to use tools, creating a field laboratory like that which Matsuzawa et al. have developed at Bossou (Matsuzawa, 1994). Field laboratories provide opportunities for many kinds of longitudinal, developmental, and experimental studies. For example, at our field laboratory we investigated capuchins' selectivity for stone hammers, anvils, and nuts (Fragaszy et al., 2010b; Liu et al., 2011; Visalberghi et al., 2009b) and interindividual differences in the kinematics of lifting, striking, and transporting hammer stones (Etho*Cebus*, unpublished data; Liu et al., 2009a). Overall, the more comparable data we obtain on wild capuchins and wild chimpanzees, the more powerful will be our comparisons of these two tool-using genera.

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, as described in Fragaszy and Cummins-Sebree (2005). In general, this theory directs our attention to the physical and perceptual challenges of using objects as tools. 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 has received funding from the European Community's Seventh Framework Programme FP7/2007-2013, "Challenge 2—Cognitive Systems, Interaction, Robotics'," under grant agreement No FP7-ICT-IP-231722, project "'IM-CLeVeR—Intrinsically Motivated Cumulative Learning Versatile Robots," and from the National Science Foundation.

The authors thank J. Lockman, H. Takeshita, and S. Itakura for discussions about the model of tool use presented in Table 39.1.

Note

[1] Hauser (1997) tested cotton-top tamarins (*Saguinus oedipus*) in a choice paradigm (following Brown, 1990, who tested 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 et al. (2003) used looking time to evaluate 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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