Chapter 12

Capuchins as Stone-knappers?: an Evaluation of the Evidence

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Comparisons of tool-using behaviours in human and non-human primates can help answer this question: is stone knapping a uniquely hominin behaviour? More specifically, comparisons between humans, apes, and capuchins may allow us to determine whether certain tool-using capabilities (including propensities to knap stone) are the result of divergent or convergent evolution. We review findings from our lab and those of others with capuchin monkeys to generate a set of possible requirements for stone knapping to develop in a primate species based on a perception–action model. We also speculate on the likelihood that a population of tufted capuchins (Cebus apella) *could spontaneously develop these skills.*

The hand is the cutting edge of the mind.
(Jacob Bronowski)

For many centuries, the ability to use tools was considered to be a uniquely human behaviour, something that divided humans from the rest of the animals. However, as Beck (1980) documented compellingly, we are not the only animal species that uses tools. Many species, from fish to mammals, use tools, but the position of humans at the top of the mountain is hardly challenged by non-human species. Other animals typically use an object as a tool in one or a few specific situations, and their actions with tools lack the variety and complexity of human actions. This leads to an evolutionary conundrum. How can we understand tool use (by humans) as the outcome of a continuous evolutionary process if we see only its discontinuous nature with respect to tool use by other species? This is where studies of tool use in non-human primates can help. A few species of non-human primates commonly use tools for varied purposes and in flexible ways; these include two species of great apes, orangutans (*Pongo pygmaeus*) and chimpanzees (*Pan troglodytes*) and one genus of monkeys, capuchins (*Cebus*) (Boesch & Boesch-Achermann 2000; Matsuzawa 2001; Tomasello & Call 1997; Visalberghi & Fragaszy 1999; in press). Both chimpanzees and capuchins sometimes use stones as pounding tools. Pounding with a stone can be seen as a precursor to stone knapping; consequently, these taxa are of the most interest with respect to the purposes of this volume.

The primary goal of the international workshop that led to this volume was to determine in what sense stone knapping is a uniquely hominin behaviour. To do this, we must answer a set of related questions about tool-using actions in other species, and particularly about their use of stones as pounding or cutting tools. First, do other primates exhibit behaviours similar to stone knapping, in form or consequence? Second, if they do not, could they develop such behaviour under appropriate conditions? If so, what constitutes appropriate conditions? In this chapter, we examine these questions with respect to the capuchin monkey (*Cebus*), and particularly with respect to tufted capuchins (*Cebus apella*), the species studied most extensively in captivity. Capuchins, from Central and South America, are phylogenetically far removed from the great apes and humans, as Old World (African and Asian) and New World (American) primates last shared a common ancestor an estimated 40 million years ago (Jones *et al.* 1992). Capuchins are much smaller (average adult body weight, ~3 kg) than apes and are more arboreal than chimpanzees (Fragaszy *et al.* 2004). Yet, they are alone among monkeys that use objects (including stones) as pounding and cutting tools, the first step in stone knapping.

Studying tool-using behaviours in capuchin monkeys gives us a unique opportunity to study the origins of tool use. Because of their phylogenetic distance from great apes and humans, capuchins allow us to investigate *convergent* evolution (i.e. how certain ecological conditions can promote the evolution of similar traits in species that are not closely related: Raven & Johnson 1992) of tool-using abilities. If we study only the great apes, and the great apes exhibit certain types of tool-using abilities that are similar to simple human tool use, it is difficult to determine the evolutionary trajectory of those behaviours: is the similarity a result of common descent or convergent evolution? In contrast, similarities in tool-using behaviours between capuchins and anthropoids (humans and apes) can be safely laid at the feet of convergent evolution. No other monkeys show the proclivities to manipulate objects and to use tools that capuchins do (Fragaszy *et al.* 2004). This activity is not a primitive trait, shared between capuchins and anthropoids through common ancestry.

Capuchins also provide an opportunity to examine the ontogeny of tool use. These monkeys, like humans and apes, develop skill through practice at managing the movement of objects, producing appropriate forces, achieving precision placement, etc. in tool-using situations (Cummins-Sebree & Fragaszy in prep.). Like humans and apes, they pass through a lengthy period of juvenescence in which the basic elements of manual activity are present but skill in manual action is developing, and young individuals develop problem-solving skills, including the use of tools, in a supportive social context (Fragaszy *et al.* 2002; 2004; Resende *et al.* 2003). Thus they provide an independent model of development of skilled tool use in highly-social individuals.

In this chapter, we briefly review characteristics of capuchin monkeys that impact their use of objects as tools. Then we review what is known about capuchins' tool use, with emphasis on stone tools, from observations of wild and semi-free ranging monkeys and studies with captive monkeys. We evaluate this evidence from a perception–action viewpoint (Gibson 1979; Lockman 2000; Smitsman 1997; Smitsman *et al.* this volume); that is, in relation to the requirements to produce spatial and force relations between objects and the individual's ability to discover and to make use of appropriate affordances to meet these requirements. Finally, we evaluate capuchins' behavioural characteristics in relation to hypothesized requirements for stone knapping as these are understood for humans. We shall see that capuchins have some potentially advantageous characteristics for stone knapping, but face many significant constraints that humans do not, or that humans overcome through growth and persistence. Thus capuchins' actions with stones, although impressive in some respects, are not likely to extend spontaneously to stone knapping. Whether knapping might be instantiated in capuchins through carefully-scaffolded learning remains to be determined.

Capuchin monkeys: the tool users of the New World

Fragaszy *et al.* (2004) provide a comprehensive review of the behavioural biology of the capuchin monkeys; we touch here only on highlights that in our opinion are most relevant to skilled use of stones as tools. These include manual dexterity, proclivity to combine objects and surfaces in action, and tendency toward terrestriality. Capuchin monkeys are well known for their manipulative and destructive style of foraging, in which they use their hands to search for hidden foods and extract small objects from embedding surfaces or from husks, shells, or other protective coverings (e.g. Boinski *et al.* 2001; Christel & Fragaszy 2000; Fragaszy & Adams-Curtis 1991; Janson & Boinski 1992; Panger 1998). Capuchins are the only New World monkey genus known to use a precision grip, including thumb-forefinger opposition (Christel & Fragaszy 2000; Costello & Fragaszy 1988). Precision grips and other aspects of individuated digit control afford greater dexterity than the whole-hand grips used by other New World monkeys. They also imply haptic sensitivity to force and friction during action, although these aspects of manual function have not been studied. Manual actions are used to explore objects in other ways as well: Visalberghi & Néel (2003) describe how capuchin monkeys lifted nuts in their hands and tapped the shells with their fingers to evaluate whether the shell merited opening (contained nut meat) or not (were empty). Capuchin monkeys explore objects with their hands using similar actions as do humans (Lacreuse & Fragaszy 1997). Altogether, they appear to have sufficient manual dexterity to knap stone.

Capuchin monkeys discover how to use objects as tools through persistent exploratory actions with objects, including actions that combine objects and surfaces. Capuchins of all ages forcefully bang objects against surfaces in a very common form of exploration, just as do human children (Fragaszy & Adams-Curtis 1991; compare with Lockman this volume). Exploratory banging supports discovery of how to use an object to pound something else for effect; capuchins readily discover that they can use a hard object to break open something less strong.

Using stones as tools virtually requires a terrestrial habit (Fragaszy *et al.* 2004; Visalberghi 1997).

Banging something against a surface is easiest if the surface is solid and stationary, for postural reasons and also for precision of striking (a moving target is more challenging). The ground is an ideal fixed (often flat) solid surface; a swaying tree limb is not. If a pounding tool is dropped on the ground, the actor can retrieve it readily. If a pounding tool is dropped from the top of a tree, retrieving it is more problematic. Finally, finding a hard object to use to pound is more likely on the ground than up in a tree. For all these reasons, highly-arboreal animals, no matter what other characteristics they may have, are unlikely to use stones as tools. Capuchins, although primarily arboreal, spend substantial amounts of time on the ground when food is to be found there more readily than elsewhere and when risks of predation are offset by access to resources (Fragaszy 1990; Rose 1994). Thus, they are occasionally in the right place to discover the value of pounding objects against a surface using another object (i.e. hammering).

In sum, capuchins exhibit the necessary prerequisites to use stones as pounding tools: they are dexterous, they produce pounding actions commonly in exploratory and instrumental situations, and they spend time on the ground when conditions favour doing so. Thus it should come as no surprise that capuchins in captive conditions routinely use stones and other hard objects as pounding tools. Until very recently, however, we had limited evidence that capuchins in nature did so. Fernandes (1991) reported the first direct observation of a capuchin monkey hammering; it used a piece of oyster shell to pound open an oyster still fixed to the substrate. It is illuminating that the food was embedded in the ground. But this case concerned a single individual. A better-studied circumstance concerns capuchin monkeys in Tietê Ecological Park, São Paulo, Brazil. These monkeys live in a habitat devoid of natural predators, and they are provisioned well with pelleted food and fruit, so food is abundant. Palms (*Syagrus romanzoffiana*) are also abundant, and the monkeys relish the small nuts of these palms. They cannot bite these hard nuts open; they can only open them by banging the nuts with a stone against a hard surface (such as another stone). Fortunately for the monkeys, loose stones are abundant in this park, the nuts are abundant on the ground, and the monkeys collect nuts and bring them to anvil sites near the trees under which the nuts are collected. The monkeys devote much time and energy to opening palm nuts by banging them with stones against the anvil surface (Mannu 2002; Ottoni & Mannu 2001; Resende *et al.* 2003). Very recently, Oxford (2003) and Fragaszy *et al.* (in review) document that wild monkeys in the cerrado woodland of Piauí, Brazil, where palm-fruit clusters grow directly from the ground, routinely use stones to pound open palm nuts. Like the monkeys in Tietê Ecological Reserve, the monkeys in Piauí go to the ground to collect palm nuts, transport them to an anvil site, and use a stone to pound them open on the anvil surface. Systematic observation of the monkeys in Piauí is just beginning, but already this population has confirmed that some wild capuchins use stone tools routinely in a manner and context superficially similar to that reported for wild chimpanzees in west Africa (e.g. Matsuzawa 2001; Boesch & Boesch-Achermann 2000).

Capuchins' actions with stone tools

Capuchins in captivity use sticks to probe, sweep, and pound; cups to hold liquids, paper towels to absorb water, and stones to pound (e.g. Anderson & Henneman 1994; Westergaard & Fragaszy 1987; Westergaard *et al.* 1995; Westergaard & Suomi 1993; 1994; 1995; see Fragaszy *et al.* 2004 for a comprehensive review). Although we have extensive descriptions of successful use of different tools, and know something about the facilitative role of social context for younger animals in particular (Resende *et al.* 2003; Visalberghi & Fragaszy 1990; 1996; Westergaard & Fragaszy 1987), we know almost nothing about the biomechanical or kinematic aspects of tool use, nor about the acquisition of skilled action. Thus we cannot yet compare capuchins to other species in these domains. We are, however, beginning to understand the range of situations they can manage in using objects, and we review some of the relevant findings in this domain later in this chapter.

Experimental studies shed some light on capuchins' aptitude for using stone tools and for modifying stones. Studies of capuchins using a tool to pound something open have been conducted in four laboratories. The first reports documented that capuchins used stones to pound open loose nuts (Anderson 1990; Antinucci & Visalberghi 1986) or a metal object to pound open nuts fixed to a surface (Fragaszy & Visalberghi 1989), confirming earlier anecdotal reports going back hundreds of years, to Erasmus Darwin (Darwin 1794) and others. More germane to the topic of stone knapping, Westergaard and colleagues conducted a series of studies on capuchins using and modifying stones for different purposes (Westergaard & Suomi 1993; 1994; 1995; Westergaard *et al.* 1995). For example, Westergaard & Suomi (1995) presented capuchins with a variety of objects (including stones) that could be used as pestles for grinding sugar cane. Seven of 18 capuchins used a stone to grind and pound the sugar cane; the percentage of tool-using bouts per individual involving stone pestles ranged from 24 per cent to 82 per cent. Some of the monkeys also combined food biscuits with the sugar cane, adding the biscuits into the test apparatus between bouts of grinding. The monkeys modified stick pestles using their teeth and hands, leading the authors to conclude that manual and dental actions can produce artefacts that are similar in appearance to those left on stick tools by early hominins. However, they did not modify stone pestles.

Westergaard & Suomi (1997) found that capuchins transferred stone tools and food across groups. Two groups of capuchins were given different items: one group received stones (sharpened quartzite), while the other group received a container of hazelnuts (a desirable food item for capuchins) with an acetate lid. The cages of the two groups were pushed together so that the monkeys could transfer food and/or stones. Over 100 times across 64 trials (out of 68), monkeys in the second group obtained stones provided by the first group, and three capuchins in the second group used those stones to cut through the acetate lid to get the hazelnuts. Capuchins in the second group 'provided' food to the first group by giving or by leaving the nuts within arm's length in 62 of 68 trials for a total of 192 food transfers. These behaviours indicate that capuchins are capable of 'sharing' food and tools, as seen in chimpanzees (Savage-Rumbaugh *et al.* 1978; Matsuzawa 2001). The process by which food and stones moved between cages was primarily passive, enabled by individuals in the two groups approaching their common cage walls in a tolerant manner and leaving objects within reach of their neighbours. Tolerance of nearby others while feeding is characteristic of capuchins, most particularly of adults towards infants and juveniles less than two years old (Fragaszy *et al.* 1997; 2004).

Westergaard & Suomi (1994) investigated the extent to which capuchin monkeys modified stones and later used those as cutting tools. When provided with quartzite stones, six of eleven capuchins used three actions that produced stone flakes (sharp debris). The three actions consisted of: a) pounding the stone against a stable, stationary surface; b) striking the stone against a portable, but stabilized stone surface (i.e., a stone positioned on a perch); and c) pounding one stone in hand to another stone in the other hand. Two individuals used the third technique, the one we consider most like stone-knapping. Westergaard & Suomi also provided the capuchins with stones and a container of syrup with a sheet of clear acetate covering the opening of the container. Three monkeys used the stones without modification to cut or strike open the acetate covering. Two monkeys used two stones in combination (as a 'chisel and hammer') to open the acetate. One capuchin attempted to use larger stones to cut the acetate; when this failed, he struck stones to other stones in ten bouts, producing flakes and sharp cores that he then used to cut through the acetate.

In a second study of stone flaking, Westergaard & Sumoi (1995) provided seventeen capuchins from the groups in the previous study with quartzite stones over a four-week period and monitored their actions with those stones. Eleven capuchins used five techniques to modify stones presented to them: throwing a stone onto a surface, pounding a stone with a piece of wood, striking a stone against the caging material, striking one stone against another positioned on a surface, and striking a stone in hand to another stone in hand. The capuchins produced almost 300 flakes, and 93 per cent of the flaked cores contained at least one sharp edge. The experimenters removed the stones and flakes, and one week later gave the monkeys a collection of cores and flakes, along with a lidded container holding peanut butter. Three capuchins that used stones to cut in the previous study also used the flakes and sharp cores to cut into the container of peanut butter.

Westergaard's studies provide evidence that capuchins can modify stones using species-typical pounding behaviours and that they will use the sharpened edges produced through their actions. Both of these behaviours are precursors to stone knapping. However, we cannot assume that capuchins modified the stones intentionally, as is implied in human stone knapping. Moreover, the cores the monkeys created were crude at best. Figures show only a few clean breaks per core, and the cores do not resemble well-knapped stones (see Bril *et al.* this volume; Pelegrin this volume). Stone knapping implies hitting a core stone with a percussor stone to produce a conchoidal fracture (Pelegrin this volume). At the present time, we have no evidence that capuchins produce conchoidal fractures. Thus in several fundamental respects, capuchins' actions do not merit the label of 'stone knapping'. Nevertheless, their actions provide an interesting counterpoint to human stone knapping in other ways. We consider these facets of their actions next.

Components of stone-knapping: How do capuchins measure up?

Components of action important for stone knapping in humans include stable upright postural, bimanual coordination (one hand to strike and the other to resist the strike), specialized roles for each hand, appropriate positioning of the stones in each hand, and application of appropriate force with the percussor to the core on the right part of the core and at the appropriate angle. Selection of stones and their positioning in the hands precede and follow these actions. Clearly there are many steps to get to the point where striking one stone with another will reliably produce a useful outcome, as many chapters in this volume attest. Capuchins most obviously possess one of the fundamental components of knapping, that is, applying force with an object held in the hand or hands to another object or surface (basic percussive striking). This, as we have seen, is a common element in their foraging repertoire and their exploratory behaviour. But what of other elements of action more specific to knapping? Below we reconsider capuchins' actions in the various studies of pounding with stones, and other tool-using situations, with respect to the action components of stone knapping.

Bimanual coordination, manual laterality, postural stability, and force requirements

As Corbetta (this volume) pointed out, infants' bimanual capabilities increase concurrently with postural stability, and so does their ability to solve object-related problems, such as opening a container or (much later) knapping stones. Increased postural stability is also linked to an increase in the strength of lateral preference for the acting hand (see Corbetta for humans, Holder for non-human primates, this volume). Bimanual activity with portable objects is a general capability of non-human primates. It appears in infant capuchin monkeys reared with their mothers from the third month of life, just a few weeks after unimanual activity is evident (Adams-Curtis *et al.* 2001), and capuchin monkeys commonly use both hands in manipulation from infancy onward. Even in infancy they exhibit differentiated roles for the two hands in bimanual manipulation (Adams-Curtis *et al.* 2001), and such activity is common throughout their lives. The prehensile tail of capuchin monkeys is an important support for bimanual activity; it provides postural stability from many positions other than vertically upright. Capuchins have a much wider range of stable postures than do humans or apes, thanks to their prehensile tails (e.g. Bergeson 1996; Youlatos 1999). Thus, demands for bimanual action and postural stability do not limit capuchins' opportunities to knap stone.

The evidence to date suggests that capuchins often show no particular lateral bias in simple reaching or other ubiquitous activities (such as which limb is used to initiate locomotion), but they readily exhibit individual biases when performing finely modulated movements with the hands or when dealing with strong postural demands, such as maintaining a bipedal stance (Anderson *et al.* 1996; Panger 1998; Westergaard *et al.* 1997; 1998a). As a general rule, the more demanding the task with regard to posture or dexterity, the stronger are individual biases, suggesting that individual bias arises from practice with the task (e.g. Fragaszy & Mitchell 1990; Limongelli *et al.* 1994; Spinozzi & Cacchiarelli 2000; Spinozzi & Truppa 1999; 2002). However, there is no consistent direction of asymmetry across the (small) populations. For example, Westergaard & Suomi (1993) report that eight of fourteen capuchin monkeys that used a stone to crack open a nut preferentially used the left hand; four preferentially used the right hand, and the other two exhibited no bias. This mixed outcome (in terms of direction of bias across individuals) is typical of studies assessing manual preferences in non-human primates.

A group-wide directional bias for the use of one hand has been found in more than one group of capuchins, but only in tasks with a high demand for fine spatial positioning and repositioning of the fingers and incorporating a strong haptic component. The tasks in question involved locating and prehending seeds placed in crevices of irregularly-shaped objects, discriminating seeds from similarly-shaped pieces of tinfoil, or searching for grapes buried in wood shavings or under water and discriminating them from stones of similar size and shape. A left-hand bias was evident in three groups of capuchin monkeys in these conditions (64 monkeys, three studies combined: Lacreuse & Fragaszy 1999; Parr *et al.* 1997; Spinozzi & Cacchiarelli 2000). Forty-two of the monkeys preferred left or right hands equally often when they picked up small pieces of food, whether they could see their hands or not, suggesting that reliance on touch alone is not sufficient to induce consistent use of the left hand (Lacreuse & Fragaszy 1999; Spinozzi & Cacchiarelli 2000).

Maintaining a bipedal stance without the use of the tail as an anchor is posturally demanding for capuchins. Spinozzi and colleagues (1998) measured preferences for the acting hand in a group of capuchins in reaching and retrieval tasks requiring quadrupedal and bipedal postures. A unimanual task entailed simple reaching for food, while the bimanual task required the monkeys to retrieve food from a plastic tube. Both tasks were presented close to or on the ground and higher off the ground. The capuchins did not exhibit hand preferences in the quadrupedal-unimanual condition, but they did exhibit a group-level right-hand preference for the upright-unimanual and both bimanual conditions. The strength of hand preference increased across conditions in the following pattern: quadrupedal-unimanual, upright-unimanual, upright-bimanual, and a bimanual pattern induced by placing the tube 5 cm from the ground. In this situation the monkeys adopted a crouched position in which the torso touched the ground while the hands manipulated the tube.

For most manually-skilled individuals, hand preference is evident for the acting hand (see chapter by Holder this volume). In tasks requiring the use of tools, capuchins may exhibit individual hand preferences for the acting hand, although not a population-level preference (Anderson *et al.* 1996; Cummins-Sebree & Fragaszy 2005; in prep.; McGrew & Marchant 1997; Westergaard *et al.* 1998a). A hand preference for the acting hand may aid the acquisition of skill in stone-knapping, perhaps by supporting the development of a routinized motor pattern for efficiently striking the core stone (Wilson 1998). A routinized pattern might support more efficient perceptual learning that leads to each hand adjusting striking force or resistive force and positioning for optimal outcomes. Capuchins can develop strong manual preferences, but they rarely are as lateralized as humans for skilled manual action. This characteristic mitigates against the development of skilled knapping.

We do not have any information on the forces that capuchins can produce through percussion. Given that they are much smaller than humans (remember, an average adult capuchin weighs a mere 3 kg), we cannot expect them to generate equivalent kinetic force. Their smaller hands can hold smaller stones, and they generate a much smaller moment arm when striking. The physics of this arrangement clearly limit the force they can produce compared to humans. The force required to flake a stone does not scale with its weight, but with its hardness and crystalline structure. Thus capuchins are at a stiff disadvantage compared to larger-bodied primates with respect to flaking stones by manual action alone.

Knapping stone skillfully requires precise positioning of the percussor and core stones with respect to each other, skill that takes humans a long time to acquire (Roux *et al.* 1995). Can capuchins master this kind of haptic-kinesthetic-visual coordination of action? We do not know; we have no evidence bearing on this issue. We do, however, have experimental evidence bearing on the more general theme of capuchins' abilities to produce and modify spatial and force relations between objects and surfaces in other situations. We review some of these studies to illustrate capuchins' capabilities in this general domain.

Sliding an object across an irregular surface

Consider first the challenge of using a tool to move an object across a surface. If the surface is smooth and continuous, then sliding the object is straightforward. If there is a hole or a barrier along the projected path of retrieval, however, one must use the tool to manoeuvre the desired object around the aberration. For example, suppose a group of children are playing a baseball game in a fenced yard. The ball rolls under the fence and out of a child's reach; however, his or her baseball bat is sufficiently long to rake in the ball. If the ground between the ball and the child is fairly smooth and continuous, then the child may retrieve the ball with little effort. But suppose there are bumps or hollows along the potential trajectory for retrieving the ball. In that case the child must attend to the surface features and manoeuvre the bat so that the ball does not fall into a hollow or become lodged behind a bump.

We wanted to know if capuchins could detect and avoid surface aberrations when retrieving food with a tool (Cummins-Sebree & Fragaszy in prep.). The design of our study was inspired by one reported by Povinelli (2000) with chimpanzees, although our theoretical perspective, the details of our procedure, and our interpretation of our findings differ substantially from his. Povinelli's (2000) aim was to determine if the chimpanzees would select, in advance of action, a tool and a platform that did not contain a hole *vs* an identical tool on a platform that had a hole in front of the desired food item. According to Povinelli, if the chimpanzees understood the causal relations governing the movement of the food by the tool, and the fate of the food when it fell into the hole, they would select the tool and platform that did not contain the hole. If they did not have a 'concept of causality', then they would choose between the platforms at random. In this task, the platforms were constructed with vertical walls on three sides, the blade of the hoe tool was wider than the hole, and the only movement that could be made with the hoe was a straight pull towards the body (i.e. no horizontal movement of the tool was allowed). Povinelli found that the chimpanzees initially chose at random between the two platforms and tools, although several individuals quickly developed a preference for the platform with no hole.

We interpreted the chimpanzees' actions as reflecting their ability to detect through action the relevant properties of the surfaces. Accordingly, we arranged our study to provide different opportunities to learn about the surfaces through action. We presented capuchins with three types of platforms (plain, containing a hole, or containing a barrier) in a dichotomous choice task in three phases of testing. We measured the frequency of choices made in selecting the platform from which to retrieve a food treat, as well as success in retrieving the treats. Working from a perception–action model, we predicted that capuchins would not initially attend to a hole in a platform in

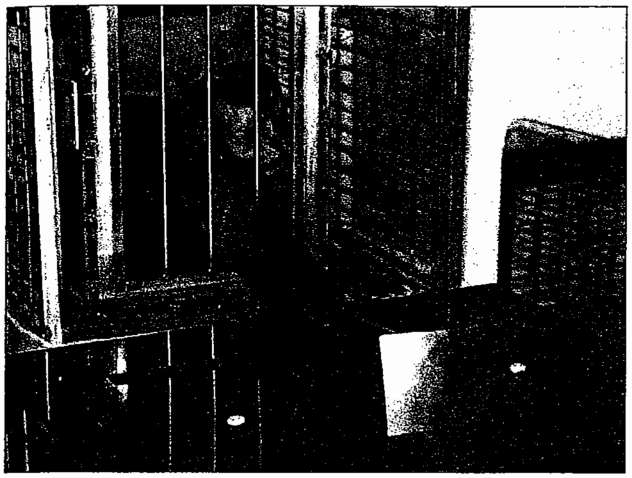

Figure 12.1. *Phase 1: our subject chooses to retrieve food from the plain platform instead of from the hole platform and is successful.*

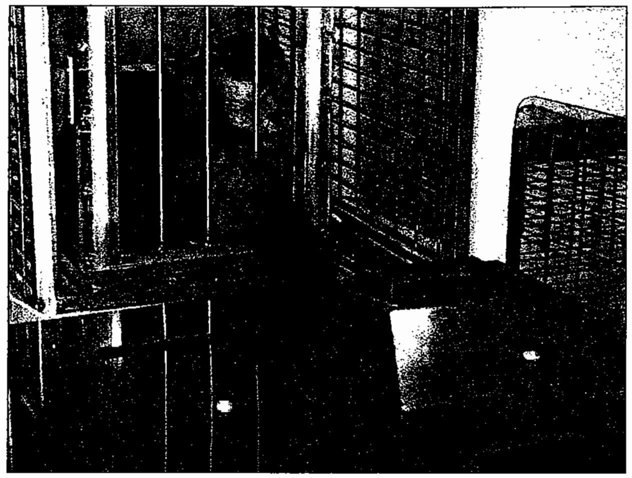

Figure 12.2. *Phase 2: our subject chooses to retrieve food from the barrier platform instead of from the hole platform and is successful.*

the early phase of testing, and thus would not avoid it when attempting to retrieve a treat with the tool. Consequently, the capuchins would be less successful at using the hoe tool on the platform with a hole than on the platform with a barrier, where the treat could be moved behind the barrier but could still be retrieved through persistent efforts. We hypothesized, however, that our subjects would avoid a barrier on a platform early in testing, because the barrier would be more visually salient than the hole, and because the monkey could more reliably gain information about a solid obstacle by striking it with the tool than it could gain information about the hole by swiping across it. We also predicted that as the capuchins progressed through testing, they would learn to attend to the hole and to modulate their actions with the tool when moving food past the hole.

Four adult male tufted capuchin monkeys (*Cebus apella*) participated in this task. We constructed two dark gray PVC platforms to present to the monkeys that each contained a hole in the centre of the front quarter. We could place a PVC block below the hole to yield a plain, continuous platform, or above the hole to yield a platform with a barrier (see Figs. 12.1–12.3). We provided a hoe to be used as a tool to retrieve small pieces of dried fruit and oat cereal. The design of our apparatus allowed movement of the hoe tool horizontally and vertically, and the blade of the hoe could fall into the hole.

We divided testing into three phases. For all phases, we presented a food treat at the centre of each of two platforms so that the treat would be in view but behind either the hole or the barrier. The hoe was placed in the centre, between the two platforms, so that the handle was within the monkey's reach. In

Figure 12.3. *Phase 3: our subject successfully maneuvers food from around a barrier.*

Phase 1, we presented the plain platform and either the hole platform or the barrier platform (see Fig. 12.1). In Phase 2, we presented the hole and barrier platforms together (see Fig. 12.2). In Phase 3, we presented two similar platforms with either the holes or the barriers (see Fig. 12.3). Our dependent variables were choice of platform and success at retrieving the food.

In Phase 1, none of the four capuchins preferred the plain platform over the hole platform, and their rate of success suffered when they chose the hole platform. Two of the four capuchins, however, preferred the plain platform when it was paired with the barrier platform, and their success rates were higher accordingly. In Phase 2, one subject preferred the barrier platform to the hole platform, and he succeeded at retrieving his treats at above-chance levels. Two of the other three capuchins chose the hole platform more often than the barrier platform, even though they continued to lose the treat into the hole more often than they were able to retrieve it. By Phase 3, two of the four subjects mastered using the hoe to retrieve the treat around both the barriers and the holes, while one subject continued to perform at chance levels. The fourth subject chose the platform on his right and used his left hand for almost all trials, regardless of which platform was on his right.

We suggest that capuchins can detect barriers on surfaces more readily than they can detect holes in the same type of surfaces. Moreover, the monkeys can move a desired object past a barrier more easily than past a hole. This is sensible, not only because of the visual salience of barriers, but also because of proprioceptive information the monkey produces when it contacts the barrier with the hoe. The hole is less visually salient, although the hole can provide proprioceptive information about the surface if the blade falls into it (which occurred often for our capuchins). Also, repeated attempts at retrieval are possible when the treat touches the barrier but not when the treat contacts the hole. Thus, for several reasons, the monkeys learned to manage moving past barriers more quickly than past holes.

Managing multiple relations concurrently

Monitoring the position of the food relative to the hole and the tool simultaneously demands joint attention to two dynamic spatial relations external to the actor's body: the relation between the hoe and the food, and between the food and the hole. These relations are dynamic because the position of the food changes over time, and thus its relation to both hoe and hole change over time as well. Thus capuchins' management of this problem is impressive. Stone knapping also requires managing multiple simultaneous dynamic spatial relations, in this case, minimally, between the two stones and between each stone and each hand. This aspect of stone knapping would not, by itself, prevent capuchins from achieving basic success at the task. We do not know if capuchins can also concurrently monitor the position of objects in the hand to achieve specific points of contact between objects, or what kinds of practice support learning to do this. This aspect of using objects as tools challenges young children (Lockman 2000) and it challenges adult human stone knappers with years of experience (Roux *et al.* 1995).

Selecting a tool and positioning it

To knap stones to yield sharp flakes and core stones, one must select percussor and core stones of appropriate material, and of appropriate size, shape and mass for the actor. Capuchins' choices of stones for pounding have not been studied. Capuchins' choices, however, have been studied in other kinds of tool-using tasks. The results of these other studies bear on the general question of attention to affordances of objects. We use affordance here to mean the usefulness of an object for a particular user and a particular use. For example, suppose a child's ball has rolled underneath the sofa and he or she cannot reach it directly. To retrieve it, the child would need to use an object long enough to make contact with the ball, as well as thin enough to be held comfortably in the hand. The tool should also be light in weight but rigid enough to transfer the force of the child's swipe to the ball so that ball would move from underneath the couch. Though the tool could be of various shapes, one that is shaped like a hook may work well because the ball could be manoeuvred within the crook of the hook. Other properties of the selected tool may not be important, such as its colour, texture, or familiarity.

We conducted a series of experiments to determine what properties guided tufted capuchins' selection of tools to retrieve food treats (Cummins-Sebree & Fragaszy 2005). We presented our subjects with hook tools differing in colour, shape, texture, and size, and in their orientation to a food treat (i.e. the crook surrounding the food, or the food outside the crook) in a dichotomous choice task. We measured frequency of choices of the various tools, as well as success in using the tools to retrieve food treats. This set of experiments was a replication of a study done by Hauser (1997) in which he provided these same types of tools to cotton-top tamarins (*Saguinus oedipus*), another New World primate species that, unlike capuchins, is not known for their object-manipulation skills. We predicted that the capuchins would select tools based on their shape and size, but not on their size or texture; we also expected the capuchins to choose tools that minimized the actions required to pull the treat within reach (i.e. select tools that contained the food within the crook). In situations in which the treat resided outside the crooks of both tools, we predicted the capuchins would attempt to realign a tool and occasionally succeed at using the tool in this manner. By modulating their behaviour, the capuchins would learn how to use particular tools.

Six adult male tufted capuchin monkeys (*Cebus apella*) participated in this task. We constructed the hook tools from flexible copper tubing. We used wire to make 'bumps' and punctured holes into the tubing to provide different textures, and we painted them different colours. The tools were placed two at a time on a plain PVC platform, along with food treats (dried fruit and oat cereal).

We administered a training session, followed by three experimental phases. In the training session, we presented each subject with two blue hooks (similar to candy canes in appearance); one hook contained the treat within the crook, while another treat lay outside the crook of the other hook. In Experiment 1, we presented two tools that differed in one of four properties from the original blue hooks: colour, shape, texture or size. For Experiment 2, we presented each subject with two novel tools that differed in the location of the treat; some tools contained the treat within the crook ('possible'), while others did not have the treat within the crook, and thus required additional manipulation to retrieve the treat ('convertible'). These tools could differ dramatically in colour, shape, and texture from the original blue cane (see Fig. 12.4). In Experiment 3, we presented tools that were 'possible' tools in Experiment 2 as 'convertible' tools, along with novel tools in the 'possible' orientation. Our dependent variables were choice of tool and success at retrieving the food.

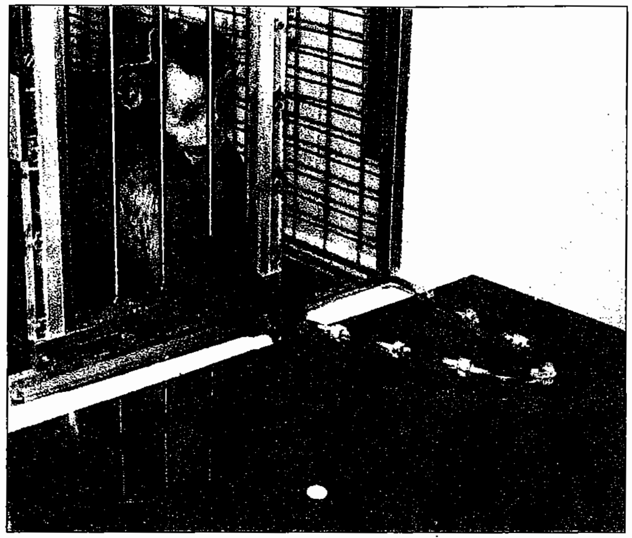

Figure 12.4. *Experiment 2: our subject chooses a 'possible' tool instead of a 'convertible' tool to retrieve food and is successful.*

In Experiment 1, the capuchins did not exhibit a preference for hook tools based on colour, shape, texture, or size. However, the monkeys preferred 'possible' tools to 'convertible' tools when they were paired together in Experiments 2 and 3, regardless of the familiarity of the tool. When 'convertible' tools were chosen, the capuchins often attempted to reposition those tools to retrieve the treat, and they occasionally were successful at doing so. Though they did not often succeed with 'convertible' tools, their success with those tools increased from 2 retrievals out of 24 attempts in Experiment 2 (8 per cent) to 13 retrievals out of 35 attempts in Experiment 3 (37 per cent). For further details see Cummins-Sebree & Fragaszy (2005).

The performance of the tufted capuchins differed in some ways from the cotton-top tamarins' performance (Hauser 1997). The tamarins chose tools based on their shape and size, but not on their colour or texture, while the capuchins showed no preferences based on those properties. Like capuchins, tamarins chose 'possible' tools more often than 'convertible' tools when paired together. However, when a 'convertible' tool was chosen, the tamarins never attempted to realign the tool so that the treat could be retrieved (Hauser pers. comm.). Thus, the tamarins never succeeded at retrieving food with a 'convertible' tool. On the other hand, the capuchins attempted to reposition 'convertible' tools, and they were occasionally successful when doing so. We predict that the capuchins' success rates with those tools would increase if given additional opportunities to manipulate them in this task.

We suggest that the differences in performance between the two species are due to their differing propensities for object manipulation and their ability to modulate actions with their arms and hands, and thus with the tool. It seems the tamarins find it more challenging to alter their action when pulling in a hook. Tufted capuchins manipulate objects more often and in more varied ways, and they modulate actions with objects more flexibly than tamarins can. As seen in the increased success with convertible tools between Experiments 3 and 4, the capuchins were learning to modulate their actions to align an appropriate part of the tool-object to the treat. They clearly did not achieve full skill in using oddly-shaped objects to pull in food, but they were on their way. Overall, these findings suggest that capuchins are attentive to the properties of objects and vary their actions to explore and to exploit varying objects. These characteristics are necessary for learning to knap stones.

Conclusions

We consider the following characteristics as potentially enabling capuchins' discovery that stones can be modified through action to improve their functionality: a) good postural stability while seated or standing bipedally (often aided by their prehensile tails), freeing the hands for action; b) aptitude for bimanual action, especially role-differentiated bimanual action; c) ubiquitous pounding of objects on substrates as a species-typical perception-action routine used in foraging and exploration; d) common discovery of tool use, especially incorporating percussion; and e) terrestrial habits. We see continuity between human and non-human primates in these features of action related to stone-knapping. Indeed, features (a) to (d) are the same features that provide ontogenetic continuity in human stone knapping, as laid out in other chapters in this volume. Capuchins are very small, however, compared to humans, and therefore they cannot produce the same kinetic forces by their strikes as can humans. This characteristic mitigates against capuchins modifying stones in the same ways as humans.

Skilled stone knapping involves selection, planning, and integration of multiple relational demands in action. We have only a little evidence suggesting that capuchins can manage these aspects of knapping to the level required for effective knapping. We have seen that capuchins can monitor two dynamic relations simultaneously while using a hoe tool in one hand to slide food across a discontinuous surface. We also have shown that they can modulate their movements to become more skilled at positioning the familiar hoe and to reposition novel variably-shaped objects to use them to sweep in food. Thus they plan action with objects and integrate multiple spatial, force, and temporal relations in these actions to some extent. But we have not examined capuchins' abilities to modulate actions of the two hands in an integrated task requiring precise positioning and production of force, as occurs in knapping, nor have we examined any aspect of planning in tool use situations beyond selection of a single object to use in a given circumstance, or a sequence of actions to gain a specific tool (e.g. Westergaard *et al.* 1998b).

Given our current understanding of capuchins' flexibility in other manipulation tasks, and their rate of mastering various tasks incorporating multiple relations, we predict that capuchins could master the basic elements of knapping through carefully-scaffolded learning experiences, although most likely they would require far more practice for improvement at each aspect than do adult humans. But they are unlikely, unless perhaps they devote a lifetime to knapping under expert tutelage, to match a moderately-skilled human knapper in any aspect of skill. Capuchins generate the same kinds of information for learning through action that humans do, but they seem to learn from their actions or recognize the significance of various information less slowly and less richly than humans, and they modulate their actions through a smaller range than do humans. The human advantage is cumulative and synthetic: we do not possess any single proclivity or action capability relevant to stone knapping that capuchins do not possess, but we are better at every single step, and / or acquire skill in each domain more quickly, so that we can master additional levels of integration, cope with variations more quickly, modulate our movements more precisely, etc. Rapidly-improving action skills enable detection and focused attention to relevant properties of the stones, to their position in the hand, and so forth, and therefore to what we recognize collectively as planning. In other words, embodied cognition in humans is vastly richer than in capuchins, and we believe this is what supports stone knapping (and many other familiar skills) in humans (and explains its absence in other species). Capuchins show us how fundamental action is to the human condition.

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