

3 Chimpanzees plan their tool use

Richard W. Byrne

Centre for Social Learning and Cognitive Evolution and Scottish Primate Research Group, School of Psychology and Neuroscience, University of St. Andrews

Crickette M. Sanz

Department of Anthropology, Washington University

David B. Morgan

Lester E. Fisher Center for the Study and Conservation of Apes, Lincoln Park Zoo
Wildlife Conservation Society, Congo Program

Introduction

To a cognitive psychologist, chimpanzee tool use is exciting because of the opportunity it brings to examine how apes deal with a range of challenging situations that in humans would invoke planning. By *planning* it is meant a special kind of problem solving in which an appropriate course of action for the immediate or distant future is worked out by means of mental computation with brain representations of past or present situations (Miller *et al.*, 1960). These include: a working representation of the current situation that presents a problem; episodic memories of specific past instances and events; and semantic knowledge about how things work or how people behave.

Because a tool is not itself a goal-object, but has meaning and functionality only in regard to achieving a goal, problem solving with tools often makes more of the planning process “visible” than is normally the case (Seed & Byrne, 2010). Because a tool often must be selected to meet specific criteria in order to work, or – more telling still – may have to be made from specific raw materials in a particular way, getting an appropriate tool becomes an extra stage in the planning process. Thus, to approach a cognitive understanding of animal planning, studying tool use is by no means the only approach, but it is certainly a good one. Historically, however, understanding cognition has not been the major driving force in the study of tool use in great apes in primatology: that stemmed instead from anthropology, a subject with a very different agenda.

To oversimplify, anthropology’s interest in ape tool use has been predicated on one version of the “silver bullet” theory of human origins – specifically, that using a tool provided the magic ingredient that converted an ancient ape to a person. “Man the tool maker,” a phrase attributed to Benjamin Franklin, sums it up – and famously, when Jane Goodall told Louis Leakey of her findings on chimpanzee tool manufacture, his first thought was for the re-definition that it would inevitably prompt some people to suggest – to stop chimpanzees

being seen as too human! Additionally, for more pragmatic reasons, the archaeology of early man has been dominated by tools because stone tools are so robust and (usually) identifiable, compared to other hominin traces. Paleoanthropology's apparent fixation with tools is no surprise. But these factors have led to disproportionate focus on the tool, not the process of making or using it (with honorable exceptions: e.g., Wynn, 1993, 2002).

Many species of non-human animals also use tools (Shumaker *et al.*, 2011), whereas few make them. Such a disproportion is consistent with the idea that tool making is much more difficult than tool using; and because humans share tool making with few other species, it is tempting and commonplace to make the assumption that tool manufacture must therefore be cognitively challenging. But we suspect that behind that slightly glib assumption there may be a more interesting but often unspoken logic: that tool making is genuinely challenging because it requires *forethought*, whereas tool use might be driven by the stimulus configuration alone: the perceived problem as physically confronts the animal. As the everyday examples of spiders' webs and wasps' nests remind us, complexity of manufacture need not imply complexity of cognition. To investigate whether cognitive complexity is involved requires a psychological rather than an anthropological approach, and it is from the psychology of human problem solving that the analysis of this chapter is derived.

The psychology of animal problem solving

Most studies of human problem solving have used culturally constructed, "artificial" tasks, such as chess or formal logic, and almost all of them have posed problems in symbolic, often verbal form: the next move in chess; the solution of a puzzle in formal logic; the choice of a dinner menu; and so on (e.g., Newell *et al.*, 1958; de Groot, 1965; Newell & Simon, 1972; Byrne, 1977). This restriction on choice of task poses a problem for attempts to use the comparative method to investigate the evolution of planning: the non-verbal behavior of animals simply cannot be assessed in the same way. In order to understand the evolutionary roots of human planning, therefore, cognitive researchers have a choice: either they can attempt to infer mental processes from observable behavior, or they can deny that planning is even possible without language – and give up. The latter approach is obviously defeatist, and suspiciously self-serving when it comes to promotion of human superiority, although it has been much espoused within experimental psychology (e.g., Macphail, 1985, 1998). However, the more empirical alternative is not an easy option.

Under natural circumstances, it is often ambiguous exactly what an animal's goals are. Retrospectively assuming that their goals must have been to achieve what they are eventually seen to achieve has more than a hint of Dr. Pangloss. Unfortunately, the obvious alternative – experimentally setting goals for the animal – has its own problems. To set a goal for a non-human animal, the experimenter employs a schedule of rewards whose distribution correlates with "success" on the task the experimenter wishes to get the animal to attempt. The idea is that the reward schedule gives the animal an understanding – a mental representation – of the task, which it then tries to solve, reaching its

goal by planning. Yet an animal merely operating under the hill-climbing, reward-maximization strategy of reinforcement learning would also show behavior that *looks* representation-based and goal-oriented. Moreover, even if we could be sure that genuinely future-directed planning was happening, the planning itself remains invisible and has to be inferred by its consequences. Human studies normally ask subjects to “think aloud.” Under some circumstances, forced verbalization may be misleading; but where subjects find concurrently talking to be a natural behavior, their verbal output may be quite closely linked to the symbolic processes that underlie the planning (Byrne, 1983). Even then, there remains ambiguity. If every verbalized step results in overt behavior, fine; but what of long pauses – is the subject thinking furiously, or dozing off? With non-verbal animals, things get much worse. We are then reliant purely on overt, goal-directed behavior; and when we are lucky enough to witness a sequence of behavior which is goal-directed throughout, we are still left with uncertainty in the end as to whether and to what extent the animal *anticipated* the favorable outcome it has apparently worked “toward.”

Beset by so many difficulties, denial of the possibility of planning in non-human animals is understandably tempting: if all planning is language-based, then non-human animals do not plan. On this philosophy, everything that we observe animals doing is the result of two hill-climbing algorithms: (1) genetical evolution by natural selection, which has equipped animals with morphology and behavior that has allowed their ancestors to be successful, and therefore probably will still work for them; and (2) associative learning, which allows correlations in the environment to be passively noticed and remembered, and allows the results of trial-and-error exploration to be recorded so that future behavior becomes more effective than past behavior. These processes are gradual ones, not the most efficient we can imagine – but without language, they are believed by many experimental psychologists to be the best that can exist, and they do work.

The earliest version of this belief, the *tabula rasa* idea of behaviorist learning theory, was firmly set aside by the work of ethologists. But subsequently, learning theorists have shifted to the famous “null hypothesis” of Euan Macphail – that all animals learn in the same way, such that animal learning theory, if correctly employed, can account for everything (Macphail, 1985). According to this canon, the only real differences among species lie in their different motor capacities; the varied limits imposed on them by different perceptual systems; and a range of innate predispositions (constraints on learning: Garcia & Koelling, 1966; Garcia *et al.*, 1966) that guide the same learning process to different endpoints in biologically appropriate circumstances. However, in most complex, real-world situations, persistence of the belief that animal learning theory is sufficient to explain changes in behavior is based more on faith than any testable hypothesis of how that could happen (Byrne & Bates, 2006). Worse, this approach is a bit of a dead end when it comes to explaining how the undeniably special *human* planning abilities arose in evolution: that problem simply becomes another one – how human language arose. Indeed, more cynically, the “null hypothesis” might be seen as a rear-guard action to avoid contemplating the unthinkable: the heretical possibility that animals might plan and think in ways that are recognizably like our own. (For example, see the arguments used by Suddendorf *et al.* (2009) to resist the conclusion, from

experimental investigations by Mulcahy and Call (2006) and Osvath and Osvath (2008), that apes are able to anticipate their future use of a tool.) The study of ape tool use has had an important role in opening up the possibility of animal planning and thought to serious scrutiny.

A framework for analyzing tool use

Animal tool use is often just *assumed* to imply “advanced abilities,” “cognitive sophistication” or “complexity in behavior” – presumably meaning that the animal is showing signs of abilities such as planning, thinking, anticipation of the future or mental computation. However, deciding whether a case of animal tool use requires planning is not straightforward. Life would be simple if our choice were between a theory that predicted intense deliberation, dramatic leaps of insight and preternatural anticipation of every possible problem, versus one that predicted a gradual increase in competence that depended on continual interaction with the world. The trouble is, even adult humans playing chess (and how much more “cognitively sophisticated” can one get?) show continual improvement with practice. Moreover, leaps of insight are often identified afterwards, when one has forgotten the steps that led to them (Byrne, 1975). In chimpanzees, we might try to identify “insight” where the animal has been inactive for a while and then suddenly acts successfully (e.g., Köhler, 1925) – but that risks a selection bias, if cases of prolonged inaction and then sudden failure are ignored. Just as in the study of human problem solving, there is always a risk that inaction may be torpid dozing rather than intense thought.

Perhaps the involvement of planning in tool use is easier to detect when the tool using is part of a tradition, a cultural product? The greatest achievements of human thought and planning have been built on the cultural legacy of others: they are dependent on social learning, including teaching and imitation. The old idea that cultural learning is how *we* do things, while trial-and-error fumbling is how *animals* do them, is now thoroughly discredited. True, teaching has been pretty elusive to document in animals. In the 17 years since the definitive survey of Caro and Hauser (1992), teaching has been firmly established only in meerkats, babblers and ants (Franks & Richardson, 2006; Thornton & McAuliffe, 2006; Raihani & Ridley, 2008). In none of those three positive cases is there any serious suggestion that the teaching is based on any deep (theory of mind) appreciation by the teacher of the cognitive deficiencies of the learner (Csibra & Gergely, 2009). But in non-Western cultures explicit pedagogy may be less important for cultural learning (Gaskins, 2006), and less glamorous social influences of several kinds have been detected in a huge range of non-human species – with some of the sturdiest evidence of imitation and cultural learning coming from the oddest species: coral reef fish, quail and budgerigars (Hoppitt & Laland, 2008). So, for tool use, is planning an essential part of the explanation of imitation and cultural learning? That depends what is meant by those terms. If imitation means only evoking the same behavior as is seen, an action already in the observer’s repertoire, used many times before in other contexts (e.g., Whiten *et al.*, 1996; Stoinski *et al.*, 2001), then it can be explained by a very simple

mechanism: response facilitation of matching actions (Byrne, 1994; Hoppitt & Laland, 2008). Experimental demonstrations of cultural transmission within chimpanzee groups may be based on no more than this (Whiten, 2005; Whiten *et al.*, 2007). Some aspects of even human cultures may likewise be based on rather simple learning processes: it is not safe to assume that cultural traditions of tool use require planning.

Rather than making assumptions about particular tasks, what is needed in order to evaluate and compare the mental processes underlying behavior – including tool using and tool making – is an appropriate formalism in which seemingly “clever” actions can be evaluated. Such a formalism must be capable of allowing comparison between humans and other animals “on a level playing field” if we are ever to understand the evolution of the human capacities by means of comparative evidence. Because it is no longer used in attempts to explain human abilities, the associationist formalism preferred by learning-theory psychologists just will not do. However, associationism is still so dominant in animal behavior that it cannot just be ignored: When and why is a cognitive approach preferable?

Whether an animal, or some particular behavior it has shown, should be deemed “cognitive” or “associative” is not an empirically decidable issue. Those are *theoretical frameworks* for analysis of what exists, not *kinds* of existence that can be told apart, even in principle: there is no possible acid test between them. In the 1960s, cognitive psychology as a discipline discarded the whole behaviorist, learning-theory framework as unhelpful. Anyone from the cognitive psychology tradition thus unashamedly tended to talk as if animals had mental representations that governed their behavior (e.g., Tomasello & Call, 1997). Many in the field of animal behavior still hanker for the simplicity of association learning theory (e.g., Heyes, 1993). Learning theory is simpler in that fewer mental entities are proposed – but the danger is that these “simple” explanations of complex phenomena are always constructed post hoc (Byrne & Bates, 2006). Like the wares of snake-oil salesmen, associations can be claimed to have cured everything . . . afterwards! With convenient “help” (e.g., retrospectively asserting what the animal will have noticed or not noticed, and thus which entities “must have been” associated), associationist accounts can be made to fit everything that happened – once we know what it was. Where associationist explanations fail is therefore in their *adequacy*. When it comes to the real world or to the rich captive environments, from which apparently “clever” animal performances are often reported, associationist explanation does not work as a coherent system to produce testable predictions. Moreover, often the post hoc explanations of association theory “over-explain”: that is, if they did work as explanation for the species in question, it would be difficult to stop them working to “explain” a great deal of complex behavior in other species – complex behavior that actually never happens.

That is not to deny that rules for making links, including associative links, might form a useful part of a cognitive model; but the explanatory “work” of a cognitive model lies also in its organization, whereas the associationist version of animal learning tends to lack such organization. For instance, Heyes and Ray (2000) proposed a theory of animal imitation to account for imitative learning of chains of actions that the animal observes. They described their model as associationist, as if it flowed naturally from traditional

animal learning – yet the associations in the model turn out to be of two, qualitatively different, sorts. “Vertical” links are formed between actions-as-seen and actions-as-done. For instance, an animal that watches itself in a mirror is said to form a vertical association between the perceptual representation of, say, its mouth configuration and the motor program that it is currently executing and which produces that configuration. “Horizontal” links are instead formed between successive movements observed in others. By combining the two, Heyes and Ray suggest that an animal can execute a horizontal sequence by using the vertical links to convert what it sees into what it can do. Nowhere is it specified how the system (the animal’s brain) “knows” when to make or use vertical and when horizontal links. But it is evident that simple undifferentiated associations would not do: the model has to have structure. As this case illustrates, by the time an “associationist” account has been specified fully enough to meet the criterion of adequacy, it has become a cognitive model. As such, it has presumably lost some of the “simplicity” and “parsimony” that animal learning theorists yearn for. In this chapter, therefore, we will typically use cognitive descriptions (or everyday language) to spell out what must be involved in the chimpanzee behavior we discuss, in terms of the *mental representations* underlying their actions.

Diagnostics of planning

Consider the associationist alternative to planning: what characteristic attributes of behavior would it predict? To a cognitive theorist, that depends on the mental representation it creates. Radical behaviorists would never talk of mental representations, and the concept remains highly suspect to animal learning theorists, a legacy of behaviorism. However, if we allow a modest level of mental structure, once considered perfectly acceptable to learning theorists (Broadbent, 1961), then we can characterize the results of learning purely by association as characteristically *string-like*. The likely “path,” through an imaginary network of possible behavior sequences, is determined by past association frequencies between options, along with direct input from the environment. The external inputs that contribute to determine this path are the *immediately perceptible* features of the environment. (If the task were a navigational one, then paths can be interpreted literally, but the logic applies equally to all behavior.) Endpoints are not *anticipated* in such a system.

Thus, a chimpanzee might see a termite mound and – because of past learning – the sight might trigger a chain of associations that leads from earth mound to (delicious) termite, and also to (useful) sticks, and thence to raw stick-material, triggering the chimpanzee to search for suitable stuff. (As readers will perhaps guess, we have some skepticism as to whether such a network of associations would work efficiently, in the face of the complexity of a real African forest. But let’s give it the benefit of the doubt.)

Alternatively, the chimpanzee’s behavior might be a result of a mental planning device, which – in principle – can base its decisions on mental representations that encode a structural description of the situation. This structural description might include *remembered* and *inferred* characteristics, as well as the immediately perceptible features

in common with the associationist account. Planning might be linear, but could also be *hierarchically* organized: working “down” from a rough or abstract specification, which is successively expanded into a richer structure of motor action. Hierarchical organization permits greater flexibility in several ways. Modularity allows efficiency, when a behavioral sequence assembled in one context is applied to another. Redundant sections of the sequence can be omitted if there is some simple test for their necessity. Iteration to a criterion allows just enough repetition to achieve a detectable result. Hierarchical organization thus generates a distinctive signature (Lashley, 1951; Miller *et al.*, 1960; Dawkins, 1976; Byrne, 2003): The hierarchical structure may be shown up in an analysis of hesitation pauses or behavior at choice points, for instance the omission of optional steps or deployment of alternative processes, depending on the subject’s perception of the changing task. Finally, in planning, the desired end may be evoked in advance, so that behavior may sometimes be driven by the mismatch between an *anticipated future state* in the subject’s mind and an appreciation of the current state of play, rather than driven always by past and present states that can be perceived or remembered. With association learning, of course, no result is anticipated: action is “pushed” by the operation of automatically triggered, learned responses, rather than “pulled” by the attraction of an attainable goal representation. Equally contrasting with the “fixed action patterns” of early ethology, efficient planning requires comparison of what has been achieved against a pre-specified criterion, to terminate behavior when success has been achieved. In the terms of Miller *et al.* (1960), a *test–operate–test–exit* sequence is a visible indication of using such a criterion. A more elaborate mental representation of a desired future end state has traditionally been called a “schematic anticipation” in human problem solving (Newell & Simon, 1972). Even in the absence of verbal reports, there are potentially ways of detecting an anticipatory schema, both by naturalistic observation and experimental manipulation, especially in tool use: for instance, if tools need to be obtained before moving to the site of use, the criteria for tool selection or construction must come from memory.

In this chapter we evaluate the current data from a single African study site, the Goulougo Triangle of the Republic of Congo, for any of these diagnostic signs of planning in tool use. Is chimpanzee tool use at Goulougo regulated only by immediately perceptible features of the environment, or also by inferred or remembered aspects? Linear and string-like in behavioral organization, or containing signs of flexible, hierarchical organization with optional omission and substitution of subordinate routines? “Pushed” by intrinsic motivation guided by constraints and affordances of the environment, or “pulled” toward a desired future state imagined as a schematic anticipation?

Evidence of planning in Goulougo tool use

Behavior driven by memory and inference

Chimpanzees exhibit several types of tool use to access hidden or encased food items at Goulougo, as at other sites. Extracting and dipping tools are used to gather social insects

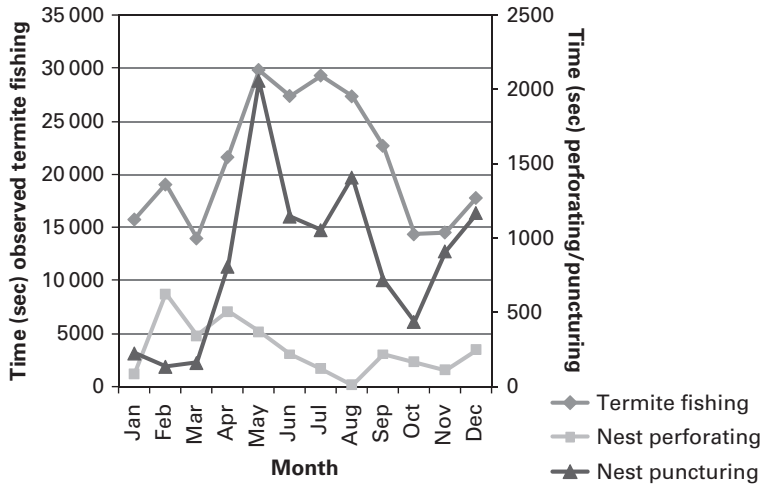


Figure 3.1 Seasonality in tool use observed in termite gathering by chimpanzees of the Goulougo Triangle.

that are not visible until extracted (e.g., *termite fish*) and liquids from recessed areas in trees (e.g., *fluid dip*, *leaf sponge*). These tools are often fashioned from small twigs, herb stems, leaves or pieces of grass. They may be reused in successive bouts, but do not tend to be conserved for future use by the tool maker or others. This is in contrast to tools used to open insect nests (e.g., *puncture termite nest*, *pound bee hive*). Those tools tend to be more substantial, being made of stout sticks or branches, and may be left at a particular tool-using site for reuse over consecutive visits. In all these cases, the goal toward which the behavior is directed must be inferred or remembered from past experience.

Parker and Gibson (1977) hypothesized that intelligent tool use in cebus monkeys and great apes evolved as an adaptation for feeding on seasonally available embedded food resources. Indeed, chimpanzee tool use to gain access to nuts, termites and ants shows distinct seasonal peaks (McGrew *et al.*, 1979; Yamakoshi, 1998; Sanz *et al.*, 2010). This most often coincides with the times that these food resources are available, such as the increase in ant dipping by chimpanzees in the Goulougo Triangle that coincides with the seasonal movements of *Dorylus* ants (see Figure 3.1; Sanz *et al.*, 2010), and the wet-season termite fishing on mound-making termites which go deep underground during dry periods (e.g., Uehara, 1982; Goodall, 1986). Seasonality in termite gathering could be related to changes in the structure of the mound, location of termites relative to the surface of the nest in different seasons or the annual reproductive cycle of termites. Evidently, memory and inference are not required to explain seasonal consumption that tracks availability: Parker and Gibson's argument was rather that year-round dependence on an embedded resource would select for morphological adaptations, while occasional but important access to hidden resources might depend on psychological abilities.

In any case, chimpanzees in the Goulougo Triangle seem to have developed tool strategies to overcome some of these difficulties, as they exhibit termite fishing throughout all months of the year. There are peaks in termite fishing and puncturing between May and August, but fishing is still seen in the other months, and at these times the use of perforating tools to open

the surface of epigeal nests is most common. This suggests that using perforating tools provides access to this food resource at a time when it would not otherwise be available, resulting in a two-stage process in which each stage requires a quite different tool.

Hierarchical organization of tool-using or tool-making programs

Chimpanzees in the Goualougo Triangle show flexibility in omitting redundant steps in their tool-using sequences, and in deploying alternative processes when necessary to achieve their goal of gathering termites. The two-stage puncturing and fishing task comprises several behavioral “subroutines,” each of which consists of specific behavioral elements. Examples of subroutines in this setting include those for the manufacture of a brush-tip tool, for puncturing a termite nest, for perforating a termite nest and for the termite fishing itself. Subroutines are relatively easy to identify as they are seamlessly executed and often separated by natural junctions in tool-using sequences. As an example, we show here the subroutines exhibited by a subadult male chimpanzee, Lewis, during a bout of gathering termites at a subterranean termite nest (November 15, 2006, observations began 08:59; descriptions of subroutines in *italic*):

9:07 Termite nest puncturing subroutine

The chimpanzee pushes a puncturing stick into the ground. After reaching the desired depth, the tool is removed by pulling upwards with both hands while the chimpanzee stands bipedally. The end of the tool or insertion point is then often smelled or visually inspected. (Humans can detect if a termite nest has been punctured by the smell of termite pheromones that are released when a nest is attacked.) If a nest has not been breached, the chimpanzee continues inserting the puncturing stick in nearby locations.

9:15 Termite fishing subroutine

This involves brush straightening, insertion and extraction of the tool, and gathering the termites from the tool. With the brush-tip fishing probe, it is often necessary to straighten or arrange the brush fibers before each insertion into the tunnel. The probe is inserted into the termite nest, and then extracted with termites clinging to the brush fibers. Termites are gathered into the chimpanzee’s mouth using either the pull-through or direct-mouthing technique.

9:27 Using a fishing probe to clear a nest tunnel

After failing to insert the probe, chimpanzee reverses the orientation of a brush-tip tool and uses the blunt end to clear loosened soil from the entrance of the fishing hole. The probe is then reoriented for fishing and the brush straightened before insertion.

9:28 Termite fishing routine

9:28 Using a fishing probe to clear a nest tunnel

9:28 Termite fishing routine

9:32 Using a fishing probe to clear a nest tunnel

9:33 Termite fishing routine

9:45 Termite nest puncturing routine

9:46 Termite fishing routine

- 9:47 Termite nest puncturing routine
- 9:56 Termite fishing routine
- 9:57 Termite nest puncturing routine
- 9:59 Termite fishing routine
- 10:00 Termite nest puncturing routine

Structural analysis of the tool-using behavior of chimpanzees in the Goualougo Triangle shows hierarchical organization and flexible use of subroutines in several contexts (Sanz & Morgan, 2009a). For example, puncturing of a termite nest is omitted if termite nest tunnels have already been opened. If a tunnel must be created, then the chimpanzee punctures repeatedly until it succeeds in accessing an active chamber in the termite nest, using a puncturing tool that may need to be manufactured. But if one can be reused from a previous bout that day, it is: manufacture is only employed when necessary. Similarly, brush-tip tool manufacturing steps are omitted when an individual has already created a termite fishing tool at that nest, or brought a tool with them from another nest location. Also, the manufacture steps are bypassed when a youngster receives a manufactured tool from its mother. The flexible use of different subroutines is also seen in honey gathering when individuals alternately use pounding and prying tools to open a hive, and then a dipping probe to extract honey (Sanz & Morgan, 2009b).

Utilization of subroutines in more than one task

Another indication of flexibility is that chimpanzees in the Goualougo Triangle are capable of applying termite fishing knowledge in different settings, and appropriately relating these skills to different tool sets (Sanz & Morgan, 2009a). Nearly identical termite fishing subroutines are generalized across subterranean and elevated termite nest tasks; subtle differences are observed in the length of the fishing probe and in biases toward particular methods of transferring termites from the probe to the mouth in these contexts. Multiple tools can be used in both the subterranean and elevated termite gathering tasks, but it is obligatory to use two tools in gathering termites only at subterranean nests. The entire length of a stout puncturing stick is inserted into the ground to create an access tunnel into the subterranean chambers of a termite nest. After successfully puncturing a nest, a fishing probe is inserted into the tunnel to extract the termites. Besides the obvious differences in the form and function of the puncturing and perforating tools, at an elevated nest the perforating twigs are used only occasionally by chimpanzees to clear debris from an existing termite exit-tunnel during the process of fishing. We predict that further analysis of the composition of tool-using behaviors will reveal that other subroutines are shared between different skilled tasks. Generalization of subroutines across tool tasks allows construction of these skills to be more efficient and less cognitively demanding.

Recovery from interruption at critical points in overall program of action

We have observed that chimpanzees are adept in coping with interruptions during their tool-using sequences. Frequent occurrences of recovery are seen when a mother's termite

gathering is interrupted by a youngster's solicitation of her tool. For example, a juvenile female named Malia was having little success fishing at an epigeal termite nest, and threw down her tool; she whimpered and reached out toward her mother, who was fishing nearby. Her mother responded by handing her own brush-tip tool to Malia; she then picked up a discarded tool from the ground and resumed fishing. On other occasions, after transferring their tool to a youngster the mother leaves the termite nest to gather tool materials.

Evaluation of success against pre-set criterion: *test-operate-test-exit*

During the termite nest puncturing subroutine, chimpanzees test to assess their progress toward reaching their anticipated goal of accessing an active termite nest chamber. Chimpanzees repeatedly puncture the ground in a particular location and then pause to inspect the end of the puncturing tool that has been inserted into the nest. The behavior of an adult male, Wallace, shows this clearly (December 29, 2003, 11:57–11:59; and see supplementary video):

Tool action: Insert/extract puncturing stick (four times)

Test: Smells/inspects tip of puncturing tool

Tool action: Insert/extract puncturing stick (three times)

Test: Smells/inspects tip of puncturing tool

Tool action: Insert/extract fishing probe

Goal: Feeds on termites from fishing probe

Termites release specific pheromones (Prestwich 1984; Billen & Morgan, 1998) which can be smelt on the end of the puncturing tool if a termite nest chamber has been breached. After sensing that an active chamber has been located, the chimpanzee inserts a fishing probe into the tunnel to extract the termites.

Anticipation of future needs

At several study sites, chimpanzees have been observed to manufacture tools or to pick up suitable materials in advance of need, sometimes out of sight of the place of use (Goodall, 1964; McGrew, 1974; Boesch & Boesch, 1984). In the Goulougo Triangle, fishing probes are newly manufactured each day, but chimpanzees have been observed transporting a manufactured probe from one termite nest to another. These observations imply that the animals are able to use a mental representation of an adequate tool or appropriate natural materials for a task that is not immediately confronting them (Byrne, 1998). Some researchers would insist that true planning requires the individual to be able to divorce themselves from their current motivational state, and they typically argue that this ability is uniquely human and refer to it as “mental time travel” (Suddendorf & Corballis, 1997). However, this seems to conflate two independent aspects of forethought: the ability to imagine feeling different emotions and motivations to now, and the ability to mentally simulate future actions (Craik, 1943; Newell & Simon, 1972). The former is extremely hard to study in non-verbal animals (but see Raby *et al.*, 2007). The latter is evidenced by any clear cases of anticipating needs which are not cued by

currently perceptible stimuli, including our observations at Goulougo of construction and transport of tools prior to encountering the problem the tools serve to deal with.

Goulougo chimpanzees show particularly detailed anticipatory planning in their transport of different types of tools necessary for particular tasks. We recorded chimpanzees arriving at termite nests carrying puncturing and/or fishing tools on 45 occasions (Sanz *et al.*, 2004). All tools were transported by adults and appropriate for the type of termite nest being approached. A chimpanzee arrived carrying both a stout stick and fishing probe on seven occasions: all were arrivals at subterranean nests, which necessitate puncturing before fishing. Chimpanzees were never observed to arrive with only a puncturing stick at either a subterranean or epigeal nest; a puncturing tool alone would not be effective at subterranean nests, or appropriate at epigeal mounds where perforating twigs and probes are used. Chimpanzees arrived at termite nests carrying only fishing probes on 38 occasions: 82% of these arrivals were to epigeal mounds and 18% were to subterranean mounds. The significance of the disparity regarding which of the two types of tool is pre-constructed and transported lies in the fact that serviceable wooden puncturing tools are usually found lying around at the mounds; fishing probes, in contrast, usually become damaged in use. The chimpanzees are evidently able to anticipate their likely future needs for *both* of the two necessary steps in the process, and rightly conclude that it is the second step for which a pre-made tool would be valuable.

As researchers have reported from other sites, we have also noted chimpanzees arriving at termite nests with sufficient materials to manufacture multiple tools (Goodall, 1964). This might indicate anticipation of a likely future need for more than one tool, either as a result of a tool becoming inefficient with wear or the likelihood of sharing it with another individual; alternatively, carrying excess material may be accidental. Chimpanzees have been observed to repair tools in mid-use. When using a brush-tip fishing probe, for instance, chimpanzees often pause to repair or maintain the brush (Sanz *et al.*, 2009). This is in contrast to the termite fishing method used by Gombe chimpanzees, who actively remove the frayed end of a termite fishing probe (McGrew *et al.*, 1979). We have also observed chimpanzees modifying puncturing tools during tool-using bouts, sharpening the point (by reducing the diameter of the distal section of the tool, which is accomplished by removing side sections of the tool tip with either their teeth or fingers) for easier insertion into a subterranean termite nest. The length of a bee-hive pounding tool may also be modified mid-use. For example, a pounding tool can be shortened to produce an effective lever. Modification is presumably triggered by the immediate state of the tool and requires no anticipation, although as with tool construction the process of modification may be guided by a mental representation of what an adequate tool should be like.

Summary

Behaviorist learning and cognitive science differ fundamentally as frameworks for explaining behavior, and the main reason that the former has been discarded in human

experimental psychology is its inability to make clear advance predictions with action as complex as everyday human activities. Association learning explanations can readily be fashioned after the event; they often seem plausible, but generally lack any demonstration of computational adequacy. If doubts as to adequacy could be set aside, then an associative learning explanation of chimpanzee tool use might differ only subtly from an anticipatory planning account in its observable consequences for behavior. In this chapter we have examined the behavior of chimpanzees at one study site where tool use is particularly prominent for characteristic signs of planning.

In the Goulougo Triangle of northern Republic of Congo, tools are used extensively for extractive foraging, in which the foods that are the goal of the process are not directly visible. Some of these processes involve two steps, for instance puncturing the ground to gain access to subterranean termites, and then fishing for those termites using the access route thus created. Different types of tool are used in the two steps. Although sometimes the resources to fashion suitable tools may be present at the site of use, often tools are constructed in advance and transported to the site, implying anticipation of future need and the ability to use a mental representation of a suitable tool away from the task itself. In the case of two-step tasks, the sturdier puncturing tools are often left lying in serviceable condition at the feeding site; the fact that chimpanzees make and bring a tool for the second stage of the process, a slender fishing tool likely to be unusable when discarded, shows that anticipation extends to the whole complex future sequence. The behavioral sequence itself shows a number of signs of hierarchical planning, rather than the string-like and inflexible organization to be expected from associative learning or use of fixed action patterns. Organization is modular, with smooth and fluid execution within but not between modules, and modules are often used as iterated subroutines. The criterion that stops an iterated sequence is often some type of test, such as the revealing scent of a punctured termite nest, producing a “test–operate–test–exit” pattern of behavior. Subroutines can be shared between different tool-using programs. Flexibility of planning is shown in the omission of any redundant steps, and the smooth recovery from any interruptions.

Whether an association model of learning is also capable of generating elaborate behavior of the types we have reported here, with characteristics mimicking those of planning, is a moot point: but exactly that is adhered to as an article of faith by many animal-learning theorists. Computer simulation of behavioral learning has the potential to demonstrate that such faith is justified, but the experience of human experimental psychology does not offer strong grounds for optimism. In the meantime, we suggest the most parsimonious conclusion is that chimpanzee tool use – and by implication, much else in great ape behavior – is best seen as a planning activity.

References

- Billen, J. & Morgan, E. D. (1998). Pheromone communication in social insects: sources and secretions. In R. K. Vander Meer, M. D. Breed, K. E. Espelie & M. L. Winston (eds.) *Pheromone Communication in Social Insects: Ants, Wasps, Bees, and Termites* (pp. 3–33). Boulder, CO: Westview Press.

- Boesch, C. & Boesch, H. (1984). Mental map in wild chimpanzees: an analysis of hammer transports for nut cracking. *Primates*, **25**, 160–170.
- Broadbent, D. E. (1961). *Behaviour*. London: Methuen.
- Byrne, R. W. (1975). Memory in complex tasks. Doctoral thesis, Cambridge University.
- Byrne, R. W. (1977). Planning meals: problem-solving on a real data-base. *Cognition*, **5**, 287–332.
- Byrne, R. W. (1983). Protocol analysis in problem-solving. In J. S. B. T. Evans (ed.) *Thinking and Reasoning: Psychological Approaches* (pp. 227–249). London: Routledge and Kegan Paul.
- Byrne, R. W. (1994). The evolution of intelligence. In P. J. B. Slater & T. R. Halliday (eds.) *Behaviour and Evolution*. Cambridge: Cambridge University Press.
- Byrne, R. W. (1998). The early evolution of creative thinking: evidence from monkeys and apes. In S. Mithen (ed.) *Creativity in Human Evolution and Prehistory* (pp. 110–124). London: Routledge.
- Byrne, R. W. (2003). Imitation as behaviour parsing. *Philosophical Transactions of the Royal Society of London B*, **358**, 529–536.
- Byrne, R. W. & Bates, L. A. (2006). Why are animals cognitive? *Current Biology*, **16**, R445–R448.
- Caro, T. M. & Hauser, M. D. (1992). Is there teaching in non-human animals? *Quarterly Review of Biology*, **67**, 151–174.
- Craik, K. J. W. (1943). *The Nature of Explanation*. Cambridge: Cambridge University Press.
- Csibra, G. & Gergely, G. (2009). Natural pedagogy. *Trends in Cognitive Sciences*, **13**, 148–153.
- Dawkins, R. (1976). Hierarchical organisation: a candidate principle for ethology. In P. P. G. Bateson & R. A. Hinde (eds.) *Growing Points in Ethology*. Cambridge: Cambridge University Press.
- De Groot, A. D. (1965). *Thought and Choice in Chess*. The Hague: Mouton.
- Franks, N. R. & Richardson, T. (2006). Teaching in tandem-running ants. *Nature*, **439**, 153.
- Garcia, J. & Koelling, R. A. (1966). Relation of cue to consequence in avoidance learning. *Psychonomic Science*, **4**, 123–124.
- Garcia, J., Ervin, F. R. & Koelling, R. A. (1966). Learning with prolonged delay of reinforcement. *Psychonomic Science*, **5**, 121–122.
- Gaskins, S. (2006). Cultural perspectives on infant–caregiver interaction. In N. J. Enfield & S. C. Levinson (eds.) *Roots of Human Sociality: Culture, Cognition and Interaction* (pp. 279–298). Oxford: Berg.
- Goodall, J. (1964). Tool-using and aimed throwing in a community of free-living chimpanzees. *Nature*, **201**, 1264–1266.
- Goodall, J. (1986). *The Chimpanzees of Gombe: Patterns of Behavior*. Cambridge, MA: Harvard University Press.
- Heyes, C. M. (1993). Imitation, culture, and cognition. *Animal Behaviour*, **46**, 999–1010.
- Heyes, C. M. & Ray, E. D. (2000). What is the significance of imitation in animals? *Advances in the Study of Behavior*, **29**, 215–245.
- Hoppitt, W. J. E. & Laland, K. N. (2008). Social processes influencing learning in animals: a review of the evidence. *Advances in the Study of Behavior*, **38**, 105–165.
- Köhler, W. (1925). *The Mentality of Apes*. London: Routledge and Kegan Paul.
- Lashley, K. S. (1951). The problem of serial order in behaviour. In L. A. Jeffress (ed.) *Cerebral Mechanisms in Behaviour: The Hixon Symposium* (pp. 112–136). New York: Wiley.
- Macphail, E. M. (1985). Vertebrate intelligence: the null hypothesis. In L. Weiskrantz (ed.) *Animal Intelligence* (pp. 37–50). Oxford: Clarendon Press.
- Macphail, E. M. (1998). *The Evolution of Consciousness*. Oxford: Oxford University Press.
- McGrew, W. C. (1974). Tool use by wild chimpanzees feeding on driver ants. *Journal of Human Evolution*, **3**, 501–508.

- McGrew, W. C., Tutin, C. E. G. & Baldwin, P. J. (1979). Chimpanzees, tools, and termites: cross cultural comparison of Senegal, Tanzania, and Rio Muni. *Man*, **14**, 185–214.
- Miller, G. A., Galanter, E. & Pribram, K. (1960). *Plans and the Structure of Behavior*. New York: Holt, Rinehart and Winston.
- Mulcahy, N. J. & Call, J. (2006). Apes save tools for future use. *Science*, **312**, 1038–1040.
- Newell, A. & Simon, H. A. (1972). *Human Problem Solving*. New York: Prentice-Hall.
- Newell, A., Shaw, J. C. & Simon, H. A. (1958). Elements of a theory of human problem solving. *Psychological Review*, **65**, 151–166.
- Osvath, M. & Osvath, H. (2008). Chimpanzee (*Pan troglodytes*) and orangutan (*Pongo abelii*) forethought: self-control and pre-experience in the face of future tool use. *Animal Cognition*, **11**, 661–674.
- Parker, S. T. & Gibson, K. R. (1977). Object manipulation, tool use, and sensorimotor intelligence as feeding adaptations in cebus monkeys and great apes. *Journal of Human Evolution*, **6**, 623–641.
- Prestwich, G. D. (1984). Defense mechanisms of termites. *Annual Review of Entomology*, **29**, 201–232.
- Raby, C. R., Alexis, D. A., Dickinson, A. & Clayton, N. S. (2007). Planning for the future by western scrub-jays. *Nature*, **445**, 919–921.
- Raihani, N. J. & Ridley, A. R. (2008). Experimental evidence for teaching in wild pied babblers. *Animal Behaviour*, **75**, 3–11.
- Sanz, C. & Morgan, D. (2009a). Complexity of chimpanzee tool using behaviors. In E. V. Lonsdorf, S. R. Ross & T. Matsuzawa (eds.) *The Mind of the Chimpanzee: Ecological and Experimental Perspectives*. Chicago, IL: University of Chicago Press.
- Sanz, C. M. & Morgan, D. B. (2009b). Flexible and persistent tool-using strategies in honey-gathering by wild chimpanzees. *International Journal of Primatology*, **30**, 411–427.
- Sanz, C., Morgan, D. & Gulick, S. (2004). New insights into chimpanzees, tools and termites from the Congo Basin. *American Naturalist*, **164**, 567–581.
- Sanz, C., Call, J. & Morgan, D. (2009). Design complexity in termite-fishing tools of chimpanzees (*Pan troglodytes*). *Biology Letters*, **5**, 293–296.
- Sanz, C., Schöning, C. & Morgan, D. (2010). Chimpanzees prey on army ants with specialized tool set. *American Journal of Primatology*, **71**, 1–8.
- Seed, A. M. & Byrne, R. W. (2010). Animal tool use. *Current Biology*, **20**, R1032–R1039.
- Shumaker, R. W., Walkup, K. R. & Beck, B. B. (2011). *Animal Tool Behavior: The Use and Manufacture of Tools by Animals*. Baltimore, MD: Johns Hopkins University Press.
- Stoinski, T. S., Wrate, J. L., Ure, N. & Whiten, A. (2001). Imitative learning by captive western lowland gorillas (*Gorilla gorilla gorilla*) in a simulated food-processing task. *Journal of Comparative Psychology*, **115**, 272–281.
- Suddendorf, T. & Corballis, M. C. (1997). Mental time travel and the evolution of the human mind. *Genetic, Social and General Psychology Monographs*, **123**, 133–167.
- Suddendorf, T., Corballis, M. C. & Collier-Baker, E. (2009). How great is great ape foresight? *Animal Cognition*, **12**, 751–754.
- Thornton, A. & McAuliffe, K. (2006). Teaching in wild meerkats. *Science*, **313**, 227–229.
- Tomasello, M. & Call, J. (1997). *Primate Cognition*. New York: Oxford University Press.
- Uehara, S. (1982). Seasonal changes in the techniques employed by wild chimpanzees in the Mahale Mountains, Tanzania, to feed on termites (*Pseudacanthotermes spiniger*). *Folia Primatologica*, **37**, 44–76.
- Whiten, A. (2005). The second inheritance system of chimpanzees and humans. *Nature*, **437**, 52–55.

-
- Whiten, A., Custance, D. M., Gomez, J.-C., Teixidor, P. & Bard, K. A. (1996). Imitative learning of artificial fruit processing in children (*Homo sapiens*) and chimpanzees (*Pan troglodytes*). *Journal of Comparative Psychology*, **110**, 3–14.
- Whiten, A., Spiteri, A., Horner, V., et al. (2007). Transmission of multiple traditions within and between chimpanzee groups. *Current Biology*, **17**, 1038–1043.
- Wynn, T. (1993). Layers of thinking in tool behavior. In K. R. Gibson & T. Ingold (eds.) *Tools, Language and Cognition in Human Evolution* (pp. 389–406). Cambridge: Cambridge University Press.
- Wynn, T. G. (2002). Archaeology and cognitive evolution. *Behavioral and Brain Sciences*, **25**, 389–437.
- Yamakoshi, G. (1998). Dietary responses to fruit scarcity of wild chimpanzees at Bossou, Guinea: possible implications for ecological importance of tool use. *American Journal of Physical Anthropology*, **106**, 283–295.