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REVIEW

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Distributed primate cognition: a review

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Abstract A model of "distributed cognition" is contrasted with the "mental representation" model exemplified by Tomasello and Call's *Primate Cognition*. Rather than using behavior as a basis for inferences to invisible mental events such as intentions, the distributed approach treats communicative interactions as, themselves, directly observable cognitive events. Similar to a Vygotskian approach, this model characterizes cognition as "co-constructed" by the participants. This approach is thus particularly suitable for studying primates (including humans), whose reliance on multiparty negotiations can undermine the researcher's ability to extrapolate from observable outcomes back to individual intentions. Detailed (e.g., frame-by-frame) analyses of such interactions reveal cross-species differences in the relevant media of information flow (e.g., behavioral coordination, relative gaze) as well as in the flexibility and complexity of the trajectories observed. Plus, with its focus on dynamics, the distributed approach is especially useful for modeling developmental and evolutionary processes. In discussing enculturation and the ontogeny of imitation, its emphasis is on changes in how expert and novice participate in such events, rather than how either may represent them. Primate cognitive evolution is seen as involving changes in context sensitivity, multi-tasking, and the coordination of social attention. Humans in particular – in, especially, the context of teaching – are seen as having specialized in linking co-perception with the refined sensory-motor coordination that enables them to translate observed behavior into strategically similar action. Highlighting the continuity between human and nonhuman development, this promising, complementary model enables us to tap the richness of micro-ethology as a cognitive science.

Keywords Primates · Mental represenation · Distributed cognition · Social behavior

Introduction

In the Introduction of their excellent recent book, *Primate Cognition* (Tomasello and Call 1997; for a review, see Whiten 1998), the authors maintain that one "defining characteristic of cognitive processes is some form of *mental representation*" (p. 10, italics theirs). Here they voice a fundamental premise of what I will call the "mental representation" (or MR) model of cognition. In their thoughtful application of this model to a huge corpus of research, Tomasello and Call (hereafter T&C) generate a comprehensive and largely coherent account of our current knowledge base on cognition in nonhuman primates. Based on this model they infer, for example, that these animals form mental representations of their physical environments, their conspecifics, and their strategies for foraging and social interaction. T&C's book not only brings a unifying framework to some 60 years of disparate research, but the resulting interpretations facilitate comparison with studies of human cognition. By the same token, however, T&C's use of the MR model subjects their efforts to a set of theoretical and practical difficulties that are increasingly being recognized as plaguing the human work done from this perspective.

In recent years, a kind of "paradigm shift" (Kuhn 1962) has been taking place in the study of human cognition. Some researchers, especially those interested in cognitive development, have turned from models that focus on internal mental representations to ones that see cognition as a more distributed process – i.e., a process that occurs not just within but also *between* individuals (e.g., Rogoff and Lave 1984; Wertsch 1985a; Lave 1988; Rogoff 1990; Resnick et al. 1991; Salomon 1993; Wosniak and Fischer 1993; Hutchins 1995a). In this view, cognition is expanded from an individual enterprise to a distributed activity that involves a variety of socio-cultural elements, including the behavior of multiple individuals, their use of

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objects, and their shared histories. (see D'Andrade 1980; Cole 1985; Wertsch 1985b). In such a model, the units of analysis are typically not mental structures in individual minds, but "real-time" interactions between the various participants and their environments. That is, while not denying that internal processes are involved, the observable group processes that occur during social learning and discourse are, themselves, taken as a form of cognition. By tracking patterns of change through such manifest dynamical systems, the analyst can, for instance, chart information flow, characterize task complexity, and document developments in the roles of participants. Plus, with its emphasis on change over time, this approach is optimal for modeling ontological and evolutionary development. Given that the latter, as we shall see below, are particularly problematic for MR models to handle, distributed models offer a promising, complementary alternative.

In this paper, I will first describe the main features of the distributed approach and then apply such a model to many of the same data and issues T&C address in their book. Hopefully, this exercise will accomplish two things. For one, as a kind of meta-analysis of theoretical modeling, it may illustrate how a change in perspective can throw different aspects of the data into relief, and impact on both the hypotheses and the explanations that are generated. Such a comparative approach can also help demonstrate the inherent strengths and limitations of each model, which may, in turn, enable other researchers to decide which model best suits their research goals. My second aim, then, is to provide a coherent overview of the distributed model, in the hopes that it will be adopted by some investigators and may ultimately prove useful in advancing the study of primate, and other animal, cognition.

Models of distributed cognition

A fundamental assumption of the distributed approach is that communication, itself, is a "cognitive" process (see Bateson 1972, 1979; Bruner 1990). Cognition can be broadly defined as the flow of information through a system. Cognitive analyses can thus be performed on informational trajectories through any number of communicative systems. For example, researchers might assess the relative timing and distribution of electro-chemical interactions in the brain, the growth and reorganization of a complex knowledge base, or the social discourse between motivated, discriminating, and reactive individuals. In each of these systems, as elements interact, some sort of message or meaning is conveyed through the system.

One consequence of the above is that the traditional boundaries of cognition can be expanded to include not only invisible mental processes going on inside each participant's head, but also the observable activities and materials involved in the interactions. Together, these constitute the "media" (Hutchins 1995a) of information flow. In practice, a distributed analysis gives a situated account of changes across these media that focuses on the elements' interactions with each other and with their shared environment (see Lave 1988; Rogoff 1990; Duranti and Goodwin 1992; Wosniak and Fischer 1993; Cole 1995; Nardi 1996). From this perspective, then, much of cognition is "*apparent* in the adaptations made by the participants" (Rogoff and Gardner 1984, p. 95; italics mine.) That is, researchers can actually observe cognitive events being played out in dynamic, social processes. Such processes are not studied only as pointers to a private cognition, but as the very stuff of a distributed cognition.

Critical to this approach is the notion of the "co-construction" of cognitive events. Co-construction refers to the mutual constraints that interactors place on one another's, and their own, behavior (see Grannott 1993; Brown et al. 1993; Fischer and Grannott 1995). Methodologically, this means that to be interpretable, behavior cannot be scored in isolation; it requires a specification of the context provided by the behavior of others. Take, for example, a social coordination mediated by gaze. In this setting, the observation of one individual glancing at another must be treated one way if the second individual is facing the first, and a different way if the second has its back to the first. It also means that time is an integral part of this analysis, since changes in both the immediate and the long-term contexts impact on the role a given behavior plays in a cognitive trajectory. Thus, in the gaze example, an unmet glance plays one role in an exchange of several such glances and a different role if it is the only one observed. Just what those roles are is determined by whether and how such interactions function to propagate information through the shared environment.

Much of the work that has been done from this perspective is based on the seminal ideas of the Russian developmental psychologist Lev Vygotsky (e.g., Vygotsky 1962, 1978; see also Wertsch 1979, 1985b; Cole 1985; Bruner 1990). In a Vygotskian approach, a key feature of cognitive development is the "zone of proximal development". This refers to the situation in which children participate, at first with limited understanding, in interactions with others who are more proficient than they are until, over time, they too become proficient. Thus for example, in early conversations between toddlers and adults, the adult may provide most of the effort to achieve some coordination with the child. She may, for instance, actively direct the child's attention to a common focus of interest, exaggerate her own response to that object, and mimic and praise any relevant contributions the child makes. Later, the child will come to initiate such interactions himself and to respond to increasingly subtle cues as to when and how to make his contributions. In this view, it is only as a result of such co-constructed activity that the child comes to "internalize" such interactions and can, eventually, manipulate those internalizations even in settings far detached from their original contexts. Since changes in the type and effectiveness of such coordinations are what are experienced and internalized during cognitive development, these changes are also what the cognitive scientist observes and analyzes from a distributed perspective.

Similarly, the social practices that nonhuman primates engage in and observe during their interactions can be taken as the content of *their* distributed cognition. In turn, the refinement and increasing efficiency of these interactions can be presumed to reflect the internalization of such patterns[1]. Thus, although the emphasis in this approach is on observable behavior, it can, to some degree, be used to inform theories on the nature of the mental events that come to be associated with observed activity. In contrast with the standard MR approach, however, these events, especially during development, are not assumed to generate or drive the behavior, but to be a product of it. Note, then, that it is not the inclusion of mental representations alone that constitutes an MR account, but their use as explanatory principles. It is the Vygotskian reversal of this stance – wherein representation is seen as developing out of interaction – that enables the study of distributed cognition to maintain its focus on behavior-in-context.

Given that focus, research in this area tends to occur in real-world settings, as opposed to the controlled confines of a laboratory. (For discussions of ecological validity, or its lack, in much of cognitive research, see Neisser 1976; Bronfenbrenner 1979; Cole and Engestrom 1993; Duranti and Goodwin 1992). As a result, versions of this model have been applied to situations as diverse as adults problem-solving while they shop for groceries (Lave et al. 1984), to toddlers coordinating their play (Eckerman and Didow 1989; Eckerman et al. 1989), to pilots in a cockpit working with air traffic controllers to land a jet airplane (Hutchins 1995b; Hutchins and Klausen 1996). In all of these studies, a detailed analysis of the ongoing activity is used to assess changes in the patterns of coordination between the various elements involved.

In fact, the methodology employed in this work is similar to that practised by ethologists studying animal behavior in the field. To T&C, ethological descriptions of primate behavior are important for generating hypotheses and for informing experimental design. However, since, as they rightly point out, traditional observations are often equivocal as to the nature of the mental representations that underlie them, T&C do not consider this methodology a viable one for addressing cognition as defined by their model. In contrast, from the distributed perspective, ethological observations are precisely the method of choice. That is, ethology *can* be a cognitive science, provided it includes data on the long-term status of relationships, on the group dynamics in a given situation, and, especially, on the *micro-level dynamics of particular interactions* within that situation. The latter is usually done via frame-by-frame video scoring of the precise relative timing of communicative signals and other emotional and attentional behaviors. The units of analysis in this procedure are always interactions, and changes in those relations are charted over time. In the resulting descriptions of "cognitive trajectories", the range and flexibility of the media involved provide a measure of the system's complexity, as well as a basis for comparison with other species.

T&C recognize and appreciate the distributed model and cite some of the above authors in their chapter on human cognition (see also Tomasello 1992; Tomasello et al. 1993a). However, suggesting that such a model might also be applied to nonhuman primates is probably *not* something that T&C would agree with. This is because they see the principal evolutionary change that distinguishes nonhuman primates from humans as essentially "one that changed cognition from a basically individual enterprise to a basically social-collective enterprise" (p. 401). While I would very much agree that collaboration was a key area of hominid specialization, perhaps my one fundamental point of disagreement with T&C concerns whether nonhuman primate cognition can also be subject to such a distributed analysis. In the remainder of this paper, I will argue that it can (see also Coussi-Korbel and Fragaszy 1995; Bard 1995; Strum et al. 1997; King 1997; Savage-Rumbaugh et al. 1998), and that doing so shines a revealing light on both the ontogeny and phylogeny of primate, including human, cognition.

Focusing on behavior

Any empirical model of cognition must, of course, rely on observable phenomena. The MR and distributed models differ mainly in how they perform and use such observations. In the MR model, observable behavior is used primarily as a source of inferences about the representations that constitute cognition. T&C invest a great deal of effort in generating and supporting such inferences, as putative differences in representational abilities are critical to their comparative arguments. The distributed model, on the other hand, by taking observable interaction as, itself, a cognitive event, shifts the focus of such arguments to the detailed comparison of the range and variability of behavior. While presenting its own unique challenges, one advantage to this shift is that it allows researchers to circumvent some of the difficulties that arise in justifying inferences to unobservable mental events.

In T&C's model, a pivotal difference between human and nonhuman cognition lies in the capacity to represent the intentions of others. Nonhuman primates are held to represent their own strategies and goals, but not to form representations of the representations of others. Generating evidence for such "theory of mind" (Premack and Woodruff 1978) distinctions imposes demanding constraints on methodology, and continues to produce controversial interpretations (e.g., Cheney and Seyfarth 1990a, 1990b; Povinelli et al. 1990; Whiten 1991; Heyes 1993a, 1994; Povinelli 1994). Even working out the grounding assumptions of this approach is difficult, since some axiomatic elements – like "intentions" or "goals" – can be said to exist even in the absence of observable behavior.

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[1] Although I characterize the distributed model I am applying to nonhuman primates as essentially Vygotskian, note that, like T&C, Vygotsky (1978) saw such co-constructed cognition as unique to humans.

Consider some of the complications, for example, involved in establishing a correspondence, especially in nonhuman primates, between observable outcomes and "goals".

Ethologically, "goal" has traditionally been linked with the outcome of motivated (i.e., outcome-satiated) behavioral trajectories. For example, in one set of habitual, dyadic, primate interactions, one animal may position itself such that its genitalia are particularly conspicuous to the other, may produce certain facial expressions and vocalizations, or perhaps align its gaze for eye contact. Most of us doing behavioral studies would readily label such behaviors as, for example, "sexual presents", or even "solicitations". We would also be apt to agree that, even if the sequence does not, on some occasions, actually result in sex, it would be reasonable to consider the situation as one in which the presenter indeed had the "goal" of having sex. The utility, however, of operationally defining goals in terms of typical outcomes can quickly decline as outcomes become less predictable. While some behaviors, like "sexual presents", are highly ritualized, the interpretation of many other primate signals is, as T&C point out, variable and context-dependent. Primates also show what T&C call "equi-finality" – accomplishing the same end by a variety of means – introducing additional variability into the system. Plus, as the large corpus of data they review makes clear, the capacity to engage in "negotiations" (see de Waal 1996) is a quintessential primate adaptation. Negotiation further undermines such inferences since, when individuals with conflicting motivations can converge, through negotiation, onto a single outcome, that outcome can no longer be assumed to reflect either individual's original representation (see Strum et al. 1997). Ironically, it is this very primate-typical complexity which, at once, both inclines us to the folk-theoretical use of terms like "goals" and makes a rigorous, behavior-based definition of "goal" less tenable than it might be for a simpler organism.

These same flexible, context-dependent negotiations that undermine the MR model's grounding in observable events are precisely the types of interactions the distributed model is designed to handle. That is, in cases such as these, *the cognition we need to study has become a group event.* The distributed model is made-to-order here since it assumes that cognition is created through interaction and is manifest in the observable dynamics of the group. All descriptions are situated in context, and flexibility offers a direct measure of complexity. Thus, from this perspective, the occurrence of such negotiations is an asset, providing visible enactments of socio-cognitive events for us to analyze.

Consider, for example, how this shift in focus impacts on T&C's powerful depiction of social learning as "ontogenetic ritualization". This is the process by which, for example, acts of engagement (such as the beginning of a play bout) can be abbreviated, within an animal's lifetime, into brief signals of solicitation (e.g., Tomasello et al. 1985, 1989, 1994). In T&C's account of this process, an initiator repeats a behavior sequence that resulted in engagement, notices the anticipation of a recipient, understands that the first part of its own behavior was sufficient to evoke that response, and then intentionally produces the first part alone. In some respects, this is similar to a distributed account in that it describes the co-accommodation of the participants to changes they detect in one another's behavior – e.g., the recipient reacting earlier and earlier to the initiator's behavior, or the initiator abbreviating its output while monitoring whether a response is still evoked. However, especially during social learning, when cognition is described in terms of the representations of only one individual, some important relevant information is lost. That information can be retained by carving the world into more social units of analysis.

If we examine the cognitive terms in T&C's description – *anticipate*, *notice*, *understand*, *intend* – we see that some are more amenable to this translation than others. That is, *anticipate* and *notice* are cognitive events that, even in T&C's scheme, can be defined in terms of social relationships. *Anticipate* (described, in the recipient, as an increased readiness to respond) can be equated with a decrease in the difference between the onset times of the two animals' behaviors. Similarly, *notice* can correspond to the relative timing of attentional and signalling behaviors: e.g., the initiator orienting its gaze towards the recipient while the latter is responding. In contrast, *understand* and *intend* must be taken as inferable, internal states that are required for, but not definable as, a change in the interaction. In the distributed model, these two stages would be collapsed into the single step of "brings its behavior into coordination with the other" (see Hutchins 1995a; Strum et al. 1997). In this way, not only is the cognitive event of *coordinate* now, like *anticipate* and *notice*, defined as an observable change, but the critical role played by the other participant is also again made explicit. *Coordination* qualifies as a cognitive event because it characterizes a particular pattern of information flow through the system – i.e., one that promotes a more reliable and efficient engagement. In fact, it is just such *coordinations* that function as the principal units of analysis in many assessments of distributed cognition in human interactions (e.g., Eckerman and Didow 1989; Duranti and Goodwin 1992; Grannott 1993; Hutchins 1995a; Goldsmith and Rogoff 1997).

T&C, of course, recognize the importance of grounding in observables and grapple with this when they discuss the notoriously entangled web of concepts and paradigms in the current discourse on imitation (for discussions, see Mitchell 1987; Galef 1988; Whiten and Ham 1992; Tomasello et al. 1993a; Byrne 1999). One source of the difficulties faced in this research is that types of imitation (e.g., social facilitation, emulation, true imitation) are distinguished by the types of representational processes that are presumed to underlie them. For example, in T&C's scheme, the duplication of another's behavior is seen as "emulation" if the mimic can be said to represent the desirable outcome brought about by the other and then independently work to attain that outcome for itself. This is set in contrast to true "imitation" which requires the ability to represent the intention of the other, focusing the mimic's imitative efforts on the particular way the demonstrator *chose* to perform the task.

In dealing with issues as slippery as these, we would soon find ourselves adrift without behavioral criteria to distinguish one kind of imitation from another, and T&C take pains to provide and justify such criteria. In sum, their criteria for true – i.e., human – imitation consist in the *fidelity* and *novelty* of the reproduced behavior. That is, for T&C, the most convincing cases of imitation are ones that involve the precise duplication of particular actions, and especially when those actions are not already in the mimic's behavioral repertoire. If fidelity and novelty are indeed the critical measures of human-like imitation, the distributed perspective's focus on behavior could readily accommodate these criteria. Fidelity could be established as a particular level of coordination that must be met by two behaviors (an assessment that might not be as straightforward as it at first appears, even in humans – A. Horowitz, unpublished work). Observer judgments of novelty are more difficult (as T&C themselves point out) but would be at least theoretically possible, especially since the distributed model calls for collecting longitudinal information on the individuals involved (see Cole and Engestrom 1993; Hutchins 1995a).

However, to date, the actual results of such experiments with nonhuman primates vary considerably across methodologies and subjects, and are subject to a variety of interpretations. The distributed model sidesteps the attached debate to some degree, since its focus is less on implicating the capacity to represent than on characterizing the capacity to do. To accomplish the latter, it must address the phenomenon of behavior duplication in a somewhat different way. As described above, a distributed account aims to identify the contextual constraints with which participants are required to come into coordination. In experimental research, this works best in analyses that scrutinize task demands, and how they change, during training and testing. Such analyses, in effect, track the "scaffolding" that, in the Vygotskian model, is presumed to be provided by the more expert participants during all socio-cognitive development. These analyses are also less concerned with the final outcome (e.g., number of "successful" trials) than with the nature of the subject's interaction with that scaffolding.

In fact, even at a gross (data-poor) level, such task analyses can be revealing. Consider, for example, the "do this" task used in comparative research on imitation. In this task, subjects are generally trained (i.e., physically molded and/or shaped by reinforcement) to reproduce a behavior performed by the experimenter, on the verbal cue "do this", and then tested on novel (untrained) behaviors. By T&C's criteria, ape performance on this task may offer the best evidence for imitation in nonhuman primates, since even animals with relatively restricted exposure to humans eventually demonstrate at least some level of fidelity and novelty (see next section for a discussion of the effect of "enculturation" on such performance.) Although published reports rarely include the sort of detailed description that the distributed model requires, many include hints as to the apparent salience of certain stimuli, the range of activities produced, as well as the inter-animal contingencies that exist involving such elements.

In one recent "do this" study (Myowa-Yamakoshi and Matsuzawa 1999), for example, adult chimpanzees performed better (including some first-trial imitations) on trials when one object was used on another, than when a behavior was directed toward a single object or when an object was directed at the self. The authors, aiming to "concentrate solely on the subjects' visual-motor information processing rather than on their understanding of the goal or intention behind the demonstrated actions" (p. 129) interpreted these results as indicating that their subjects were "less sensitive to body movements" of the demonstrators than they were to the "directionality" of one object acting on another. In an earlier study with juvenile chimpanzees (Custance and Bard 1994), the subjects had greater success with self-directed behaviors, but this followed training in which the demonstrator not only touched her own body but then also made contact with the relevant body part of the subject. Perhaps such multi-modal (visual and tactile) input facilitates generating a response involving that part. Also, although not explicit in their analysis, a close review of the results of Custance et al. (1993) suggests that their chimps were more capable of imitating actions performed with the hands than with the face. For example, in both this and an earlier study (Hayes and Hayes 1952), chimps were unable, even after extensive training, to reproduce an eye blink (except by using their fingers to hold their eyes closed – see also de Waal 1989, on bonobos). Hayes and Hayes (1952) suggest that blinking may "be absent from [the] voluntary motor repertory" of these animals. (Although, note, an eye blink was successfully mimicked in a similar study with an enculturated orangutan – Miles et al. 1996.) All of the above authors, including T&C, also point out other physical limitations in nonhuman subjects relative to their human demonstrators, including clumsy bimanual manipulations, inaccurate throwing, and poor vocal articulation.

While almost none of these reports include play-by-play accounts of demonstrator-imitator interactions, a related paper by Custance and Bard (1994) does include some information on the course of such interactions. In fact, those authors argue that, even in humans, "imitation requires scaffolding" (p. 216; see also Tomasello et al. 1993b). In their study, two 4.5-year-old chimpanzees began their training by tending to "co-act" with their demonstrator. That is, they would make contact or enter the human's (personal) space while performing at first "generalized" behaviors and, later, better approximations of the demonstrated act. Similarly, Visalberghi and Fragaszy (1990) report that, in infant capuchins, "observation and co-action were concurrent events" in the acquisition of tool use. In contrast, it is apparent from these studies that fairly arduous training is required to establish the "turn taking" that characterizes the more spontaneous emergence of delayed imitation in human infants. In similarly qualitative descriptions of spontaneous “everyday imitation” in (variably enculturated) orangutans, other researchers (e.g., Russon and Galdikas 1993; Miles et al. 1996) have emphasized the contexual requirement of an individual with whom the subject has a strong, stable bond. In the wild, such an individual – usually the mother – provides a protected, provisioned setting where the offspring can feel at ease enough to invest time in at-first inept performances of ultimately profitable skills. When that parent is replaced by a human, such bonds help to motivate the co-enactment and later delayed imitation of even novel, species-atypical behaviors.

By thus fostering hypotheses that focus on the limits and range of physical control, and on the structure of effective scaffolding – rather than on the animals’ construal of the situation – this approach makes the comparative developmental story much easier. Bard and Vauclair (1984), for example, in a study of adult-infant communication during object manipulation, assessed the behavior of human-human, human-ape, and ape-ape pairs. They found that, in contrast to the human adults, the ape adults rarely acted on the objects in ways that would direct or engage the infants’ attention. Plus, the infant apes were much more likely to attend to and manipulate objects when interacting with humans than with their own mothers. This is just the sort of study that can begin to build a comparative database on distributed cognition (see Johnson 1993).

Unfortunately, data on co-attention are conspicuously absent from nearly all accounts of imitation research. From a distributed perspective, a researcher might want to ask, for example, if and when the demonstrator exchanged glances with the subjects and/or any gaze following occurred, which aspects of the demonstrator’s behavior were attended by the demonstrator herself, and which by the mimic, at what points during the sequence, and so on. This sort of information is of special interest since contingencies between co-attention and motor activity are of particular importance in human cognitive development.

Development: adopting a single standard

In what I believe is one of the keenest insights of their book, T&C suggest that a core difference between infants and nonhuman primates is what they call the former’s capacity to “tune in” to others and to get others to tune in to them. This involves a variety of behaviors including, for instance, joint attention, pointing, and gaze following, and the gradual elaboration and coordination of these activities with others. They also make the compelling argument (as have others: e.g., Bates 1979; Bruner 1983; Baron-Cohen 1995; Moore and Dunham 1995; Karmiloff-Smith 1992) that such behavior is the basis for the emergence of proto-declarative communication, pedagogy, tasks involving “multiple-perspective taking”, and other such human specializations. My one point of contention, then, from a purely distributed perspective, would concern the *role* that T&C assign to mental representations in these processes. That is, T&C say:

> “An organism would *only* attempt to tune into the attention of others or get others to tune into their attention if they understood them as beings able to intentionally direct their attention to specific entities on demand.” (p. 405 – italics mine)

By this account, the ability to see others as intentional is a *prerequisite* for the types of behavior that T&C claim sets the infant apart from other primates. That is, it is the possession or activation of this “foundational” (p. 408) representation of the intentionality of others that drives the infant’s behavior and enables it to engage in a variety of human-specific interactions. My argument here concerns not whether humans – or apes – ultimately can or do form such representations, but how treating such representations as prerequisites can create unnecessary problems for a parsimonious account of comparative cognition.

The strain on parsimony is apparent, for example, in an MR account of the “enculturation” of apes. Enculturation is the process that occurs when apes (or humans, for that matter) are raised by humans in a human environment (see Tomasello et al. 1993a; Call and Tomasello 1996). In their book, T&C engage in a stimulating discussion of this process, which they rightly point out is still too little understood. It poses a difficulty for their model since enculturated apes, unlike apes without such experience, tend to perform as well as human children on a variety of cognitive tasks which are held to require human-specific representational abilities. In grappling with this contradiction, T&C are led to give what is, very nearly, a distributed account of ape enculturation. That is, they argue that it is through interaction with humans who, among other things, act to encourage joint attention and expose the apes to the function and benefits of artifacts, that the apes come to alter their repertoire of skills. This is consistent with their position on humans, of course, to whom they readily admit more distributed models apply. Maintaining their MR approach, however, they are also reluctantly led to conclude that these apes may “understand the intentions of others in ways that their wild conspecifics do not” (p. 393).

A fully distributed account would not be compelled to this conclusion – either for enculturated apes or for human infants (see Eckerman and Stein 1990, and further discussion). It would, instead, maintain its focus on the types, limits, and patterns of emergence of the coordinations that occur between the apes (or infants) and the adult humans. T&C do this, to some extent, in their discussion. They point out, for example, that the human must generally exert a greater effort to elicit joint attention with apes than with infants, and that there is far less spontaneous proto-declarative (i.e., attention directing) signaling by the apes than by the children. However, the lack of data on the particulars of such interactions – either during the course of enculturation or during training and testing of the relevant cognitive tasks – is especially frustrating for the distributed model. Answering the sort of questions that this model wants to ask requires an assessment of the micro-level details of these interactions, seeking the patterns of information flow that are eventually incorporated into the juvenile's repertoire.

T&C clearly value parsimony in their account of nonhuman primate cognition, attempting to redress what they (perhaps rightly) see as a bias in the field toward anthropomorphic attributions to nonhuman primates. But there may be significant additional parsimony to be gained from considering such attributions *to infants* as likewise anthropomorphic! That is, the latter attributions are influenced by introspective and linguistic support in that, later in life, language-proficient humans do represent one another's behavior in intentional terms. But such terms are far detached from their original contexts, and have come to act as a kind of "shorthand" that can mask both their origins and their current function. The MR model assumes that, when infants behave in ways similar to their more sophisticated interlocutors, their behavior reflects essentially the same type of representations that are evoked in their elders. This assumption obscures the co-constructive processes of cognitive development and can mislead us as to the nature of adult representations (see Langacker 1987, 1992; Fauconnier 1994; Hutchins 1995a). Thus, for both comparative and developmental purposes, we might do well to adopt a *single standard* to assess such behavior. The distributed model provides such a standard in that it assesses behavior more at face value, letting the complexity and flexibility that are actually observable be the measure of the cognition involved.

Adopting such a standard reorganizes the MR account of infant performance, especially on tasks for which that model proposes the attribution of intention is required. Consider, for example, the ingenious "find the toma" experiments (e.g., Tomasello and Barton 1994; Tomasello et al. 1996). In this task, an adult announces that it will "find the toma" and then, as the child watches, the adult searches through a bag of novel toys, pulling out one after another. As T&C describe it:

> "... children as young as 18 months of age will assume that the "toma" is the one [object] whose extraction seems to satisfy the adult's searching intention (the adult looks happy, stops searching, etc.)... The overall point is that, in acquiring the linguistic conventions of those around them, human children rely on their ability to understand others as intentional agents" (p. 409)

A distributed model's take on this result would not depend on the 18-month-old representing others as intentional, but only in its being familiar with enactments of the "finding" game. That is, the very sorts of behavior that T&C cite as indicative of a "satisfied intention" – looking happy, stopping the search – are likely to be familiar to the child as typical of the terminal phase of the activity that accompanies the use of the word "find". Furthermore, the object also associated with this phase is generally the one named during the search. The Vygotskian perspective proposes that children can proficiently co-enact parts of such a sequence and even use some terms appropriately before they fully internalize those actions, let alone represent coherent explanatory principles for them. It is an important and interesting result that children can learn words in such non-ostensive contexts. But, by seeing language development as a change in the child's facility at coordinating its behavior with others, the distributed model suggests what the child learns in this process is *how to participate*.

To study such processes, the researcher begins by identifying which aspects of the environment are inherently salient to the participants. For example, primates, including humans, are particularly sensitive to face-like stimuli (e.g., Bruce et al. 1981; Keating and Keating 1982; Leonard et al. 1985) as well as to changes in the direction of the head and/or eyes (e.g., Perrett et al. 1985; Brothers and Ring 1993). The researcher would also note regularities in how a juvenile's attention is drawn or diverted by the activity of others. Plus, it would consider the changing range of motor control apparent in the juvenile's evolving participation. Among the media that come under such control are gaze, gesture, facial expression, actions on others and on objects, and vocalizations, including spoken words. As participants interact, contingencies between states of these media – e.g., synchronicity, complementarity, or proximal triggering – emerge and change. In this way, cognitive trajectories are made available, in shared experience, for internalization – and for study. Long-term patterns in the timing and refinement of such trajectories constitute cognitive development.

Early on, this sort of co-activity occurs primarily within the framework of stereotyped engagements, precursors of the much more flexible and sophisticated "language games" (Wittgenstein 1953) that come to occur between adults. Some of these infant/adult games – like "pointing out", "naming" and the above "finding" game – focus on the manipulation of attentional states. These feature words like "see" and "know" and patterns of co-attention (like noticing looking, or directing attention) that play a role in the kinds of interactions that the MR model sees as depending on the representation of intention (for discussion, see Bruner 1983; Karmiloff-Smith 1992; Gomez et al. 1993; Astington 1996). According to Vygotsky, as the child matures, his internalization of such experiences enables him to produce pertinent behaviors in the presence of just a fragment of their original context. Words are among the most important of these fragments. They begin as imitated articulations, are heard and performed in a widening array of relevant contexts, and are finally creatively and flexibly combined in complex conversations, as well as in the generation of explanations of one's own and others' behavior. Like all explanations, these can be seen as one-sided conversations that conform, in complicated ways, to group patterns of word use and information assimilation. Since such explanations are meaningful only if they would constitute a relevant contribution to discourse on the subject, even at this sophisticated level, what the explainer has mastered is "how to participate" (Hutchins 1995a; Cole 1996; Wertsch 1998).

As should be clear from the above, although the distributed model does not emphasize representation, the data from this approach are more compatible with certain theories of representation than they are with others. "Media", as used in this paper, for instance, draws heavily from the notion of Hutchins (1995a) of "representational media", across which "representational states" are held to be propagated. This approach allows behavior itself to be taken as a representation; but, even in Hutchins' theory, some representational states are states of "mind". Other theories of mental representation may also be applicable. For example, taking each participant as an active negotiator of its environment corresponds well with the notion of a situated, action-based "schema" (e.g., Minsky 1975; Schank and Abelson 1977; D'Andrade 1991; Mitchell 1999). Similarly, representing development as learning "how to participate" could be facilitated by the ecological concept of "affordance"[2] (Gibson 1979). Piaget's notions of "accommodation" and "assimilation" certainly also resonate with this approach of focusing on the evolving interaction of the subject with its environment (Piaget 1952, 1954, 1971). Contemporary theories of "embodied" representations (e.g., Johnson 1987; Varela et al. 1996; Fauconnier 1994; Clark 1999) might also be particularly useful, given that they see even abstract forms like metaphor and counter-factuals as developing out of real-world interactions. All of the above are consistent with the Vygotskian "internalization" of shared experience.

It is important to recognize, here, however, that, unlike the MR model, the distributed model does not depend on such representations being of one sort over another. Instead, its goal lies in identifying a set of context-sensitive behavioral protocols that *work* – that is, that enable the participants to procure and modify physical and social resources, and foster a gradually increasing parity in the skills of the novice and its interlocutors. Since it is assumed that these protocols are co-constructed, and their development is demonstrated in the changes in fluidity and complexity of the coordinations that occur, the study of such interactions should be sufficient to provide a coherent cognitive account.

Consider the impact, then, of applying this single standard back to ape enculturation. Recall that T&C argue that it is "being treated as intentional beings" – i.e., engaging in activity that "presupposes a reciprocity of understanding" (p. 393) – that somehow leads nonhuman primates to form intentional representations of others. In contrast, the distributed model would translate this observation as "being treated as if they could participate", and the cognition involved as being embodied by the degree and manner in which the primates respond to such affordances. Similarly, nonhuman primates' development, in their own species-typical environments, could also be tracked along such interactive trajectories. Furthermore, the practices in which any of these animals came to participate would be taken as the content, ultimately, of their internalizations. However, given the real-time trajectories as a basis for comparative analyses, experimentally generating a response that would logically necessitate or refute a "human-like" representation would no longer be required.

While the above emphasizes the importance of developmental research, the arguments apply equally well to adult learning or discourse. This being the case, the course of adult primate negotiations could also be subject to such an analysis. Adopting this approach can not only help us to understand the developmental pathways our different species take, but can yield insights into their possible evolutionary origins as well.

Cognitive evolution: the elaboration of attentional behavior

Generating an evolutionary scenario for the emergence of hominid cognitive abilities is a task that particularly taxes the MR model. For example, although T&C take the proposals of other researchers (Parker and Gibson 1979; Milton 1981, 1988; van Schaik and von Hooff 1983; Byrne and Whiten 1988; Dunbar 1993) seriously enough to review and critique them, they refrain from giving their own version of what they call an "evolutionary fairy tale" (p. 425). Furthermore, they acknowledge that their approach generates a "chicken-or-the-egg" problem: i.e., "...how could it be that children learning to treat others intentionally depended on adults treating them intentionally? Which came first...?" (p. 423). I would argue that the fault here lies not in the logic or imagination of the authors, but rather in the MR model itself which leads them into this theoretical cul-de-sac. That model postulates the discontinuous appearance of a unique new form of representation that must appear in multiple individuals simultaneously in order to be effective. Not only would this be a highly unlikely event, but the model's reluctance to specify the "raw material" upon which natural selection was to have operated would strain any neo-Darwinian account.

In contrast, the distributed model makes this task much easier by providing a common ground between human and nonhuman cognition that can help to bridge the phylogenetic gap. Because of its focus on behavior, and in particular on the social coordination of behavior, the types and extent of coordination seen in human and nonhuman primates can be directly compared. Observable differences can be used to generate hypotheses that are grounded in the apparent structure and adaptive consequences of that behavior (see Smillie 1993). Plus, by taking such coordinations as cognitive evolution's "raw material", the theorist is faced with the much more tenable problem of postulating how selection may have accomplished feasibly small but critical changes that could "tweak" the nonhuman repertoire into the human one. In addition, by treating cognition as a manifest process of coordination, the distributed model also eliminates the vexing chicken-or-the-egg problem. This is because, given *any* configuration of species-specific skills, adults

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[2] T&C suggest that representations of "affordances" may account for nonhuman primates' limited success at imitation. However, this is presented as an alternative to the human's representation of intention in such tasks.

are always more proficient than immature animals, and thus are always available to provide scaffolding for the development of the youngsters' participation.

T&C have already highlighted a key evolutionary development in primates relative to many other mammals – i.e., their engagement in "tertiary" social interactions. These are interactions in which the protagonist's behavior is based not just on its own relationships (e.g., kinship, rank, or friendship) with others, but also on the relationships that exist *between* the other animals (e.g., de Waal and van Hooff 1981; Gouzoules et al. 1984; Cheney et al. 1995; Silk 1999). Thus, for example, not only is there coalitional behavior in primates (see Harcourt and de Waal 1992), where one animal may recruit aid from a second against a third, but the animal that is recruited can often be predicted based on its rank relative to, and thus likely effectiveness against, the third animal. In this context, the focus of the MR model is on the recruiter's ability to mentally represent the relationships of others, a representation it presumably uses to motivate its decision. However, by shifting our perspective from the decision to the act, it becomes easier to generate hypotheses on the possible contexts in which such acts could have been adaptive.

The recruiter's behavior can be thought of as displaying a keen *context sensitivity*, in which its actions vary with the particular configuration of individuals present. With this emphasis, we are guided to consider situations that may have exerted selective pressure for such "audience effects" (see Marler et al. 1986; Seyfarth and Cheney 1986; Hauser 1990). For example, dealing with primate *idiosyncrasy*[3] might have provided one evolutionary "ratchet" that involved coping with an ever-changing range of distinctive audiences. In this scenario, the more an individual depends on learning, the greater the impact its individual experience will have on its behavior. Such individual differences could, in turn, pressure groupmates to more finely-tune their responses to the proclivities of their distinctive audiences. This, in turn, could require a greater dependence on learning, which would lead to greater individual differences, and so on and so on. Note that such a development could impose particular demands on, and payoffs for, immigrating individuals faced with integrating into a group of strangers. Additional refinements in such skills may also have occurred in precursor species which, like today's bonobos (Kano 1982), chimpanzees (Nishida 1979; Goodall 1986) and spider monkeys (Symington 1990), lived in *fission/fusion societies*. Such a social structure would provide opportunities for audience-specific payoffs that might not be available in a species in which group membership was relatively fixed (Johnson 1990).

However, to effectively assess the rudiments of hominid cognition in nonhuman primates, the distributed model would demand an even closer look at the particulars of behavior during primate-typical coordinations. It might begin by asking, for example, what visible indicators of the relative rank of others are available to a potential primate negotiator. This information has already been provided by generations of primate ethologists who, themselves, have been concerned with determining the rank of their subjects. In many species, stereotyped signals indicating rank in dyadic interactions have been identified – e.g., "bowing" in chimpanzees (de Waal 1982; Goodall 1986), "peering" in female bonobos (Johnson et al. 1999), and "fear grimaces" in several species (e.g., Hinde and Rowell 1962; Altmann 1967; see Redican 1975). In addition, as Chance (1967; see also Chance and Jolly 1970) suggested long ago, attentional behavior may also be an indicator, with subordinates looking to and following dominants more often than the reverse (see also Yamagiwa 1992; McNelis and Boatright-Horowitz 1998; Johnson et al. 1999). Given the degree of flexibility that, as we shall see below, primates display in their attentional behavior, this type of activity may be of particular interest to cognitive scientists.

T&C's own recognition of the importance of investigating social attention is evident in their significant contribution to the research that has been done on this topic since their book was published (e.g., Call et al. 1998; Tomasello et al. 1998, 1999; Hare et al. 2000). In the array of recent work, certain patterns seem to be emerging. First, it has long been clear that many primate species engage in "gaze following" under natural conditions (e.g., Kummer 1967; Chance 1967; Plooj 1978; van Schaik et al. 1983; Fragaszy and Visalberghi 1989; Tomasello et al. 1998; C.M. Johnson, unpublished work). Typically in such an interaction, one animal appears attracted to some aspect of its environment and others observe it and then also so direct their attention. Recent tests of the limits of such abilities include work with chimpanzees who can follow an experimenter's gaze around barriers or to specific points behind their heads (Povinelli and Eddy 1996a, 1996b, 1997; Call et al. 1998; Tomasello et al. 1999). Other experiments place subjects in an "object-choice task" in which they must select one of two stimuli on the basis of attentional cues from an experimenter, or sometimes from a conspecific. In these tasks, most of the animals tested learned to use gestural and/or head-turning cues (Anderson et al. 1995, 1996; Itakura 1996; Itakura and Anderson 1996; Povinelli and Eddy 1996a; Emery et al. 1997; Itakura and Tanaka 1998; Peignot and Anderson 1999; Vick and Anderson 2000). However, in many of these cases, extensive training seems to be required (although see further discussion below). This leads Hare et al. (2000) to suggest that perhaps the cooperative context of information sharing in the above-described object-choice task is less "natural" for most primates than the *competitive* use of attentional behavior. In their study, the researchers found that subordinate chimpanzees would preferentially choose food a dominant could not see, while a dominant would first choose food visible to both and only after choose the food only it could see. This pat-

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[3] While an investigation of "personality" in nonhumans is currently underway (see Gosling and John 1999), there are few data on primate idiosyncrasy (although see Boysen 1994). However, in several cognitive experiments that T&C describe there are striking individual differences in subjects' strategies and levels of success.

tern occurred even when the same animal was dominant in one pairing and subordinate in another.

Other insights into the range of natural contexts in which attentional behavior plays a role are available in the ethological data. Examples include one animal breaking up a possible coalition between others upon observing them coordinating their gaze, proximity, and contact (e.g., Kummer 1971; de Waal 1982; Nishida and Hiraiwa-Hasegawa 1986), or another mediating a reconciliation between others who are not showing co-attention or other signs of likely engagement (e.g., de Waal and van Roosmalen 1979; de Waal 1982; de Waal and Aureli 1996). In the more common recruitment scenario, the recruiter usually turns its head and eyes back and forth between its potential ally and its antagonist, often while orienting its body toward the antagonist in a confrontational posture. The relative timing and direction of "looks" in all the animals involved is, of course, relevant since, if the ally looks away when the recruiter looks at him, the subsequent flow of events is apt to be quite different than if the ally not only makes eye contact but then also follows the recruiter's gaze.

If the recruitment is successful, one common, subsequent coordination involves a marked similarity and synchrony of behavior in the allies (e.g., Kummer 1967; Packer 1977; Smuts 1985; Goodall 1986; Strum 1987; see Jolly 1985, p. 258 for discussion and illustrations) They might, for example, stand stiffly shoulder to shoulder, hair erect, turning together as the antagonist moves. They might also match and synchronize their vocalizations. Such synchronous displays are also seen in other animals (e.g., lions, Schaller 1972; wolves, Smith 1977; dolphins, Johnson and Norris 1986) and have been described as presenting an apparently larger and more formidable adversary in the form of multiple individuals demonstratedly prepared to act in unison. Species, such as higher primates, in which coalitional behavior plays an especially significant role could have been subject to additional selection favoring more subtle, prolonged, or flexible co-behavior between allies. Note, too, the link between such co-behavior and that (previously described) which spontaneously emerges during the development of imitation in chimpanzees.

In the unsuccessful version of the recruitment scenario just described, the potential ally does not meet or follow the recruiter's gaze. Averting one's gaze in the face of a solicitation, or even a threat, from another animal – what Kummer (1968) called a "cut off" behavior – is a fairly widespread pattern in primate negotiations. It generally serves to forestall or even prevent engagement between the participants (for discussions, see Altmann 1967; Chance and Jolly 1970; Johnson 1990). Gaze aversion may also be related to a trend emerging in the experimental work on social attention discussed above. Many of the species tested – with the notable exception of the chimpanzee (Itakura 1996; Povinelli and Eddy 1996a; Itakura and Tanaka 1998; but see Vick and Anderson 2000 on extensively-trained capuchins) – seem to be highly resistant to learning to use the *eyes only* as an attentional cue. There also seems to be a strong effect of enculturation on this ability (see Itakura and Tanaka 1998 on success with an orangutan, and Peignot and Anderson 1999 with a gorilla). In most primates' typical ontogenetic histories, in which gaze aversion develops as a strategy to avoid engagement, direct eye contact functions most often as a threat (although see Gomez 1996). As several authors have suggested (e.g., Emery et al. 1997; Peignot and Anderson 1999; Vick and Anderson 2000) this threatening aspect of eye contact may be what has canalized these species away from using "eyes only" as a cue.

This may represent an important distinction since humans, at a very early age (Butterworth and Jarrett 1991; Itakura and Tanaka 1998; but see Corkum and Moore 1995), can separate head orientation from direction of gaze as a cue to another's focus of attention. This may be related to the loss, in our species, of the brownish pigment that darkens the visible parts of other primates' sclera (Morris 1967; Kobayashi and Koshima 1997). By making gaze direction more salient, this anatomical change may well have been adaptive in facilitating the ontogeny of joint visual attention (see Argyle and Cook 1976; Baron-Cohen 1995; Moore and Dunham 1995). The cross-cultural occurrence, early in human development, of stereotyped engagements in eye-contact and gaze following also support such an account (see Bates 1979; Trevarthan 1979, 1993). In contrast, in my research on social gaze in captive bonobos – who, when mature, show gaze aversion, gaze following, and can use the eyes as a cue at close range (personal observation – see also Johnson 1997; Johnson et al. 1999) – the most marked difference I have observed between the gaze repertoires of our two species is the lack, in bonobo mothers and infants, of such gaze coordination "games".

Gaze aversion is also sometimes given a deceitful connotation, such as "feigning indifference" or "pretending not to notice". From the MR view, a modeler might ask if the inherent ambiguity of gaze aversion – that is, its consistency with a scenario in which the gazer's attention is genuinely engaged elsewhere – was "intentionally" exploited by the gazer. The distributed approach would shift the emphasis here, from concerns about what representations may underlie such negotiations, to a focus on exactly what the animals *do* in such contexts. For example, human observers are most likely to interpret interactions as involving deception when an (often abrupt) change in the gazer's behavior coincides with a change in the other animal's attention. So, for example, if the gazer finally looks at the recruiter *right after* the latter turns away, observers are more likely to claim that his gaze aversion involved some form of "pretense". Rather than discussing this change in terms of what the gazer might be thinking, the distributed approach would describe this as the gazer acting in accordance with one cognitive trajectory – i.e., the one that precludes engagement – until the attentional context changes, at which point a new trajectory is initiated. The abruptness of the change portrays an animal that has the capacity to rapidly adapt to subtle contextual variables and sufficient "self control" (e.g., Logue 1988;

Tobin et al. 1996) to strategically promote certain types of coordination and undermine others. Thus, as in the above discussion of imitation, a focus on the range of behavioral flexibility and on the types of cues that can elicit a response, gives us a way to characterize the real-time cognition we observe. From this angle, we are more likely to see a context-sensitive creature with rudimentary skills at *multi-tasking* (see Savage-Rumbaugh et al. 1998) than one that may (or may not) possess a Machiavellian "theory of mind".

A related type of attentional coordination, that also tends to be attributed to deceptive intent, has been called a "distraction display" (e.g., de Waal et al. 1976; Byrne and Whiten 1985; de Waal 1986; Goodall 1986; see Whiten and Byrne 1988). In this interaction, an animal with access to a potentially contested resource – including another individual – might, while in proximity to its competitor, do an extended arch of its neck and gaze fixedly at a distant point, eliciting a gaze follow from the competitor. The interaction may follow this course because, often enough, such coordinations are reinforced by something of significance to both animals actually happening at the distant focal point. The gaze follow by the second animal is more consistent with a subsequent trajectory directed away from the resource, or at least one that reduces the immediacy of its contention. Observers tend to call the interaction deceptive if the first animal exploits this diverted attention, by quickly reorienting to and/or procuring the resource. Regardless of the animal's connotation of events, however, we can describe such behavior as the exercise of sufficient self-control to accomplish a rapid, strategic shifting of cognitive trajectories.

Competitive negotiations involving gaze aversion or distraction displays, if they happened frequently enough and/or paid off significantly enough, represent additional prime candidates for an evolutionary "arms race" (see Byrne and Whiten 1988, 1992; Byrne 1994, 1995; see also Menzel 1974; Coussi-Korbel 1994; Mitchell and Anderson 1997). That is, a distracter's maneuvers establish a selective pressure to counter their own effectiveness. However, while an individual who could notice and respond to contradictory signals might be at a selective advantage, its behavior could, in turn, select for distracters who were capable of performing more coherent displays. Interestingly, this latter escalation seems to have occurred only in our species. That is, researchers sometimes find distraction displays in nonhuman primates comical because of the, to us, obvious contradictions in the first animal's signals. In the bonobos, for example, I have videotaped such an interaction in which the animal looked off into the distance and at the same time reached her grasping foot toward the resource (for a similar account involving chimpanzees, see Goodall 1986, p. 577). Human children, on the other hand, show a progression, in their deceptive displays, from producing ones that are partial and self-contradictory to more effective ones in which gaze, gesture, and language are all fully coordinated (Vasek 1986; La Freniere 1988). As we shall see below, several human specializations can be characterized as involving the elaboration and refinement of such strategic self-control.

Hominid specializations

Although our accounts of the mechanisms vary, it should be clear that both the MR and the distributed models converge on imitation and attention-directing processes as pivotal differences between human and nonhuman primates. By looking at how these processes function in typical human interactions, the distributed model can generate hypotheses concerning both the contexts and mechanisms of their evolution.

When imitation is considered in terms of the types of coordination it facilitates, two important functions come to light. The most obvious – and most often discussed – is the transfer of a skill from one individual to another. But imitation can also serve an attention directing function. As described for synchronous displays above, a similarity of behavior can garner the attention of both participants and onlookers. In addition, human imitation has expanded to include the reproduction of environmental sounds as well. Thus, for example, given the subtle cacophony of backyard sounds, a 1-year-old's imitation of one of those sounds – say, a dog barking – can result in his mother's selectively attending to that particular sound. Similarly, her subsequent imitation of that same sound indicates that her attention has been so directed, facilitating further engagement involving the now-shared topic. This sort of interaction can occur even before language *per se* has developed in the child, suggesting that it is fundamental to that development. The language that grows out of this activity also exploits the attention-focusing function of imitation. Not only do a child's delayed imitations of utterances function to "point" – or refer – to the previously shared contexts in which they were learned and used, but even sophisticated adult conversation can be seen as a collaborative process of attention direction to different aspects of or perspectives on a topic. Thus, just like the refinement of gaze following, pointing, and other attention directing behaviors, the human's special facility at imitation represents, in part, an elaboration of *diectic* behavior

Both of these functions of imitation – skill transfer and attention direction – are manifest in most examples of *teaching*. The MR model defines a teacher as an individual who acts with the intention of manipulating the knowledge state of another. The rarity of teaching in nonhuman primates (Caro and Hauser 1992; King 1994; although see Fouts et al. 1989; Boesch 1991; Maestripieri 1995) is seen as important evidence in support of the human-specificity of such representations. The distributed model, on the other hand, would interpret that evidence in terms of context-dependent differences in performance.

Consider, for example, the context of cracking nuts with a stone hammer and anvil. In some chimpanzee communities, animals develop a proficiency at this task and females, especially, practice it often (Sugiyama and

Koman 1979; Boesch and Boesch 1983). Once they become experts, the only commonly observed modification of this activity involves allowing their infants to scrounge from their efforts. In contrast, humans, in the same context, would also be likely to "demonstrate" the procedure to their young. That is, in the presence of a novice, the human expert might slow its actions down, orient them to the novice's line of sight, use various attention-directing signals (e.g., pointing, naming, or diectic phrases such as "look at this"). Such teachers will also often imitate a learner's action and then improve upon that action, drawing attention to the difference between them. The learner's imitations, in turn, shape the amount and type of effort that the teacher invests. Viewing the interaction in this way highlights the possibility that the same basic mechanisms are operating in both teacher and learner. That is, not only do both participants imitate the other, but the teacher's demonstrations can be seen as examples of *self-imitation* – a kind of modified replay of acts that the teacher has experienced itself performing in the past. This behavior can be interpreted as other than a mere repetition since the manner in which it is performed is no longer optimal for procuring food. Instead, it is a slightly altered version of the act, constrained by the learner's attention and dis/similarity of behavior, and thus is optimized for engaging the learner and facilitating its rapid acquisition of the skill.

It is no coincidence that these key processes of imitation and attention direction occur during teaching. In fact, I would argue that this context provided some of the most important selective pressures operating on hominid cognition. For example, multi-generational "extractive foraging" (Parker and Gibson 1977, 1979; see also King 1986, 1994; Parker 1996) could have provided regular opportunities for highly profitable pedagogical interactions. Presuming that mothers taught their own offspring, "kin selection" (Hamilton 1964) would argue that both participants would have much to gain from the youngster mastering such techniques at an earlier age. (Note that chimpanzees become proficient at nut-cracking at about age six; Boesch and Boesch 1990.) An immature hominid who could regularly access nutrient-rich nuts, for example, might well mature earlier, reproduce earlier, and thus potentially produce more offspring – a clear reproductive advantage for its lineage. Plus, since even incremental improvements in co-attention and co-enactment could be profitable, no major discontinuities would need to be accounted for. The imitation and attention directing skills developed in this context could then be co-opted for further adaptive refinements in a variety of social contexts.

Looking to the mechanisms of such developments, it seems reasonable to consider the neurological constraints that may have been involved. In even a cursory overview of how such constraints have changed over the course of hominid evolution, several modifications involving *sensory-motor linkages* are at once apparent. Human articulation, for example, underwent an expansion and refinement involving complex and subtle sensory/motor coordination (see discussions by Lieberman 1973, 1984; Deacon 1990, 1997; Greenfield 1991). That is, motor activity in our vocalization system requires more rapid and subtle integration of auditory and proprioceptive feedback than in any other primate. It can also be entrained by external auditory and/or visual input (McGurk and MacDonald 1976). Similarly, human skills at bi-manual, including hand-hand-eyes, coordination (presumably adaptive, at least in part, for tool use) out-class those of all other primates (e.g., Kohler 1925; Vauclair and Bard 1983; Vauclair 1984; see also Marshack 1984; Calvin 1983, 1993). Plus, the coherent, full-body control, discussed above as a means of reducing ambivalent signaling, likewise would involve complex cross-modal feedback. All of these processes require years to develop in the immature human, and are dependent engagement in appropriate sorts of experience (see Elman et al. 1996). In each of these cases, the sophistication of motor control and its integration with particular types of perceptual input together form the physical basis for the "strategic self-control" that ultimately characterizes human adult behavior.

As has been argued persuasively elsewhere (e.g., Meltzoff 1988; Donald 1993), it seems likely that the development of imitative abilities was a necessary precursor to more sophisticated human specializations like language. For example, imitative behavior appears earlier in human development (e.g., Meltzoff and Moore 1977, 1989) and is more evident, if still rudimentary, in nonhuman primates, than later refinements like speech or bi-manual coordination. And, if we look again at T&C's behavioral criteria for human imitation – novelty and fidelity – we see that they lend themselves quite readily to an account in terms of refined sensory-motor coordination. That is, those criteria are met when behaviors perceived for the first time are faithfully reenacted by the perceiver. Thus, as several authors have suggested (e.g., Meltzoff 1990; Ettlinger and Wilson 1990; Heyes 1993b; Miles et al. 1996), imitation can be seen as the capacity to translate visuo-spatial and auditory stimuli into motor output.

An interesting example of one such "translating" device has been found in zebra finches (Williams and Nottebohm 1985; Williams 1990). These songbirds store information about the species-specific song that they hear as fledglings not in the acoustic areas of their brain, which first process that information, but in the motor areas that are activated when they later produce the songs themselves. While there is as yet insufficient data to determine if such a system may also operate in any primate brains, including humans (although see Jeannerod 1994; Hari et al. 1998), recent research has revealed "mirror neurons" in pigtailed macaques which fire both when the animal performs an action and when it observes others performing it (di Pellegrino et al. 1992; Gallese and Goldman 1998; Rizzolatti and Gentilucci 1988). While these monkeys are not considered proficient imitators (Beck 1976; Visalberghi and Fragaszy 1990), suggesting that such cells do not constitute a complete mimicry mechanism, they may certainly have been a part of the neurological heritage that was modified during hominid evolution.

Perhaps one additional insight that the above distributed account can add to this proposal arises from its focus on social attention and diectic imitation. That is, perhaps a critical hominid specialization involved modified linkages involving not just perception, but *co-perception*, and motor control. Contributing to this development might be “gaze cells” like those that have been identified in monkey brains (Perrett et al. 1985, 1992; Brothers and Ring 1993). Some of these neurons give their maximum response to the stimulus of eyes looking directly at the subject, while others respond most strongly to eyes directed off to the side. Such gaze cells, in conjunction with the perceptual salience of anatomical cues like high-contrast sclera and arched, mobile eyebrows, when activated during appropriate social interactions, could generate information on co-perception that might constrain the above-mentioned translation circuitry. Other relevant subsystems might include the above-mentioned mirror neurons, refined motor control of, especially, the hands and face, as well as limbic interactions involving social motivation and emotional signaling (e.g., Semendeferi et al. 1998). Such a system could explain a great range of human-typical behavior, including our tendency to place inter-subjectivity and attributions of intention – both of which are seen, even from the MR point of view, as related to the development of co-perception – in a central place in our accounts of human uniqueness.

Thus, while the MR and distributed models converge on what they see as the important areas for future comparative research, their methodological and theoretical approaches to those topics differ significantly. The primary differences appear to lie in their focus on internal, individual versus observable group processes, and in their tendency to characterize human capacities as a discontinuous departure from those of other species versus an elaboration of traits common to all socially complex animals. For researchers interested in learning about cognition from observing naturally occurring behavior, the distributed model offers a valid and productive methodology, and a theoretical framework especially suited to assess the dynamical processes involved in cognitive development and evolution. Not only can this approach secure the researcher’s footing in empirical observation, but it may also ultimately help develop criteria for an ecologically valid and evolutionarily cogent theory of representation.

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References

Altmann SA (1967) The structure of primate social communication. In: Altmann SA (ed) Social communication among primates. University of Chicago Press, Chicago, pp 325–362

Anderson JR, Sallaberry P, Barbier H (1995) Use of experimenter-given cues during object choice tasks by capuchin monkeys. Anim Behav 49:201–208

Anderson JR, Montant M, Schmitt D (1996) Rhesus monkeys fail to use gaze direction as an experimenter-given cue in an object-choice task. Behav Proc 37:47–56

Argyle M, Cook M (1976) Gaze and mutual gaze. Cambridge University Press, Cambridge

Astington J (1996) What is theoretical about the child’s theory of mind: a Vygotskian view of its development. In: Caruthers P, Smith PK (eds) Theories of theories of mind. Cambridge University Press, Cambridge, pp 184–199

Bard KA (1995) Sensorimotor cognition in young feral orangutans (*Pongo pygmaeus*). Primates 36:297–321

Bard KA, Vauclair J (1984) The communicative context of manipulation in ape and human adult-infant pairs. J Hum Evol 13: 181–190

Baron-Cohen S (1995) Mindblindness: an essay on autism and theory of mind. MIT Press, Cambridge

Bates E (1979) The emergence of symbols. Academic Press, New York

Bateson G (1972) Steps to an ecology of mind. Ballantine, New York

Bateson G (1979) Mind and nature: a necessary unity. Dutton, New York

Beck BB (1976) Tool use by captive pigtailed monkeys. Primates 13:301–310

Boesch C (1991) Teaching among wild chimpanzees. Anim Behav 41:530–532

Boesch C, Boesch H (1983) Optimization of nut-cracking with natural hammers by wild chimpanzees. Behaviour 83:265–286

Boesch C, Boesch H (1990) Tool use and tool making in wild chimpanzees. Folia Primatol 54:86–99

Boysen ST (1994) Individual differences in the cognitive abilities of chimpanzees. In: Wrangham RW, McGrew WC, Waal FBM de, Heltne PG (eds) Chimpanzee cultures. Harvard University Press, Cambridge, pp 335–350

Bronfenbrenner U (1979) The ecology of human development. Harvard University Press, Cambridge

Brothers L, Ring B (1993) Medial temporal neurons in the macaque monkey with responses selective for aspects of social stimuli. Behav Brain Res 57:53–61

Brown AL, Ash D, Rutherford M, Nakagawa K, Gordon A, Campione JC (1993) Distributed expertise in the classroom. In: Salomon G (ed) Distributed cognitions: psychological and educational considerations. Cambridge University Press, Cambridge, pp 188–228

Bruce C, Desimone R, Gross CG (1981) Visual properties of neurons in a polysensory area in superior temporal sulcus of the macaque. Behav Brain Res 57:53–61

Bruner J (1983) Child’s talk. Oxford University Press, Oxford

Bruner J (1990) Acts of meaning. Harvard University Press, Cambridge

Butterworth G, Jarrett NLM (1991) What minds have in common is space: spatial mechanism serving joint visual attention. Br J Dev Psychol 9:55–72

Byrne RW (1994) The evolution of intelligence. In: Slater PJB, Halliday TR (eds) Behavior and evolution. Cambridge University Press, Cambridge, pp 223–265

Byrne RW (1995) The thinking ape: evolutionary origins of intelligence. Oxford University Press, Oxford

Byrne RW (1999) Imitation without intentionality. Using string parsing to copy the organization of behaviour. Anim Cogn 2:63–72

Byrne RW, Whiten A (1985) Tactical deception of familiar individuals in baboons (*Papio ursinus*). Anim Behav 33:669–673

Byrne RW, Whiten A (1988) Machiavellian intelligence: social expertise and the evolution of intellect in monkeys, apes and humans. Oxford University Press, Oxford

Byrne RW, Whiten A (1992) Cognitive evolution in primates: evidence from tactical deception. Man 27:609–627

Call J, Tomasello M (1996) The effect of humans on the cognitive development of apes. In: Russon AE, Bard KA, Parker ST (eds) Reaching into thought. Cambridge University Press, Cambridge, pp 371–403

Call J, Hare BA, Tomasello M (1998) Chimpanzee gaze following in an object-choice task. Anim Cogn 1:89–99

Calvin WH (1983) A stone's throw and its launch window: timing precision and its implication for language and hominid brains. J Theor Biol 104:121–135

Calvin WH (1993) The unitary hypothesis: a common neural circuitry for novel manipulations, language, plan-ahead and throwing? In: Gibson KR, Ingold T (eds) Tools, language and cognition in human evolution. Cambridge University Press, Cambridge, pp 230–250

Caro TM, Hauser MD (1992) Is there teaching in nonhuman animals? Q Rev Biol 67:151–174

Chance MRA (1967) Attention structure as the basis of primate rank orders. Man 2:503–518

Chance MRA, Jolly C (1970) Social groups of monkeys, apes and men. Dutton, New York

Cheney DL, Seyfarth RM (1990a) How monkeys see the world. University of Chicago Press, Chicago

Cheney DL, Seyfarth RM (1990b) Attending to behavior versus attending to knowledge: examining monkeys' attribution of mental states. Anim Behav 40:742–753

Cheney DL, Seyfarth RM, Silk JB (1995) The response of female baboons (*Papio cynocephalus ursinus*) to anomalous social interactions: evidence for causal reasoning. J Comp Psychol 109: 134–141

Clark A (1999) Being there: putting brain, body, and world together again. MIT Press, Cambridge

Cole M (1985) The zone of proximal development: where culture and cognition create each other. In: Wertsch JV (ed) Culture communication and cognition: Vygotskian perspectives. Cambridge University Press, Cambridge, pp 146–161

Cole M (1995) The supra-individual envelope of development: activity and practice, situation and context. In: Goodnow J, Miller P, Kessel F (eds) Cultural practices as contexts for development. Jossey-Boss, New York, pp 71–85

Cole M (1996) Cultural psychology. Harvard University Press, Cambridge

Cole M, Engestrom Y (1993) A cultural-historical approach to distributed cognition. In: Salomon G (ed) Distributed cognitions: psychological and educational considerations. Cambridge University Press, Cambridge, pp 146–161

Corkum V, Moore C (1995) Development of joint visual attention in infants. In: Moore C, Dunham PJ (eds) Joint attention. Erlbaum, Hillsdale, pp 61–84

Coussi-Korbel S (1994) Learning to outwit a competitor in mangabeys (*Cercocebus torquatus torquatus*). J Comp Psychol 108:164–171

Coussi-Korbel S, Fragaszy (1995) On the relation between social dynamics and social learning. Anim Behav 50:1441–1453

Custance DM, Bard KA (1994) The comparative and developmental study of self-recognition and imitation: the importance of social factors. In: Parker ST, Mitchell RW, Boccia ML (eds) Self awareness in animals and humans: developmental perspectives. Cambridge University Press, Cambridge, pp 207–226

Custance DM, Whiten A, Bard KA (1995) Can young chimpanzees (*Pan troglodytes*) imitate arbitrary actions? Hayes and Hayes (1952) revisited. Behaviour 132:837–859

D'Andrade RG (1980) The cultural part of cognition. Cogn Sci 5:179–195

D'Andrade RG (1991) The identification of schemas in naturalistic data. In: Horowitz M (ed) Person schemas and maladaptive interpersonal behavior patterns. University of Chicago Press, Chicago, pp 279–310

Deacon TW (1990) Brain-language coevolution. In: Hawkins JA, Gell-Mann K (eds) The evolution of human languages, vol X. Addison Wesley, New York, pp 49–83

Deacon TW (1997) The symbolic species: the co-evolution of language and the brain. Norton, New York

Donald M (1993) Precis of *Origins of the modern mind: three stages in the evolution of culture and cognition*. Behav Brain Sci 16:737–791

Dunbar RIM (1993) Coevolution of neocortical size, group size and language in humans. Behav Brain Sci 16:681–735

Duranti A, Goodwin C (1992) Rethinking context: language as an interactive phenomenon. Cambridge University Press, Cambridge

Eckerman CO, Didow SM (1989) Toddlers' social coordinations: changing responses to another's invitation to play. Dev Psychol 25:794–804

Eckerman CO, Stein MR (1990) How imitation begets imitation and toddlers' generation of games. Dev Psychol 26:370–378

Eckerman CO, Davis CC, Didow SM (1989) Toddlers' emerging ways of achieving social coordination with a peer. Child Dev 60:440–453

Elman JL, Bates EA, Johnson MH, Karmiloff-Smith A, Parisi D, Plunkett K (1996) Rethinking innateness: a connectionist perspective on development. MIT Press, Cambridge

Emery NJ, Lorincz EN, Perrett DI, Oram MW, Baker CI (1997) Gaze following and joint attention in Rhesus monkeys (*Macaca mulatta*). J Comp Psychol 111:286–293

Ettlinger G, Wilson WA (1990) Cross-modal performance: behavioral processes, phylogenetic considerations, and neural mechanisms. Behav Brain Res 40:169–192

Fauconnier G (1994) Mental spaces. Cambridge University Press, Cambridge

Fischer KW, Grannott N (1995) Beyond one-dimensional change: parallel concurrent socially distributed processes in learning and development. Hum Dev 38:302–314

Fouts RS, Fouts DH, Van Cantfort TE (1989) The infant Loulis learns signs from cross-fostered chimpanzees. In: Gardner RA, Gardner BT, Van Cantfort TE (eds) Teaching sign language to chimpanzees. SUNY Press, Albany, pp 280–292

Fragaszy DM, Visalberghi E (1989) Social influences on the acquisition of tool-using behaviors in tufted capuchin monkeys (*Cebus apella*). J Comp Psychol 103:172–204

Galef BG (1988) Imitation in animals: history definition and interpretation of data from the psychological laboratory. In: Zentall TR, Galef BG (eds) Social learning: psychological and biological perspectives. Erlbaum, Hillsdale, pp 3–28

Gallese V, Goldman A (1988) Mirror neurons and simulation of mind-reading. Trends Cogn Sci 2:493–501

Gibson JJ (1979) The ecological approach to visual perception. Houghton-Mifflin, Boston

Goldsmith DF, Rogoff B (1997) Mothers' and toddlers' coordinated joint focus of attention: variations with maternal dysphoric symptoms. Dev Psychol 33:113–119

Gomez JC (1996) Ostensive behavior in great apes: the role of eye contact. In: Russon AE, Bard KA, Parker ST (eds) Reaching into thought: the minds of the great apes. Cambridge University Press, Cambridge, pp 131–151

Gomez JC, Sarria E, Tamarit J (1993) The comparative study of early communication and theories of mind: ontogeny, phylogeny and pathology. In: Baron-Cohen S, Tager-Flusberg H, Cohen DJ (eds) Understanding other minds: perspective from autism. Oxford University Press, Oxford, pp 397–426

Goodall J (1986) The chimpanzees of Gombe. Harvard University Press, Cambridge

Gosling SD, John OP (1999) Personality dimensions in nonhuman animals: a cross-species review. Curr Dir Psychol Sci 8:69–75

Gouzoules S, Gouzoules H, Marler P (1984) Rhesus monkey (*Maccaca mulatta*) screams: representational signaling in the recruitment of agonistic aid. Anim Behav 32:182–193

Grannott N (1993) Patterns of interaction in the co-construction of knowledge: separate minds, joint effort, and weird creatures. In: Wosniak RH, Fischer KW (eds) Development in context: acting and thinking in specific environments. Erlbaum, Hillsdale, pp 183–207

Greenfield PM (1991) Language, tools and brain: the ontogeny and phylogeny of hierarchically organized sequential behavior. Behav Brain Sci 14:531–595

Hamilton WD (1964) The genetical theory of social behavior. J Theor Biol 7:1–52

Harcourt AH, Waal FBM de (1992) Coalitions and alliances in humans and other animals. Oxford University Press, Oxford

Hare B, Call J, Agnetta B, Tomasello M (2000) Chimpanzees know what conspecifics do and do not see. Anim Behav 59: 771–785

Hari R, Forss N, Avikainen S, Kirveskari E, Salenius S, Rizzolatti G (1998) Activation of human primary motor cortex during action observation: a neuromagnetic study. Proc Natl Acad Sci USA 95:15061–15065

Hauser MD (1990) Do chimpanzee copulatory calls incite male-male competition? Anim Behav 39:596–597

Hayes KJ, Hayes C (1952) Imitation in a home-raised chimpanzee. J Comp Psychol 45:450–459

Heyes CM (1993a) Anecdotes, training, trapping and triangulation: do animals attribute mental states? Anim Behav 46:177–188

Heyes CM (1993b) Imitation, culture and cognition. Anim Behav 46:999–1010

Heyes CM (1994) Cues, convergence and a curmudgeon: a reply to Povinelli. Anim Behav 48:242–244

Hinde RA, Rowell TE (1962) Communication by postures and facial expressions in the rhesus monkey (*Macaca mulatta*). Proc Zool Soc Lond 138:1–21

Hooff JARAM van (1967) The facial displays of catarrhine monkeys and apes. In: Morris D (ed) Primate ethology. Weidenfeld and Nicolson, London, pp 7–68

Hutchins E (1995a) Cognition in the wild. MIT Press, Cambridge

Hutchins E (1995b) How a cockpit remembers its speed. Cogn Sci 19:265–288

Hutchins E, Klausen T (1996) Distributed cognition in an airline cockpit. In: Middleton D, Engstrom Y (eds) Communication and cognition. Cambridge University Press, Cambridge, pp 15–34

Itakura S (1996) An exploratory study of gaze-monitoring in nonhuman primates. Jpn Psychol Res 38:174–180

Itakura S, Anderson JR (1996) Learning to use experimenter-given cues during an object-choice task by a capuchin monkey. Curr Psychol Cogn 15:103–115

Itakura S, Tanaka M (1998) Use of experimenter-given cues during object-choice tasks by chimpanzees (*Pan troglodytes*), an orangutan *(Pongo pygmaeus*) and human infants (*Homo sapiens*). J Comp Psychol 112:119–126

Jeannerod M (1994) The representing brain: neural correlates of motor intention and imagery. Behav Brain Sci 17:187–245

Johnson CM (1990) Evolutionary, comparative, and psycholinguistic investigations on the nature of higher-order cognitive processes. PhD thesis, Cornell University, Ithaca

Johnson CM (1993) Animal communication via coordinated cognitive systems. In: Bateson PPG, Klopfer PH, Thompson NS (eds) Perspectives in ethology, vol 10. Plenum, New York, pp 187–208

Johnson CM (1997) Behavioral competencies for social gaze in bonobos. Am J Primatol 42:119

Johnson CM, Norris KS (1986) Delphinid social organization and social behavior. In: Schusterman RJ, Thomas JA, Wood FG (eds) Dolphin cognition and behavior: a comparative approach. Erlbaum, Hillsdale, pp 335–344

Johnson CM, Frank R, Flynn D (1999) Peering in captive, mature bonobos (*Pan paniscus*). Primates 40:397–407

Johnson M (1987) The body in the mind: the bodily basis of reason and imagination. University of Chicago Press, Chicago

Jolly A (1985) The evolution of primate behavior, 2nd edn. Macmillan, New York

Kano T (1982) The social group of pygmy chimpanzees (*Pan paniscus*) of Wamba. Primates 23:171–188

Karmiloff-Smith A (1992) Beyond modularity: a developmental perspective on cognitive science. MIT Press, Cambridge

Keating CF, Keating EG (1982) Visual scan patterns of rhesus monkeys viewing faces. Perception 11:211–219

King BJ (1986) Extractive foraging and the evolution of primate intelligence. Hum Evol 1:361–372

King BJ (1994) The information continuum: evolution of social information transfer in monkeys, apes and humans. School of American Research, Sante Fe

King BJ (1997) Donated versus co–constructed knowledge in primates. Am J Primatol 42:122

Kobayashi H, Koshima S (1997) Unique morphology of the human eye. Nature 387:767–768

Kohler W (1925) The mentality of apes. Routledge and Kegan Paul, London

Kuhn TS (1962) The structure of scientific revolutions. University of Chicago Press, Chicago

Kummer H (1967) Tripartite relations in hamadryas baboons. In: Altmann SA (ed) Social communication among primates. University of Chicago Press, Chicago, pp 63–72

Kummer H (1968) Social organization of hamadryas baboons. University of Chicago Press, Chicago

Kummer H (1971) Primate societies. Harlan Davidson, Arlington Heights

La Freniere PJ (1988) The ontogeny of tactical deception in humans. In: Byrne RW, Whiten A (eds) Machiavellian intelligence. Clarendon, Oxford, pp 238–252

Langacker R (1987) Foundations of cognitive grammar, vol I. Stanford University Press, Stanford

Langacker R (1992) Foundations of cognitive grammar, vol II. Stanford University Press, Stanford

Lave J (1988) Cognition in practice: mind, mathematics and culture in everyday life. Cambridge University Press, Cambridge

Lave J, Murtaugh M, Rocha O de la (1984) The dialectic of arithmetic in grocery shopping. In: Rogoff B, Lave J (eds) Everyday cognition: its development in social context. Harvard University Press, Cambridge, pp 127–159

Leonard CM, Rolls ET, Wilson FA, Baylis GC (1985) Neurons in the amygdala with responses selective for faces. Behav Brain Res 15:159–176

Lieberman P (1973) On the evolution of human language: a unified view. Cognition 2:59–94

Lieberman P (1984) The biology and evolution of language. Harvard University Press, Cambridge

Logue AW (1988) Research on self-control: an integrating framework. Behav Brain Sci 11:665–709

Maestripieri D (1995) Maternal encouragement in nonhuman primates and the question of animal teaching. Hum Nat 6:361–378

Marler P, Dufty A, Pickert R (1986) Vocal communication in the domestic chicken II. Is a sender sensitive to the presence and nature of a receiver Anim Behav 34:194–198

Marshack A (1984) The ecology and brain of two-handed bipedalism: an analytic, cognitive and evolutionary assessment. In: Roitblat HL, Bever TG, Terrace HS (eds) Animal cognition. Erlbaum, Hillsdale, pp 491–512

McGurk H, MacDonald T (1976) Hearing lips and seeing voices. Nature 264:746–748

McNelis NL, Boatright-Horowitz SL (1998) Social monitoring in a primate group: the relationship between visual attention and hierarchical ranks. Anim Cogn 1:65–69

Meltzoff AN (1988) The human infant as *Homo imitans*. In: Zentall TR, Galef JBG (eds) Social learning: psychological and biological perspectives. Erlbaum, Hillsdale, pp 319–342

Meltzoff AN (1990) Towards a developmental cognitive science: the implications of cross-modal matching and imitation for the development of representation and memory in infancy. Ann NY Acad Sci 608:1–37

Meltzoff AN, Moore K (1977) Imitation of facial and manual gestures by newborn infants. Science 198:75–78

Meltzoff AN, Moore K (1989) Imitation in newborn infants: exploring the range of gestures imitated and the underlying mechanisms. Dev Psychol 25:954–962

Menzel EW Jr (1974) A group of young chimpanzees in a one acre field: leadership and communication. In: Schrier AM, Stollnitz F (eds) Behavior of nonhuman primates. Academic Press, New York, pp 83–153

Miles HL, Mitchell RW, Harper SE (1996) Simon says: the development of imitation in an enculturated orangutan. In: Russon AE, Bard KA, Parker ST (eds) Reaching into thought: the minds of the great apes, Cambridge University Press, Cambridge, pp 278–299

Milton K (1981) Distribution patterns of tropical plant foods as an evolutionary stimulus to primate mental development. Am Anthropol 83:534–548

Milton K (1988) Foraging behavior and the evolution of primate intelligence. In: Byrne RW, Whiten A (eds) Machiavellian intelligence: social expertise and the evolution of intellect in monkeys apes and humans. Oxford University Press, Oxford, pp 285–305

Minsky M (1975) A framework for representing knowledge. In: Winston PH (ed) The psychology of computer vision. Mc Graw-Hill, New York, pp 27–52

Mitchell RW (1987) A comparative developmental approach to understanding imitation. In: Bateson PPG, Klopfer PH (eds) Perspectives in ethology, vol 7. Plenum, New York, pp 183–215

Mitchell RW (1999) Deception and concealment as strategic script violation in great apes and humans. In: Parker ST, Mitchell RW, Miles HL (eds) The mentalities of gorillas and orangutans. Cambridge University Press, Cambridge, pp 295–315

Mitchell RW, Anderson JR (1997) Pointing, witholding information and deception in capuchin monkeys (*Cebus apella*). J Comp Psychol 111:351–361

Moore C, Dunham PJ (1995) Joint attention: its origins and role in development. Erlbaum, Hillsdale

Morris D (1967) The naked ape. Jonathan Cape, London

Myowa-Yamakoshi M, Matsuzawa T (1999) Factors influencing imitation of manipulatory actions in chimpanzees (*Pan troglodytes*) J Comp Psychol 113:128–136

Nardi BA (1996) Studying context: a comparison of activity theory, situated action models and distributed cognition. In: Nardi B (ed) Context and consciousness: activity theory and human-computer interaction. MIT Press, Cambridge, pp 69–85

Neisser U (1976) Cognition and reality. Freeman, San Francisco

Nishida T (1979) The social structure of chimpanzees in the Mahale Mountains. In: Hamburg DA, Mc Cown ER (eds) The great apes. Benjamin/Cummings, Menlo Park, pp 73–122

Nishida T, Hiraiwa-Hasegawa M (1986) Chimpanzees and bonobos: cooperative relationships among males. In: Smuts BB, Cheney DL, Seyfarth RM, Wrangham RW, Strusaker TT (eds) Primate societies. University of Chicago Press, Chicago, pp 165–177

Packer C (1977) Reciprocal altruism in *Papio anubis*. Nature 265: 441–443

Parker ST (1996) Apprenticeship in tool-mediated extractive foraging: the origins of imitation, teaching and self-awareness in great apes. In: Russon AE, Bard KA, Parker ST (eds) Reaching into thought: the minds of the great apes. Cambridge University Press, Cambridge, pp 348–370

Parker ST, Gibson KR (1977) Object manipulation, tool use and sensorimotor intelligence as feeding adaptations in *Cebus* monkeys and great apes. J Hum Evol 6:623–641

Parker ST, Gibson KR (1979) A developmental model for the evolution of language and intelligence in early hominids. Behav Brain Sci 2:367–408

Peignot P, Anderson JA (1999) Use of experimenter-given manual and facial cues by gorillas (*Gorilla gorilla*) in an object-choice task. J Comp Psychol 113:253–260

Pellegrino G di, Fadgia L, Fogassi L, Gallese V, Rizzolatti G (1992) Understanding motor events: a neurophysiological study. Exp Brain Res 91:176–180

Perrett DI, Smith PAJ, Potter DD, Mistlin AJ, Head AS, Milner AD, Jeeves MA (1985) Visual cells in the temporal cortex sensitive to face view and gaze direction. Proc R Soc Lond B 223:293–317

Perrett DI, Hietanen JK, Oram MW, Benson PJ (1992) Organization and functions of cells responsive to faces in the temporal cortex. Philos Trans R Soc Lond B335:23–30

Piaget J (1952) The origins of intelligence in children. International Universities Press, New York

Piaget J (1954) The construction of reality in the child. Norton, New York

Piaget J (1971) Biology and knowledge. University of Chicago Press, Chicago

Plooj FX (1978) Some basic traits of language in wild chimpanzees? In: Lock A (ed) Action, gesture and symbol. Academic Press, New York, pp 111–131

Povinelli DJ (1994) Comparative studies of mental state attribution: a reply to Heyes. Anim Behav 48:239–241

Povinelli DJ, Eddy TJ (1996a) Chimpanzees: joint visual attention. Psychol Sci 7:129–135

Povinelli DJ, Eddy TJ (1996b) Factors influencing young chimpanzees' (*Pan troglodytes*) recognition of attention. J Comp Psychol 110:336–345

Povinelli DJ, Eddy TJ (1997) Specificity of gaze-following in young chimpanzees. Br J Dev Psychol 17:213–222

Povinelli DJ, Nelson KE, Boysen ST (1990) Inferences about guessing and knowing by chimpanzees (*Pan troglodytes*). J Comp Psychol 104:203–210

Premack D, Woodruff G (1978) Does the chimpanzee have a theory of mind? Behav Brain Sci, 4:515–526

Redican WK (1975) Facial expressions in nonhuman primates. In: Rosenblum LA (ed) Primate behavior: developments in field and laboratory research, vol 4. Academic Press, New York, pp 103–194

Resnick LB, Levine JM, Teasley SD (1991) Perspectives on socially shared cognition. American Psychological Association, Washington, DC

Rizzolatti G, Gentilucci M (1988) Motor and visual-motor functions of the premotor cortex. In: Rakic P, Singer W (eds) Neurobiology of neocortex. Wiley, New York, pp 269–284

Rogoff B (1990) Apprenticeship in thinking: cognitive development in social context. Oxford University Press, Oxford

Rogoff B, Gardner J (1984) Adult guidance of cognitive development. In: Rogoff B, Lave J (eds) Everyday cognition: its development in social context. Harvard University Press, Cambridge, pp 95–112

Rogoff B, Lave J (1984) Everyday cognition: its development in social context. Harvard University Press, Cambridge

Russon A, Galdikas B (1993) Imitation in ex-captive orangutans. J Comp Psychol 107:147–161

Salomon G (1993) Distributed cognitions: psychological and educational considerations. Cambridge University Press, Cambridge

Savage-Rumbaugh ES, Shanker GS, Taylor TJ (1998) Apes, language and the human mind. Oxford University Press, Oxford

Schaik CP van, Hooff JARAM von (1983) On the ultimate causes of primate social systems. Behaviour 85:91–117

Schaik CP van, Noordwijk MA van, Warsono B, Sutriono E (1983) Party size and early detection of predators in Sumatran forest primates. Primates 24:211–221

Schaller GB (1972) The Serengeti lion. University of Chicago Press, Chicago

Schank RC, Abelson R (1977) Scripts, plans, goals and understanding. Erlbaum, Hillsdale

Semendeferi K, Armstrong E, Schleicher A, Zilles K, Hoesen GW van (1998) Limbic frontal cortex in hominoids: a comparative study of area 13. Am J Phys Anthropol 106:129–155

Seyfarth RM, Cheney DL (1986) Vocal development in vervet monkeys. Anim Behav 34:1640–1658

Silk JB (1999) Male bonnet macaques use information about third-party rank relationships to recruit allies. Anim Behav 34:1640–1658

Smillie D (1993) Darwin's tangled bank: the role of social environments. In: Bateson PPG, Klopfer PH, Thompson NS (eds) Perspectives in ethology, vol 10. Plenum, New York, pp 119–142

Smith WJ (1977) The behavior of communicating: an ethological approach. Harvard University Press, Cambridge

Smuts BB (1985) Sex and friendship in baboons. Aldine, New York

Strum SC (1987) Almost human: a journey into the world of baboons. Norton, New York

Strum S, Forster D, Hutchins E (1997) Why "Machiavellian intelligence" may not be Machiavellian. In: Whiten A, Byrne R (eds) Machiavellian intelligence II. Cambridge University Press, pp 50–85

Sugiyama Y, Koman J (1979) Tool-using and -making in wild chimpanzees at Bossou, Guinea. Primates 20:513–524

Symington MM (1990) Fission-fusion social organization in *Ateles* and *Pan*. Int J Primatol 11:47–61

Tobin H, Logue AW, Chelonis JJ, Ackerman KT (1996) Self-control in the monkey *Macaca fascicularis*. Anim Learn Behav 24:168–174

Tomasello M (1992) The social basis of language acquisition. Soc Dev 1:67–87

Tomasello M, Barton M (1994) Learning words in non-ostensive contexts. Dev Psychol 30:639–650

Tomasello M, Call J (1997) Primate cognition. Oxford University Press, Oxford

Tomasello M, George B, Kruger A, Farrar M, Evans A (1985) The development of gestural communication in young chimpanzees. J Hum Evol 14:175–186

Tomasello M, Gust D, Frost GT (1989) The development of gestural communication in young chimpanzees: a follow-up. Primates 30:35–50

Tomasello M, Kruger AC, Ratner HH (1993a) Cultural learning. Behav Brain Sci 16:495–552

Tomasello M, Savage-Rumbaugh ES, Kruger C (1993b) Imitative learning of actions on objects by children chimpanzees and enculturated chimpanzees. Child Dev 64:1688–1705

Tomasello M, Call J, Nagell K, Olguin R, Carpenter M (1994) The learning and use of gestural signals by young chimpanzees: a trans-generational study. Primates 35:137–154

Tomasello M, Strosberg R, Akhtar N (1996) Eighteen-month-old children learn words in non-ostensive contexts. J Child Language 22:1–20

Tomasello M, Call J, Hare B (1998) Five primate species follow the visual gaze of conspecifics. Anim Behav 55:1063–1069

Tomasello M, Hare B, Agneta B (1999) Chimpanzees, *Pan troglodytes*, follow gaze direction geometrically. Anim Behav 58:769–777

Trevarthen C (1979) Instincts for human understanding and for cultural cooperation: their development in infancy. In: Cranach M von, Foppa K, Lepenies W, Ploog D (eds) Human ethology: claims and limits of a new discipline. Cambridge University Press, Cambridge, pp 530–571

Trevarthen C (1993) The function of emotions in early communication and development. In: Nadel J, Camaioni L (eds) New perspectives in early communication and development. Routledge, New York, pp 48–81

Varela FJ, Thompson E, Rosch E (1996) The embodied mind. MIT Press, Cambridge

Vasek ME (1986) Lying as a skill: the development of deception in children. In: Mitchell RW, Thompson NS (eds) Deception: perspectives on human and nonhuman deceit. SUNY Press, Albany, pp 271–292

Vauclair J (1984) Phylogenetic approach to object manipulation in human and ape infants. Hum Dev 27:321–328

Vauclair J, Bard KA (1983) Development in manipulations with objects in ape and human infants. J Hum Evol 12:631–645

Vick SJ, Anderson JR (2000) Learning and limits of use of eye gaze by capuchin monkeys (*Cebus apella*) in an object-choice task. J Comp Psychol 114:200–207

Visalberghi E, Fragaszy DM (1990) Do monkeys ape? In: Parker ST, Gibson RK (eds) "Language" and intelligence in monkeys and apes. Cambridge University Press, Cambridge, pp 247–273

Vygotsky LS (1962) Thought and language. MIT Press, Cambridge

Vygotsky LS (1978) Mind in society: the development of higher psychological processes. Harvard University Press, Cambridge

Waal FBM de (1982) Chimpanzee politics. Cape, London

Waal FBM de (1986) Deception in the natural communication of chimpanzees. In: Mitchell RW, Thompson NS (eds) Deception: perspectives on human and nonhuman deceit. SUNY Press, Albany, pp 221–244

Waal FBM de (1989) Peacemaking among primates. Harvard University Press, Cambridge

Waal FBM de (1996) Conflict as negotiation. In: McGrew WC, Marchant LF, Nishida T (eds) Great ape societies. Cambridge University Press, Cambridge, pp 159–172

Waal FBM de, Aureli F (1996) Consolation, reconciliation, and a possible cognitive difference between macaque and chimpanzee. In: Russon KA, Bard KA, Parker ST (eds) Reaching into thought: the minds of the great apes. Cambridge University Press, Cambridge, pp 80–110

Waal FBM de, Hooff J van (1981) Side-directed communication and agonistic interactions in chimpanzees. Behaviour 77:164–198

Waal FBM de, Roosmalen A van (1979) Reconciliation and consolation among chimpanzees. Behav Ecol Sociobiol 5:55–66

Waal FBM de, Hooff J van, Netto WJ (1976) An ethological analysis of types of agonistic interaction in a captive group of Java monkeys (*Macaca fascicularis*). Primates 17:257–290

Wertsch JV (1979) From social interaction to higher psychological processes: a clarification and application of Vygotsky's theory. Hum Dev 22:1–22

Wertsch JV (1985a) Culture communication and cognition: Vygotskian perspectives. Cambridge University Press, Cambridge

Wertsch JV (1985b) Vygotsky and the social formation of mind. Harvard University Press, Cambridge

Wertsch JV (1998) Mind as action. Oxford University Press, Oxford

Whiten A (1991) Natural theories of mind: evolution, development and simulation of everyday mindreading. Blackwell, Oxford

Whiten A (1998) Review of *Primate Cognition*. Anim Cogn 1:76

Whiten A, Byrne R (1988) Tactical deception in primates. Behav Brain Sci 11:233–244

Whiten A, Ham R (1992) On the nature and evolution of imitation in the animal kingdom: reappraisal of a century of research. In: Slater PJB, Rosenblatt S, Beer C, Milinsky M (eds) Advances in the study of behavior. Academic Press, New York, pp 239–283

Williams H (1990) Bird song. In: Kesner RP, Olton DS (eds) Neurobiology of comparative cognition. Erlbaum, Hillsdale, pp 77–126

Williams H, Nottebohm F (1985) Auditory responses in avian vocal motor neurons: a motor theory for song perception in birds. Science 229:279–282

Wittgenstein L (1953) Philosophical investigations. Macmillian, New York

Wosniak RH, Fischer KW (1993) Development in context: acting and thinking in specific environments. Erlbaum, Hillsdale

Yamagiwa J (1992) Functional analysis of social staring behavior in all-male group of mountain gorillas. Primates 33:523–544