Primate causal understanding in the physical and psychological domains

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Abstract

Evidence for primates' understanding of causality is presented and discussed. Understanding causality requires the organism to understand not just that two events are associated with one another in space and time, but also that there is some 'mediating force' that binds the two events to one another which may be used to predict or control those events (e.g. a physical force such as gravity or a psychological force such as an intention). In the physical domain, studies of tool use indicate that capuchin monkeys do not have a causal understanding of the functioning of tools in terms of the physical forces involved, but rather they learn to associate aspects of their own behavior with the results it produces. Apes show some possible signs of understanding the causal relations involved in tool use in the sense that they may employ various forms of foresight in approaching novel tasks, perhaps involving an understanding of physical forces—although not to the extent of human children. In the psychological domain, nonhuman primates understand conspecifics as animate beings that generate their own behavior and, thus, they appreciate that to manipulate conspecifics communicative signals, and not physical activities, are required. However, there is very little evidence that nonhuman primates of any species understand others as psychological beings with intentions and other psychological states that mediate their behavioral interactions with the world—as human children begin to do sometime during their second year of life. More research, using a wider range of problem-solving situations, is needed if we are to become more precise in our understanding of how primates understand the causal structure of the world around them. © 1998 Elsevier Science B.V.

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1. Introduction

Debate concerning the nature of causality goes back centuries, at least to Aristotle. Psychological

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theory and research about how human beings understand causality are more recent, beginning with the speculations of Hume (1739/1978) concerning associative learning and the experiments of Michotte (1963) on causal perception. Research into the ontogeny of causal understanding in children is also very recent, with Piaget (Piaget, 1930/ 1951, 1971/1974) being a main initiator but others having conducted important research as well (e.g. see the papers in Sperber et al., 1995). Most recent of all has been research into the causal understanding of nonhuman primates. Although the topic was dealt with in some indirect ways by Köhler (1925/1976), it is only in the last two decades that primate causal understanding has been investigated explicitly (Premack, 1976; Visalberghi and Limongelli, 1996). Our intention in this paper is to review and analyze what is known about the causal understanding of nonhuman primates. We do this for both the physical and social (psychological) domains.

In his examination of causal knowledge in animals, Kummer (1995) posits a continuum whose extremes he labels: (1) 'weak causal knowledge', which is the result of associative learning and depends on an organism experiencing many repetitions of two events in close spatial and temporal contiguity; and (2) 'strong causal knowledge', which is based on an organism's immediate or rapid a priori 'interpretation' of how events may be related to one another and so does not depend on a large number of repetitions of spatially and temporally contiguous events. Strong causal knowledge may be based on evolved programs which allow a specific type of connection between noncontiguous events; if this is the case no understanding is required and no, or very little, plasticity is involved. When strong causal knowledge emerges from understanding and allows flexible responses to novel contingencies it becomes causal reasoning (see below).

Isolating causal understanding from other types of understanding is not an easy task. The traditional theme is that understanding causality means understanding 'how' and 'why' one event leads to another. Prototypically, understanding two events external to the observer has been investigated, e.g. one billiard ball collides with another and sends it into motion, but in some cases the organism's understanding of the effect of its own behavior on events in the world has been considered as well (Dickinson, 1980). The main distinction in the analysis of the causal understanding of primates, including humans, has been the distinction between various forms of associative learning versus causal understanding and reasoning.

Our analysis begins with this basic distinction. But we believe that causal understanding may be further analyzed by considering its component elements. This is especially important if the goal is to identify similarities and differences in the causal understanding of different species, or of the same species in the physical and social/psychological domains. In our view, causal understanding entails the following elements.

1.1. Antecedent and consequent events

The most basic element is two events that regularly co-occur in a consistent temporal sequence (e.g. A → B), ideally in close spatial proximity. Basic associative learning consists of pairing these two events mentally on the basis of their repeated spatio–temporal pairing in experience.

1.2. Explanatory attitude

Causal understanding goes beyond associative learning in that the organism has an hypothesis about how the antecedent event A (the cause) produces the consequent event B (the effect). This hypothesis can be tested and either confirmed or not confirmed, in which case the organism may generate a different hypothesis. Generating hypotheses involves seeking causal explanations. A key feature of the explanatory attitude is that it assumes a 'web of possibilities' from which the organism must choose: seeking the best explanation presupposes multiple explanations that may possibly connect the two events. The organism is able to choose and/or discard inappropriate explanations sometime beforehand, or with little experience because they are just not possible. Associative learning, on the other hand, does not involve a web of possible connections, but only a

one-to-one connection between antecedent and consequent. We use the term explanation to characterize the search of cause–effects relations which can shed light on how and why A leads to B.

1.3. Mediating 'forces'

An explanation for why A leads to B involves some mediating process or event that connects them through the web of possibilities. For instance, one billiard ball causes another to move because it 'imparts force' to the other, or one animal causes another to flee because it 'strikes fear' into the other. These kinds of mediating forces are understood by the organism as the how and the why of the predictable sequential relation between the antecedent and consequent events.

An appreciation of causal relationships among events allows an organism to engage with its environment in more creative, flexible, and foresightful ways. (Of course inappropriate conclusions can also be reached through causal reasoning). Thus, in some cases causal understanding enables an organism to predict events even when their usual antecedent is not present, that is, if there is some other event present that serves to instigate the mediating forces. For example, any event that serves to 'impart force' to a billiard ball (even one never before observed, e.g. wind) will move it in the same way as the impact of another ball. Anything that serves to 'strike fear' into a groupmate will cause it to flee. Conversely, if an event occurs in a circumstance in which the mediating force is somehow blocked, its usual consequent may not follow. Thus, if a billiard ball impacts another when that other is resting against a wall, it may not move. If an event that typically strikes fear into groupmates takes place in such a way that those groupmates cannot perceive it, they will not flee. Causal understanding thus has immediate consequences for effective action, as it opens the possibility of finding novel ways to either manipulate or suppress mediating forces. In general, an appreciation of causal relationships allows an organism to navigate the web of possible relations among external events creatively, on the basis of hypotheses about various mediating forces or events.

The explanatory attitude that is the key component of causal understanding may manifest itself in many ways depending on circumstances, again evidencing the flexibility of this type of understanding. We call these different manifestations 'forms of causal reasoning'.

1. Comprehension is simply understanding that an antecedent event leads to a consequent event via the operation of some mediating forces that connects them—the mediating forces constituting the how and why of the antecedent–consequent relation.
2. Prediction occurs when the organism observes the antecedent event only, but is nevertheless able to predict the consequent event due to its producing the mediating forces that should lead to the consequent.
3. Postdiction occurs when the organism observes the consequent event only, but is nevertheless able to infer backward in time to the antecedent, again via the operation of some mediating process that connects the two events causally.
4. Production refers to those cases in which the organism actively intervenes in situations to produce or block an antecedent event and/or mediating process so that the effect is under its active control.

Our working assumption is that all of the most basic aspects of causal functioning are similar when organisms deal with either the physical or the psychological (social) domains, in terms of both the component elements and reasoning processes involved. The one difference is that the specific mediating forces are different in the two cases. In particular, the inanimate entities of the physical world participate in events only if some force or energy is supplied from an 'outside' source, whereas animate entities are able to generate their own movements (see Premack, 1990 for a recent discussion on the importance of self-produced movement in social cognition). The entities involved in causal sequences may be inanimate objects only, animate beings only, or a mixture of animate beings and inanimate objects. The relevant events may occur among external entities independent of the organism's own behavior, or they may involve the individual's own behavior

directed at objects or other organisms (i.e. the organism itself may be a causal force).

As a way of investigating the similarities and differences between the causal understanding of primates in the physical and social/psychological domains, we provide a brief survey of some recent research in each domain. Most of this research consists of observing individuals as they attempt to solve either physical or social problems by devising active behavioral strategies. In the eyes of scientific investigators certain behavioral strategies seem to indicate some level or type of causal understanding, whereas other strategies do not. It is important to emphasize, however, that an experiment cannot prove that the strategy an animal uses to solve a problem is based on an understanding of causal relations. The results of an experiment can only reject the hypothesis that the solution was based on a specific association, but there are other possible associations that the animal may have used to solve a task which need further experimentation to be rejected. The rejection of the association(s) which might have fostered success increases the likelihood that the solution emerged from causal understanding (Limongelli et al., 1995). The strongest evidence for causal understanding are the behaviors indicating prediction, postdiction, and production, i.e. causal reasoning.

2. Physical causality

Humans use tools in complex ways which are characterized by the monitoring and the comprehension of the consequences of their action with the tool. Comprehension of causality transforms tool use—an adaptive behavior present in many different species—into the master key that humans use to change the world. We know that children gradually acquire the ability to analyse problems they face, to represent the outcome(s) of their action(s) mentally, and to plan their behavior accordingly (Piaget, 1952, 1954; Connolly and Dalgleish, 1989). Whereas it is well known that primates other than humans use tools little, it is less well known whether their success in using tools is based on an understanding of physical causality.

In the last several years, we have tested individuals belonging to different primate species (namely children, chimpanzees, and capuchin monkeys) in a series of tool tasks involving similar experimental paradigms (reviewed in Visalberghi and Limongelli, 1996). Here we present data concerning the ability of expert tool-users to comprehend the effect caused by their use of the tool (Section 2.1) and the ability of naive subjects to learn by imitation from a model using a tool (Section 2.2). Both problems involved the use of a stick-tool to push a reward out of a horizontal tube; the transparency of the tube provided both the experimenter and the subjects with the opportunity to continuously monitor what was happening inside it.

2.1. Problem 1: trap-tube task

The trap-tube task aims to assess whether a subject (already proficient in using a tool to push a reward out of a tube) has the ability to foresee the outcome of its action (i.e. the effect of the stick on the displacement of the reward). In this experiment, the subject is presented with a tube that has a trap-hole in the middle: the reward is placed on one of two sides of the trap (Fig. 1). In order to solve the task, the subject must insert the stick into the side of the tube from which it can push the reward out of the tube and not into the trap. Depending on the side in which the subject inserts the tool, it can either push the reward into the trap or push the reward out of the tube and obtain it.

In this task a subject can be 50% successful in every trial simply by systematically inserting the stick into the same side of the tube or by inserting it into one of the two sides by chance. In contrast, rates of success higher than chance can be obtained by avoiding the trap through a rule of action based on associative processes or else by understanding the cause–effects relations between some key features of the task, such as the trap, and the outcome of the pushing action. To develop the first strategy an individual is likely to require many repetitions.

Tufted capuchin monkeys (*Cebus apella*) and common chimpanzees (*Pan troglodytes*) were

tested in 14 10-trial blocks (Visalberghi and Limongelli, 1994; Limongelli et al., 1995). The results of the study on capuchins showed that the rate of success of three out of four capuchins was at chance level, whereas that of the fourth subject, Roberta (3 years old), was significantly higher than chance. In particular, Roberta became 85.7% successful in the second half of the experiment (Blocks 8–14). Careful analysis of her behavior and a series of control tests revealed that she was choosing the side of insertion on the basis of the distance of the reward from the openings of the tube. By looking inside the tube through its open-

(A)

(B)

Fig. 1. The trap-tube task. In order to solve the task, the subject must insert the stick into the side of the tube from which it can push the reward out of the tube and not into the trap. Depending on the side in which the subject inserts the tool, it can either push the reward into the trap or push the reward out of the tube and obtain it. (A) A capuchin monkey has inserted the stick into the correct side of the tube. Note that the reward is on the right side of the trap. (B) Insertion into the wrong side of the tube. A reward lost in a previous trial is already inside the trap.

ings, Roberta saw the spatial configuration among stick, tube and reward, and adopted the rule of inserting the stick in the opening farthest from the reward. On the grounds of the performance of this successful subject and of those of the other three unsuccessful ones, it was argued that our tool-using capuchins did not understand the causal consequences of their actions and that they did not learn to do so after repeated experiences.

Five chimpanzees were also tested in the trap-tube task. Two of the five subjects tested, Sheba and Darrell (11 and 13 years old, respectively) solved the task above chance level. As with the capuchin monkey, the chimpanzees started to be successful after about 70 trials. In the second half of the experiment, their rates of success were 98.6 and 90%, respectively. Careful analysis of their behavior and a series of control tests ruled out the possibility that their success was due to a distance-based associative-rule (the rule which was demonstrated to account for the success of the capuchin monkey). These data favor (but do not prove) an alternative hypothesis that relates success to an understanding of the causal relation between the tool using action and its outcome. The strength of this hypothesis would benefit from further control experiments designed to rule out other associative strategies of solution which do not require causal understanding (e.g. always insert from the side of the tube which is closer to the trap than to the reward).

The trap-tube task was also presented to children between 27 and 66 months of age ($N = 23$). Data show that children under 3 years of age did not figure out a successful strategy; in contrast, children over 3 years of age succeeded in the task after only a few trials (Limongelli, 1995). Children verbally explained the reason why they selected one side and not the other and described beforehand what would have happened in the two cases. They did not use a distance strategy.

2.2. Problem 2: tube task and imitation

The behavior of conspecifics may lead to further opportunities to learn about the causal structure of the environment. According to Köhler

(1925/1976) and Piaget (1954) imitation in a tool-using task is related to an understanding of the causal relations between the actions performed by the model and the outcome. We tested whether capuchin monkeys, chimpanzees and children learn by imitation to use a tool to push a reward out of a tube. For this purpose we adopted two procedures. In the case of capuchin monkeys, we scored the behavior toward the tool task of unsuccessful adult and juvenile capuchins before and after exposure to proficient conspecifics (models) repeatedly solving the task. In the case of chimpanzees and children, subjects were assigned a priori to the experimental group or the control group. The subjects of the experimental group watched the experimenter solve the task, whereas those of the control group were encouraged to try to solve it on their own.

Results showed that although the capuchin observers had ample opportunity to watch the model(s) solving the task, none of them acquired tool use by imitation, nor did they improve the orientation of the tool toward the tube after exposure to the models. Furthermore, data also showed that the visual attention of capuchin observers was not selectively focused on the events relevant for learning (e.g. insertion of the stick in the tube, pushing the reward versus holding the stick, eating the reward) (Visalberghi, 1993).

The study of the effect of modeling in chimpanzees was carried out with six infant subjects (Bard et al., 1996). Age-matched individuals were a priori assigned to the model group or to the control group. The results show that modeling (163 instances) was not effective for 2 year old chimpanzees. Three and 4 year old chimpanzees solved the task in a smaller number of trials if exposed to modeling. This result is in accordance with those of Nagell et al. (1993) in which chimpanzees exposed to conspecifics using a rake tool learned to use that tool more quickly than chimpanzees who were not exposed to conspecific demonstrators.

In the cross-sectional study with children a total of 65 subjects were tested at 12, 15, 18, 21 and 24 months (Modena and Visalberghi, 1998). Children were first presented with one 3 min trial of the tube task and those who were not successful were randomly assigned to the control group or to the model group. Results show that watching the model performing two solutions did not improve the performance of 12-month-old children, whereas it did for 15 and 18 month old children. In older children, experience with the task, that is, the presentation of two more trials, improved performance almost as effectively as modeling.

In short, whereas capuchin monkeys did not learn how to solve the tube task by watching a model, children (older than a certain age) and, to a lesser extent, chimpanzees did. The failure to learn by watching solutions performed by models can be interpreted as a lack of understanding of what the model is doing: the observer sees but does not understand that pushing the stick pushes the reward out of the tube. Learning by watching may be accomplished in a number of different ways. In this case, the most likely form of observational learning for those individuals who profited from learning is emulation learning (Nagell et al., 1993) in which the observer learns something of the affordance of the task, perhaps involving an appreciation of some of the causal relations involved. In some cases (especially the children), individuals may have actually imitatively learned the behavioral strategy of the demonstrator.

2.3. Associative and causal understanding in tool use and other tasks

The results of both problems suggest differences across species. In problem 1, capuchins do not know how and why their own actions cause certain effects; when successful, they use an associative strategy learnt over the many trials of the experiment. Also chimpanzees require many trials to solve the task above chance level, but they eventually come to a more flexible understanding. Undoubtedly, to claim causal understanding in chimpanzees further experiments are needed to discard other possible associative strategies they might have learnt. Finally, children develop an ability to reason causally, i.e. to relate events to one another and to make hypotheses about the how and why they relate in the ways they do.

The results of problem 2 also show that the three species differ in their ability to profit from observing a model. Whereas capuchins fail to learn from models, chimpanzees' performance improves with exposure to models. In contrast, children become able to imitate the behavior of the model, i.e. they show the ability "to understand and intelligently grasp what the action of the other means" (Köhler, 1925/1976).

These findings indicate that nonhuman primates' skilful use of tools is not necessarily based on a causal understanding. In contrast to young children, they need many repetitions to master tool tasks. This finding opens the possibility that they learn to associate an antecedent event with a consequent event, instead of having a causal understanding of the sequence of events. Also in other tasks, whose solution would require a causal understanding of the components, monkeys fail and chimpanzees do not perform as proficiently as one might expect from individuals who understand the causal structure of the problem (see Visalberghi (1997) for a discussion of the performances on cooperation tasks in these same species).

3. Psychological causality

Unfortunately we do not have a series of experiments on primates' understanding of social or psychological causality that is as standardized and systematic as that just reported for physical causality. But to make this account as comparable as possible to our account of the physical domain, we focus here on what might best be called social problem solving. We will look at nonhuman primates for indications that they solve social problems at least partially through an understanding of how their conspecifics work—in a manner analogous to the way they solve physical problems by understanding how inanimate objects work. The two possibilities that concern us are: (1) primates understand and can predict things about how their groupmates will behave in certain situations because they have observed their behavior in similar situations in the past (i.e. by associative learning about the behavior of others); and

(2) primates understand and can predict things about how their groupmates will behave in certain situations because they make creative inferences based on an understanding of the underlying psychological states of those groupmates (mainly in terms of the intentions and knowledge that the others might possess and that mediate their behavioral interactions with the environment).

We should stress at the outset that our interest is not in whether nonhuman primates have intentions, which we take on faith as part and parcel of the cognitive approach to animal behavior. The issue is how they understand the intentional behavior of others, and it is this that constitutes their causal understanding in the social domain. Whereas in the physical domain the mediating forces involved mostly revolve around physical force imparted from one object to another, in the social/psychological domain the mediating forces are psychological, for example, the intentions and knowledge that groupmates may possess. It is these psychological processes that potentially provide a causal explanation of the behavior of others above and beyond simple associative learning about their likely behavior in certain situations.

3.1. Social problem solving

Kummer (1967) was perhaps the first to focus our attention on the social problem solving of nonhuman primates. For example, he reported that female hamadryas baboons sometimes engage in a 'protected threat' in which they threaten one male while simultaneously presenting themselves sexually to another male who could be their ally in any actual antagonism. From a causal point of view we might say that these females know something about the way social interactions among their conspecifics work: they have learnt that their threat against one male will only achieve its goal if it is reinforced by another male. Since Kummer's study many other social strategies of this same general type have been reported for a variety of primate species, often involving one individual soliciting help from another against a third (so-called coalitions and alliances). There are even some indications (although the

data are not as systematic as might be wished) that primate individuals select their coalition partners on the basis of their rank relationships relative to that of their opponents (see Harcourt (1992) for a review and discussion), suggesting an even more fine-grained analysis of how the social interactions of groupmates work.

Very few researchers have been led to interpret these kinds of complex social interactions in terms of individuals' understanding the intentional states of one another. While it is possible that such understanding is involved, these kinds of interactions would seem to be most parsimoniously explained as individuals who have years of interactive experience with one another, using that experience to predict behavior in the current situation: the female of the previous example has been in a situation very much like this one in the past; when she had the help of a high-ranking male ally her threat against the other male was successful, and when she did not it was not. Note that this explanation does require an understanding that conspecifics work in ways that are different from inanimate objects. Specifically, conspecifics are animate beings who generate their own behavior and are manipulated not via mechanical pushing and pulling, as are inanimate objects, but rather by means of such things as communicative signals. There is no question that primates possess this type of understanding about how conspecifics behave. It is just that this understanding may operate fairly conservatively on the basis of an associative process in which behavior in the current situation is seen as similar to behavior in similar situations in the past, rather than more creatively on the basis of an understanding of the psychological states of others.

There is one type of social strategy used by primates to solve social problems, however, that has led some researchers to posit that individuals are operating with an understanding of the psychological states of conspecifics. This social strategy is so-called deception. The many reported anecdotes of primate deception, solicited and collected by Whiten and Byrne (1988) and Byrne and Whiten (1990), are well known, and we will not enter into a debate here on the scientific status of one-time observations so sharply summarized by

Bernstein (1988): the plural of 'anecdote' is not 'data'. But in some instances observations of a possibly deceptive strategy have been made repeatedly with the same individual, thus, confirming its status as an active strategy. For example, de Waal (1986) reported that a chimpanzee who was angry at another held out her hand in an appeasement gesture and when the other approached, attacked him; this happened repeatedly so it is unlikely to have been a chance confluence of events. The central question for current purposes is what kind of understanding of others underlies this behavior. On the one hand, the female might understand that if that male were to think that she wanted to appease him, he would approach her (which would allow her to attack him). So she produces an appeasement gesture in order to create that false belief. On the other hand, the female might know only that in other situations in the past appeasement gestures have induced conspecifics to approach, so this gesture might be used in this situation as well (so that she can now attack him). This is clearly an intelligent and insightful social strategy, using an established gesture in a novel problem-solving context, but it still operates on the level of an understanding and prediction of current behaviors based on past behaviors, not on an understanding of the intentional states of others.

This more modest interpretation would seem to be supported by the only experimental study of primate deception. Woodruff and Premack (1979) taught four juvenile chimpanzees to indicate to a naive human trainer which of two opaque buckets contained food, at which point they received it. After learning to do this, two different types of human trainers were introduced. First, a cooperative trainer acted as before, locating the hidden food and then giving it to the subject. A competitive trainer also attempted to locate the food, but when he found it he kept it and ate it himself. The question was whether the subjects would learn to provide accurate information for the cooperative trainer but not for the competitive trainer. In the first phase of the experiment 3 of 4 subjects pointed in a similar manner for both the cooperative and competitive trainers, with no attempts to withhold information or actively deceive either;

the other subject began to differentiate between the trainers in the second block of 24 trials. In the second phase of the experiment, all of the subjects began to withhold information from the competitive trainer, and two of the subjects actually induced the competitive trainer to choose the wrong bucket by orienting to it. The main point for current purposes is that the chimpanzees' clever strategies emerged only gradually and over many trials (with feedback on each trial, both in the cooperative and in the competitive conditions). This suggests the possibility that, as in the case of the anecdotes from the wild, what the chimpanzees in this study were doing was learning to use intelligent social strategies to get what they wanted, namely, the competitive trainer to go to the bucket without food and the cooperative trainer to go to the bucket with food. What they learnt concerns the behavior, not the intentions or beliefs, of the trainers, and it is learnable over trials with feedback by straight forward associative processes.

Mitchell and Anderson (1997) have recently adopted a similar paradigm to test capuchin monkeys. This experiment involved more than 100 training trials with the cooperator and more than 300 test trials with the cooperator and 300 test trials with the competitor. Their results show that one monkey learnt to point deceptively, and another learnt to withhold pointing and later it produced misdirected facial gestures. Given the high number of trials, it is likely that the capuchins learnt by association how to behave in relation to each interactant.

3.2. Gestures

Another line of investigation that might provide some aid in interpreting primate social strategies is their ability to learn goal-directed social behaviors by observing others, in a manner analogous to the studies of observational learning in the tube tasks. The basic idea is that if individuals understand others as intentional beings like themselves who have goals and use strategies to attain those goals, then they should be able to learn to adopt the strategies of others when the need arises. Tomasello et al. have been studying the gestural

communication of a group of chimpanzees at the Yerkes Primate Center longitudinally for over 12 years, with a special focus on the juveniles and their gestures that are learned and flexibly produced (Tomasello et al., 1985, 1989, 1994; Tomasello et al., submitted). They have asked the question of whether these chimpanzees acquire their learned gestures by imitating groupmates, or whether they acquire them by individually ritualizing them with one another. For example, an infant may initiate nursing by going directly for the mother's nipple, perhaps grabbing and moving her arm in the process. In some future encounter the mother might anticipate the infant's behavior at the first touch of her arm, and so become receptive at that point. Noting this anticipation, the infant then abbreviates its behavior to a touch on the arm in order to initiate nursing. The significance of this distinction is that ritualization does not require an understanding of the psychological states of others but only that an individual learns to anticipate and to some degree control the overt behavior of others.

There are a variety of lines of evidence from the longitudinal observations of these chimpanzees that they acquire their gestures via ritualization, not imitation. For example, when a concordance rate among individuals in this group is computed across the four longitudinal time points, certain rates of concordance among the time points are obtained. But when observations of the gestural communication of a totally unrelated group are substituted for the most recent observations of the longitudinally-observed group, the same levels of concordance result. That is to say, the gestures used by the members of one group of chimpanzees are as similar as those of another to previous longitudinal observations of either group. In addition, a recent experimental study confirms this general result (Tomasello et al., submitted). Two adult females on a total of three occasions were removed from the group and taught a new gesture that was unlike any of the natural gestures of the group. They used it to beg food from humans. When these individuals were returned to the group they continued to use these gestures. Despite repeated opportunities to observe this new gesture, however, no other individ-

ual, not even the demonstrators' offspring, adopted any of the novel gestures. Although these experimental gestures were 'artificial' and were used only with humans, these findings are useful because they support the findings from the more natural longitudinal observations.

Similar studies of monkeys are lacking, which may indicate either a lack of systematic investigation of the issue or the absence of the phenomenon. We are more inclined toward the latter explanation because whenever this topic has been explored the results have been negative. For example, one of the capuchin monkeys (Cr) observed by Visalberghi showed the behavior of slapping human hands when they were held out to her, palm up (a bout of slapping consisted of 3 or more hits in a row). Capitalizing on this spontaneously showed behavior, experimenters consistently rewarded it with food (Visalberghi, unpublished data). Despite many opportunities to observe the behavior followed by its rewarding outcome, not one of Cr's cagemates adopted it, nor did it appear in another similarly constituted group. It should be mentioned, however, that the capuchins in Cr's group touched the hand of the experimenter, without slapping it, four times more frequently than the monkeys in the other group. This suggests the operation of stimulus enhancement (the monkeys were attracted to the human hand by Cr's slapping it), but not imitative learning in which the observers understand that Cr is performing a goal-directed behavior that they may also perform when they have 'the same' goal.

The significance of these findings for our current questions is this: ritualization and associative learning do not require individuals to understand the intentions of others in the same way as does imitative learning. Ritualizing a 'touch-side' or a 'slap hand' requires only an anticipation of the future behavior of a conspecific or human and the ability to use this anticipation to repeat an instrumental action that has preceded it in the past. To imitatively learn an 'arm-raise' as a play solicit, however, would require that an individual understand that the conspecific is raising its arm for a purpose, and that when she has the same purpose she can use the same gesture. Chimpanzees do not seem to be able to do this. Chimpanzees and other

primates display much individual inventiveness and creative intelligence in their use of gestural signals. The way they use them indicates an understanding that conspecifics are animate beings that are not manipulated mechanically, but rather their behavior may be influenced by some form of behavioral or communicative interaction. It is just that they do not in any of this provide evidence that they understand their conspecifics as intentional agents, that is, as beings who have goals, and strategies for achieving those goals, which together constitute the psychological causality (mediating forces) responsible for the behavior. Nor is there any evidence from studies on nonhuman primates' 'theories of mind', in which they attempt to understand human intentions and beliefs, to indicate that they understand others as intentional agents (Tomasello and Call, 1994, 1997).

We need not review in detail all of the literature on human children to compare them to other primates in all of these ways (briefly reviewed in Tomasello and Camaioni, 1997). Suffice it to say that children learn some of their early gestures by ritualization (e.g. holding their hands over their head to request that an adult pick them up), but they learn many other of their communicative gestures during their second year of life by imitating the intentional social behavior of others (e.g. 'blowing' for hot things, 'shrugging' for 'I don't know', waving bye-bye, etc.). And of course imitative learning is how they acquire all of their linguistic symbols during this same age range. By the age 3 or 4 years, children have learned in addition to use various communicative behaviors to actively deceive others in ways that suggest some degree of understanding of some of their mental states.

3.3. Animacy and intentionality

Our overall conclusion about causality in the social domain is thus as follows. Nonhuman primates clearly learn associatively many things about their conspecifics and their likely behavior. They can then apply this knowledge creatively in new situations. This requires an understanding of the animacy of others as self-generating behaviors

who work differently from inanimate objects. Primates thus learn to use all kinds of cues to anticipate the behavior of others, for example, as in Menzel's (Menzel, 1973) famous experiments in which chimpanzees could tell which of their groupmates were on their way toward hidden food, and moreover, could guess something about the food's location (see also Coussi-Korbel (1994) for similar results with mangabeys). This reading of contextual and behavioral cues becomes even more sophisticated as it combines with an understanding of the complex social field in which primates operate. Thus primates recognize individual groupmates, know something of their own relationship to these groupmates based on past interactions with them, and know something of the relationships that other individuals have with one another based on their past interactions (reviewed in Tomasello and Call, 1994). The combination of cue detection with this kind of social knowledge allows primates to predict the behavior of others in many creative ways, for example: who can attempt to mate with whom in the presence of whom; who is headed for food; who can attempt to take food from whom in the presence of whom; who is about to leave the area; who will retaliate if a juvenile is attacked; who is likely to be a strong ally in a fight; where a frightening object or predator might be located; and who is likely to form an alliance against whom in the future. And these predictions may lead to the development of social strategies for influencing the behavior of others in such situations. However, these social strategies do not necessarily rest on an understanding of others as animate agents whose behavior is caused by mediating psychological 'forces', since all of these strategies may be formulated on the basis of a knowledge of the behavior of others in current and past situations.

There are thus different levels in the causal understanding of conspecifics. One level is the understanding of others as animate beings, they behave spontaneously and are influenced by the behavior of others, and nonhuman primates clearly have this level of causal understanding in the psychological domain. What nonhuman primates do not comprehend, in our opinion, is the causal structure of the intentional behavior of others in terms of an integrated process containing as separable components: goals, behavioral means, and perceptual monitoring. The key point here is that for organisms who can understand the goals of others, those goals serve as mediating, explanatory process that provide definitional coherence to the different behavioral and perceptual activities of others. Thus, human children simply see their mother as trying to open a cabinet, not as moving her arms around in a specific fashion, and they see it in this way because they understand and explain her behavior in terms of her goal. Although no one can be certain until more research is done, there is very little evidence that nonhuman primates see and explain the behavior of others in intentional terms in which goals serve as mediating forces. Nonhuman primates understand others as animate, and thus their understanding of psychological causality has some unique properties relative to their understanding of physical causality, but this understanding does not include, in addition, any reference to psychological 'forces' as causal mechanisms.

4. Conclusion

Much of the adaptive behavior of primates depends on individuals learning about recurrent sequences of events in their physical and social environments, and then exploiting those regularities in formulating their own behavioral strategies. We have argued that causal understanding constitutes a particular version of this process in which the antecedent and consequent events are connected with one another not on the basis of a one-to-one connection that accrues from repeated instances of A preceding B, but rather on the basis of the individual's understanding of how and why A precedes B. The how and why of this connection has to do with some mediating force or forces that connects A and B in particular circumstances, even though each of these events may under different circumstances (with other mediating forces) be connected in other ways to other events. This explanatory attitude on which we have placed such emphasis thus consists of an individual considering a web of possible connec-

tions among events through mediating forces and then settling on one of these possibilities as the how and why of some particular connection.

Differences among various taxa of nonhuman primates are difficult to document definitively at this point because we simply do not have enough systematic research. Thus, in the physical domain there is some evidence in the tube tasks that apes may be a bit more skilful than capuchin monkeys. They are much better able to anticipate the relation of tool to goal in a variety of circumstances. Similarly, when capuchin and chimpanzees have been compared in video-mediated joystick tasks chimpanzees seem to acquire a better knowledge when they produce contingencies in front of a mirror or when they use the joystick of a computer or move the cursor in a video (Jorgensen et al., 1995; for a discussion see Visalberghi, 1997). But the apes required a number of trials to learn effective procedures in all cases, thus opening the possibility that the key difference may lie in their skills of associative learning. Moreover, the tube is only one task, and in other tasks monkeys do show some very simple causal understanding based on a simple spatial relation of support (in which no inference of mediating forces is needed), so it is not the case that they have no causal understanding at all. It is worth mentioning as well that this one task involves the individual actively manipulating a tool, and so an individual's understanding of force in this task is closely tied to its understanding of the force produced by its own behavior, and there are basically no published studies of nonhuman primates' understanding of causal sequences independent of their own actions. In general, there is a great need for a wider array of causal tasks to be given to a wider array of nonhuman primates.

In the social/psychological domain we see basically no evidence of any species differences at all. All nonhuman primates understand the behavior of others as animate and capable of being influenced by various social and communicative behaviors, but none understands the behavior of others as organized around and defined by intentions or any other psychological states as mediating causal forces. All primates thus create social strategies and ritualize communicative signals in

ways that focus on the likely behavior of conspecifics in particular circumstances, but they do not set out to manipulate the psychological states of others per se. The one set of experimental studies that might seem to conflict with this conclusion is that of Povinelli and colleagues. Povinelli et al. (1991, 1992a) found that rhesus monkeys could not learn to discriminate a human who witnessed where food had been hidden from a human who had not witnessed the hiding. Povinelli et al. (1990, 1992b) found that chimpanzees could learn this discrimination, thus suggesting that they could explain the behavior of humans on the basis of the mediating psychological process of 'knowledge'. But the four chimpanzee subjects all took over 100–150 trials to learn the discrimination, and they took some additional trials to transfer this learning to a new situation (Povinelli, 1994). This again opens the possibility that what the apes were doing was learning associations between events over repeated exposures. To reject this parsimonious explanation it is crucial that the performances in the first/second trials are correct. We should be cautious in all our interpretations, however, as there are very few studies of the causal reasoning of nonhuman primates in the social domain. Again, there is a great need for a wider array of tasks to be given to a wider array of nonhuman primates.

Nonhuman primates are cognitive beings who understand much about their physical and social worlds. However, the extent to which they also adopt the explanatory attitude toward those worlds and so come to some understanding of their causal structures is unclear (Visalberghi, 1992). There are certainly some situations in which they are able to understand a series of events and their mediating connections in ways that allow them to make predictions in novel circumstances, but there are others in which they are unable to do this. In particular, when the forces involved are totally outside the individual's control, we see very little evidence that nonhuman primates have a deep understand of causality in either domain. Thus, if an individual were to see a hard-shelled fruit fall from a tree and break open, it would be amazing to most primatologists to see that individual proceed immediately to take un-

broken fruits high in the tree and drop them so as to break them open. Similarly, if an individual were to see a groupmate climb a tree to get food but then the situation was changed so that there was now a barrier to the tree, it is unlikely that the observer could predict that the groupmate would first work to remove the obstacle. In short, nonhuman primates have some understanding of the causality that operates in their physical and social worlds, but they have only a limited 'explanatory attitude' allowing for a more flexible understanding of the web of possible connections among the objects, events, and mediating forces involved.

It is inappropriate to be sceptical about nonhuman primates' skills in causal reasoning if no other animal species, including humans, can demonstrate such reasoning. But human children have been shown to have a series of causal understandings of how things work in the physical domain in the tube task (Visalberghi and Limongelli, 1996) and other tasks (Frye et al., 1996). In the social domain they know from an early age something of how their gestures are effective and achieve their intended effects on others in communicative interactions (reviewed in Tomasello and Camaioni, 1997). Indeed, when the early object manipulations of nonhuman primates are compared with those of human infants, at an age before infants are actively gesturing and before they can be tested in causal reasoning tasks, the biggest difference is the tendency of human infants to experiment on the world (tertiary circular reactions) and to take into account the results of such experimentations. This difference might be seen as the initial expression of the exaggerated human tendency to make hypotheses and to adopt an 'explanatory attitude'.

Overall, we see the processes of causal reasoning as fundamentally the same in the physical and social domains, it is just that the precise mediating forces are different in the two cases. This raises the question of whether nonhuman primates are somehow more skilful in one domain than the other, or whether their skills evolved first in the physical or social domain. Again we do not have enough solid data for definitive conclusions, but overall we see no evidence that nonhuman pri-

mates are better at causal reasoning in the social than in the physical domain, as has been argued recently by some researchers (Cheney and Seyfarth, 1990). Our view is that it is perfectly possible that some of primates' causal reasoning skills, limited though they may be, evolved first in the physical domain (presumably for foraging), but that others may have evolved first in the social domain (presumably for social and 'political' interactions of various sorts). The degree to which they may transfer across domains is an open question at this point. To clarify these issues research is needed in which various primate species solve similar problems in relatively natural settings in both the physical and social domains.

As a final point of reflection, however, we would like to propose a scenario which argues for primacy of the social domain in the evolution of human cognition and causal reasoning. Tomasello and Call (1997) have recently argued that the major cognitive difference between humans and nonhuman primates is the ability to understand others as intentional beings. In the child, this causal understanding in the social domain emerges from the ability to attribute to other individuals the same knowledge the child has about itself (including its own intentions). This achievement fosters fundamental capacities such as imitation, symbolic communication, teaching, and cooperation involving role reversal and division of labor, which all are necessary for, and contribute to, cultural evolution. The main point is that no matter which level of understanding was previously reached in the physical and in the social domains, as soon as human beings became capable of reading the intentions of others many other things followed, most especially the fact that all kinds of technical skills, knowledge, and communicative devices can be shared and taught, so that the cognition of the species become as much collective as individual. It is also possible that reading intentions leads to a different understanding of problems in the physical domain in the sense that the explanatory attitude engendered in the social domain leads to a search for mediating forces in the physical domain as well.

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