Dominance Hierarchies and the Evolution of Human Reasoning

DENISE DELLAROSA CUMMINS
Department of Psychology, California State University, 6000 J Street, Sacramento, CA 95819–6007, U.S.A.

Abstract. Research from ethology and evolutionary biology indicates the following about the evolution of reasoning capacity. First, solving problems of social competition and cooperation have direct impact on survival rates and reproductive success. Second, the social structure that evolved from this pressure is the dominance hierarchy. Third, primates that live in large groups with complex dominance hierarchies also show greater neocortical development, and concomitantly greater cognitive capacity. These facts suggest that the necessity of reasoning effectively about dominance hierarchies left an indelible mark on primate reasoning architectures, including that of humans. In order to survive in a dominance hierarchy, an individual must be capable of (a) making rank discriminations, (b) recognizing what is forbidden and what is permitted based one's rank, and (c) deciding whether to engage in or refrain from activities that will allow one to move up in rank. The first problem is closely tied to the capacity for transitive reasoning, while the second and third are intimately related to the capacity for deontic reasoning. I argue that the human capacity for these types of reasoning have evolutionary roots that reach deeper into our ancestral past than the emergence of the hominid line, and the operation of these evolutionarily primitive reasoning systems can be seen in the development of human reasoning and domain-specific effects in adult reasoning.

Key words: Human reasoning, evolution, deontic reasoning, transitive reasoning, non-human primates, neocortical ratio, dominance hierarchy.

Historically, the psychological investigation of learning and cognition has followed a common pattern. Initially, content-free, domain-general mechanisms are posited to explain a particular phenomenon. Subsequent research then seriously challenges these theories, and they are modified in order to include species-specific or other innate domain-specific constraints. The resulting explanations are typically hybrids of domain-general and domain-specific processes, yielding a description of the cognitive architecture that is complex indeed.

For example, early stimulus-response theories of classical conditioning described this capacity as a domain-general one in which an association could be made between any two stimuli through repeated pairings. The factor that was believed to influence the conditioning process was simple temporal contiguity. Subsequent research, however, quashed this pristinely simple view of the mind. It soon became apparent that the conditioning of a simple association between two stimuli depended less on the pairing itself than on the relationship between the pairing and the outcome that the subject anticipated (Rescorla & Wagner, 1972). Thus, conditioning could be blocked if the presentation of one stimuli was not *contingent* upon the presentation of another (even though the two were strongly correlated) or if conditioning were attempted in the presence of another stimulus that already

strongly predicted the occurrence of the reinforcer. The most serious blow to a domain-general view of the conditioning process was dealt by the oft-replicated Garcia effect which showed species-specific "preparedness" to learn associations between certain stimuli and not others (Garcia & Koelling, 1966; Seligman, 1970; Seligman & Hager, 1972). For example, rats will readily learn to avoid drinking water when lights are flashing if this experience is paired with electric shock. They will also readily learn to avoid drinking saccharine-tainted water if this experience is paired with nausea-inducing irradiation. Conditioning is much more difficult to achieve, however, if taste and shock are to be associated or flashing lights and nausea. Phobias among humans also show this "preparedness to associate"; people are far more likely to develop phobias to spiders and snakes than to spatulas or trees (Cook & Menetka, 1989; McNally, 1987; Sigelman, 1971). Investigation of even so simple a process as conditioning ended up revealing a complex relationship between external events and species-specific structure of mind, or, as Hilgard and Bower (1975, p. 574) put it: "One might say that the animal is innately prepro-grammed to see certain cues and responses as 'naturally fitting' together, so that they are readily learned".

A similar transition from a purely empiricist, domain-general view of cognition to a domain-specific one that respects the influence of innate constraints is very much in evidence in contemporary theories of cognitive development. Historically, the most influential domain-general theory was proposed by Jean Piaget, who envi-sioned the development of cognition as a process in which interactive experience with the world shaped the infant's unstructured and incomprehensible sense data into a coherent world view replete with permanent objects and logical concepts (Piaget, 1952 and 1972). But contemporary investigations of infant cognition using the habituation technique have produced a very different picture of infant cogni-tion. In this technique, infants are repeatedly shown a stimulus event until they become habituated to it, that is, until they become bored and decrease their looking time. Then the display is changed in some theoretically important way, and the researchers record whether or not the child dishabituates, that is, shows renewed interest in terms of a significant rebound in looking time. Using this technique, infants as young as two and one-half months of age have been found to dishabit-uate to stimulus changes that appear to violate basic physical principles such as object permanence, the continuity of object trajectories, causality (no action at a distance), and the principle that two physical objects cannot occupy the same place at the same time, (Baillargeon, 1987 and 1994; Leslie & Keeble, 1987; Spelke, 1994). Using similar techniques, infants have also been found to show an appreci-ation of the abstract concept of number (Starkey *et al.*, 1983), distinguish between animate and inanimate objects (Campos & Stenberg, 1981), and respond appropri-ately to a variety of emotional facial expressions (Vandell & Wilson, 1987). Within the first few months of life, we seem to be prepared to interpret and respond to objects and certain socio-emotional stimuli in particular ways.

Similarly, early theories of concept learning described it as a strictly bottom-up process in which the child came to acquire names for classes of objects and events through imitation and feedback-driven trial-and-error (e.g., Piaget, 1952). But even here, an innate "preparedness" to divide the world in certain ways rather than others became apparent during subsequent investigation of the phenomenon. Children as young as three years of age were found to discipline their category inductions by respecting such distinctions as broad ontological category (Carey, 1985; Keil, 1994, Soja *et al.*, 1979) and spatial relations (Clark, 1973). Investigations of adult classification learning showed similar effects; adults are more likely to classify together stimulus events that seem to share an underlying causal principle that explains why certain feature correlations should obtain (see Murphy & Medin, 1985, for a review of this literature). Classification induction, therefore, appears to be disciplined by a reasoner's naive theories. Within the first few months of life, we seem to be predisposed to notice certain correlations among stimulus events rather than others, and these predispositions continue to color our classification decisions throughout life.

Contemporary theories of human reasoning are recapitulating the historical pattern observed for theories of other cognitive functions. Initial theories described human reasoning as a content-free, domain-general process (Braine, 1978; Rips, 1983). The focus of the research programs spawned by this orientation focussed almost exclusively on proposing and testing collections of rules that define inference solely in terms of syntactic relationships, such as the Modus Ponens rule, conjunction, or conditionalization. These purely syntactic theories did not sort well, however, with mounting evidence of domain-specific content effects in human reasoning performance (e.g., Cox & Griggs, 1982; Cheng & Holyoak, 1985; Cummins, 1995 and in press; Cummins *et al.*, 1991; Gigerenzer & Hug, 1992; Griggs & Cox, 1983; Thompson, 1994). In order to salvage content-free theories, proponents have attributed content effects to "bias" (Rumain *et al.*, 1983; Evans, 1989) or content-specific parameters that modify the inputs to the content-free system (Braine & O'Brien, 1991; Rips, 1994). Other theorists have abandoned the notion of a content-free reasoner, proposing instead collections of domain-specific rules that are induced from life experiences with certain types of situations (Cheng & Holyoak, 1985 and 1989). More recently – and as would have been predicted from the historical pattern I've outlined above – theories have been proposed that explain domain-specific content effects in terms of innate "preparedness" on the part of the human reasoner to respond in particular ways to problems with certain contents. Cosmides and Tooby have argued, for example, that certain reasoning domains are innately specified in the human reasoning architecture, having emerged in response to evolutionary pressures felt by our species during the Pleistocene (Cosmides, 1989; Cosmides & Tooby, 1994). In this paper, I will argue that the evolutionary origins of some domain-specific effects in human reasoning may predate the origins of the hominid line (see also Cummins, in press a and b).

I have come to this conclusion by taking seriously David Marr's exhortation that one's research and theory ought to be guided by consideration of the types of problems the system was "designed" to solve (Marr, 1982). Marr's interest was in the visual system, and his research program began with a careful analysis of the problems this system must solve in order to allow an organism to negotiate its world successfully. Like Cosmides and Tooby, I take this approach one step further by asking which types of problems the cognitive system *evolved* to solve.

1. The Relationship between Evolutionary Pressure and Reasoning Capacity

Evolutionary theory is based on the assumption that there is a causal relationship between the adaptive problems a species repeatedly encounters during its evolution and the design of its phenotypic structures. Specifically, evolutionary theory is grounded in the following argument (Darwin, 1859; see Alcock, 1984, pp. 5–8 for a summary): Variation exists in the traits of the members of most species, and some of this variation is heritable. Because of their particular heritable attributes, some individuals will be better able to cope with survival pressures such as predation, climactic changes, or competition for food or mates. Due to the survival advantage imparted by their heritable traits, these individuals will survive better or longer and hence leave more offspring than others in their species that have different, less successful traits. The differential reproductive success of individuals based on their genetic differences is called *natural selection*. The outcome of this process is that organisms will evolve behavioral or other traits that promote individual reproductive success, which is referred to as *fitness* and is defined in terms of the number of one's offspring that live to reproduce themselves.

From an evolutionary standpoint, therefore, the fundamental problem that an organism must solve is maximizing reproductive success. This problem reduces in turn to solving the problems of acquiring mates, accessing sufficient food to feed oneself and one's progeny, and avoiding or reducing the risk of death due to predation. One way to solve these problems is by dint of force, that is, by evolving larger body size. And indeed, in many species, greater size is correlated with greater reproductive success. For example, because larger males tend to win one-on-one contests with other males for estrus females, species for which multiple copulations are possible tend to show marked sexual dimorphism, with males greatly outweighing females (Stein, 1976; LeBoeuf, 1974). Larger size, however, is also expensive; it must be maintained through high caloric intake but simultaneously interferes with foraging efficiency (Selander, 1972).

Another way to solve these crucial problems is by living in social groups. Social living yields a reduction in predator pressure by improved detection or repulsion of enemies, improved foraging and hunting efficiency, improved defense of limited resources against conspecific intruders, and improved care of offspring through communal feeding and protection. For example, lionesses bring down prey that are several times their size and weight (e.g., wildebeest and zebras) by hunting

cooperatively. During the wet season when game are plentiful on the Serengeti plains, the capture rates increase from 15% for solitary lions to over 40% for groups of five, which corresponds to an increase in daily food intake of over three kilos per lioness (Caraco & Wolf, 1975). Moreover, the hunting appears to be strategic, with one or more lioness forming a line parallel to a herd of prey while one or more circle round and drive the prey into the line (Schaller, 1972).

But there are also costs associated with sociality, including increased competition within the group for food, mates, nest sites, and other limited resources (Alcock, 1984). In most mammalian and avian species, competition and cooperation among conspecifics produces a complex social structure called the dominance hierarchy. In functional terms, a *dominance hierarchy* is simply the observation that particular individuals in social groups have regular priority of access to resources – particularly reproductive resources – in competitive situations. These individuals are referred to as dominant or higher-ranking, while those who have lower priority of access are called subordinate or lower-ranking. In it's most developed form, the dominance hierarchy is transitive, meaning that if A has priority over B, and B has priority over C, then A has priority over C, and so on. The role of dominance is most pronounced in situations characterized by high levels of competition for resources, such as high population density or the onset of breeding season (Clutton-Brock & Harvey, 1976).

The dominance hierarchy is intimately related to reproductive success. In most species, there is a direct relationship between rank and reproductive success, with higher ranking members achieving a significantly higher percentage of copulations relative to lower ranking individuals (e.g., Dewsbury, 1982; Clutton-Brock, 1988; McCann, 1981; Watts & Stokes, 1971; Bertram, 1976; Bygott et al., 1979). Among primates, this relationship between rank and reproductive success has also been observed but is sometimes much subtler (Fedigan, 1983; Robinson, 1982; Silk, 1987). For example, lower-ranking male *Papio cyanocephalus* baboons achieve an equivalent total number of copulations as higher-ranking males, but the higher-ranking males typically monopolize females on the day they ovulate (Hausfater, 1975). Rank in this species is therefore correlated with number of *effective* matings. Among chimpanzees, higher rank is associated with greater access to estrus females (de Waal, 1982; Nishida, 1979; Tutin, 1979). Due to their priority of access to resources, high-ranking individuals are also less likely to die of starvation or disease than are lower-ranking individuals (Cheney & Seyfarth, 1990, pp. 33–34).

Because maximizing reproductive success through sociality requires one to capitalize on opportunities for *cooperative* ventures while reducing the costs that derive from greater *competition* among conspecifics for resources, sociality constitutes a fertile environment for selection of variations in cognitive capacity that increase one's ability to detect and exploit cooperative and competitive opportunities. And, in fact, greater sociality has left a measurable mark on the phenotypic structures of the mammalian brain. The relative volume of the neocortex (compared to the volume of the rest of the brain) correlates with the mean group sizes

that characterize primate species, with larger group sizes corresponding to greater neocortical volume (Dunbar, 1992 and 1993; Sawaguchi & Kudo, 1990). This correlation between relative neocortical volume and group size has been interpreted to mean that greater sociality requires greater cognitive capacity, that is, that primates cannot maintain the cohesion and integrity of groups larger than a size fixed by the cognitive capacity of their neocortex (Dunbar, 1993). The neocortical constraint seems to be related to the number of relationships a primate can keep track of in a complex group environment. Unlike the relatively simple aggregation that characterizes the social structure of many bird and herbivore species, primate groups are highly structured around kinship and social networks. The greater relative volume of neocortex in these species suggests that greater reasoning capacity is needed in order to compete and cooperate successfully with large numbers of conspecifics and thereby to maximize reproductive success. In fact, I will argue that special-purpose reasoning architecture evolved for dealing with problems of cooperation and competition that members of social species face repeatedly on a daily basis.

To summarize, research from ethology and evolutionary biology seem to indicate the following about the evolution of reasoning capacity. First, solving problems of social competition and cooperation have direct impact on survival rates and reproductive success. Second, the social structure that evolved from this pressure is the dominance hierarchy. Third, mammals that live in large groups with complex dominance hierarchies also show greater neocortical development, and concomitantly greater cognitive capacity. These facts have led me to conclude that the necessity of reasoning effectively about dominance hierarchies left an indelible mark on primate reasoning architectures, including that of humans.

2. Reasoning about Dominance Relations

Primate dominance hierarchies are not static structures. They are dynamic structures in which individuals vie for control of resources. Lower ranking individuals attempt to engage in forbidden activities in order to secure a larger share of resources, and higher-ranking individuals defend their privileged access to resources by detecting and punishing acts of cheating. In order to survive, an individual must be capable of performing – on a nearly continual basis – the following tasks: (a) making rank discriminations, (b) recognizing what is forbidden and what is permitted based one's rank, and (c) deciding whether to engage in or refrain from activities that will allow one to move up in rank (i.e., garner a larger share of resources). These are the reasoning problems that impact most directly on survival and reproductive success. Other things being equal, we would expect that individuals who were more successful at solving these problems than others would gain an advantage in competing for reproductive opportunities, thereby passing along whatever heritable traits they possess. For this reason, we would expect that evolved changes in cognitive capacity would be tied to the necessity of reasoning successfully about these tasks.

The first problem (making rank discriminations) is closely tied to the capacity for transitive reasoning (Cheney & Seyfarth, 1990, pp. 83–84, 257–258), while the second and third are intimately related to the capacity for deontic reasoning (Cummins, 1996; in press; Hilpinen, 1971 and 1981; Manktelow & Over, 1991). I will briefly summarize the argument given by Cheney and Seyfarth concerning transitive reasoning with a few embellishments of my own, and then turn to deontic reasoning. The main point of these arguments is that the human capacity for these types of reasoning have evolutionary roots that reach deeper into our ancestral past than the emergence of the hominid line, and the operation of these evolutionarily primitive reasoning architectures can be seen in the development of human reasoning capacity and domain-specific effects in adult reasoning. The implication of these arguments is that, with respect to certain types of reasoning capacity, the difference between human and non-human reasoning is one of degree and not kind.

2.1. RANK DISCRIMINATION AND TRANSITIVE REASONING CAPACITY

The argument that Cheney and Seyfarth put forth regarding the capacity to make rank discriminations and transitive inferences is as follows: One strategy for working out dominance relations is simply to observe and remember the outcome of dyadic encounters between each pair of individuals in one's group until one can work out a sequential ordering of individuals indicating A is dominant to everyone, B to everyone but A, and so on. As group size increases, however, the number of outcomes that must be memorized grows exponentially. Another strategy is to reason transitively, that is, to infer some dominance relations based on knowledge of others: If one knows A is dominant to B, and B to C, then one can infer that A is also dominant to C without ever having observed a dyadic encounter between A and C.

Relative to other species, such as pigeons, non-human primates appear to have the capacity for transitive reasoning, but it seems to be most readily evoked by social stimuli. For example, squirrel monkeys and chimpanzees can perform transitive inference on object-oriented tasks only after considerable drilling with paired stimuli (Gillan, 1981; McGonigle & Chalmers, 1977). Yet they readily make transitive inferences while making kinship and rank discriminations among individuals in their social groups (Dasser, 1985, pp. 16–19; Cheney & Seyfarth, 1990, pp. 91–96). This pattern of results is readily explained if one accepts the explanation offered here that certain reasoning capacities evolved specifically to handle problems relating to dominance and kinship relations. If this were the case, we would expect the capacity to be readily evoked on tasks requiring such discriminations – the tasks for which it evolved – and transported with difficulty to logically related tasks that nonetheless have different embedding contents and goals.

A similar dissociation between dominance-based transitive reasoning and object-oriented transitive reasoning is apparent in human development. Like non-human primates, the social interactions of human children are governed by dominance

hierarchies which determine who is permitted to play with whom where and with which toys. Transitive dominance hierarchies are evident in the interactions of children as young as three, and can be reliably reported verbally by four-year-olds, meaning that children as young as three can perform the transitive inferences that are necessary to work out transitive dominance relations (Smith, 1988). Yet, this skill does not transfer readily to non-social stimuli. Like other primates, children can perform object-based transitive reasoning only if they are extensively drilled on the object pairs upon which the inference is to be performed (Bryant & Trabasso, 1971). Truly content-free transitive reasoning does not reliably appear until six years of age (Smith, 1998, pp. 103–104).

The domain-specificity that is apparent in the transitive reasoning of non-human primates and which emerges early in human development seems to be tied specifically to working out dominance relations. This is consistent with the proposal offered here that certain aspects of the human reasoning architecture were shaped by the need to solve problems relating to life within dominance hierarchies.

2.2. DEONTIC REASONING AND DOMINANCE

Reasoning about what one may, ought, or must not do is called deontic reasoning, also referred to as practical reasoning in contemporary philosophical treatments (Hilpinen, 1971 and 1981; Manktelow & Over, 1991). Whenever one reasons about what one is permitted, obligated, advised, or forbidden to do, one is reasoning deontically. This type of reasoning is distinct from indicative reasoning in which the reasoner is required to determine the epistemic status (truth) of a rule or other description of a state of affairs. When reasoning deontically, one is less concerned with what is true than in choosing a prudent course of action.

Living within a dominance hierarchy requires an individual to engage in deontic reasoning continually. Lower ranking individuals must decide whether or not to engage in forbidden activities in order to secure a larger share of resources, and higher-ranking individuals must defend their privileged access to resources by detecting and punishing acts of cheating. Successfully negotiating the complex social norms implicit in non-human primate dominance hierarchies requires a particularly advanced capacity to detect and respond appropriately to permissions, prohibitions, threats, warnings, and obligations, as we shall now see.

Contrary to folk wisdom, dominance ranking among primates is not correlated with size. Instead, one's rank in the hierarchy depends crucially on the ability to form and maintain strong alliances (Harcourt, 1988; Harcourt & de Waal, 1992; Packer, 1977; Seyfarth & Cheney, 1984; Smuts, 1985). In fact, non-human primates, and most particularly chimpanzees, have been described as consummate tacticians, with most of this tactical reasoning aimed at jockeying for position within the dominance hierarchy (e.g., Whiten & Byrne, 1988; Harcourt & de Waal, 1992). Among male primates, rank within the dominance hierarchy is acquired and maintained through dyadic aggression, and alliances determine the fate of out-

ranked individuals, including alpha males whose rank is usurped (Chapais, 1988 and 1992; Datta, 1983a-b; Goodall, 1986; Harcourt & Stewart, 1987; Harcourt & de Waal, 1992; Riss & Goodall, 1977; Uehara *et al.*, 1994). Alpha males who form or already possess strong alliances with other males maintain a relatively high, stable position within the group, while those who have no alliances or weak alliances are ostracized, maintaining a solitary existence outside the group (Goodall, 1986; Riss & Goodall, 1977; Uehara *et al.*, 1994; de Waal, 1982).

Alliances have a direct impact on reproductive success. For example, Hall and DeVore (1965) recorded fifty-three complete copulations with estrus females by six adult baboon males, including one male who, individually was the most dominant animal in the troop. Despite his greater individual dominance, this male only achieve eight copulations. His access to estrus females was effectively blocked by a coalition of three males, who, together, achieved more than twice the number of copulations of the other three males. The dominant male in this alliance achieved the majority of these copulations. The alliance this male formed, therefore, resulted in his having a higher rank than his major competitor when in the company of his allies.

In order to form and maintain an alliance among non-kin, individuals depend on the formation of *reciprocal obligations*. Vervet monkeys, for example, are more likely to respond to calls from non-kin during agonistic encounters if the caller has groomed them recently; they also form the strongest alliances with individuals who groom them most often (Cheney & Seyfarth, 1990, pp. 67–69; Seyfarth, 1976; Seyfarth & Cheney, 1984). Chimpanzees show reciprocity of supportive and retaliative interventions in aggressive encounters: The rate of intervention by individual A on behalf of B correlates with the rate by B on the behalf of A, and the rate of intervention against individual A by individual B correlates with the rate of intervention against B by A (de Waal, 1992). These supportive interactions have the structure of a promise as in 'If A grooms/supports B, then B is obligated to support B in a fight.'. A promise constitutes a commitment on the part of the promisor that becomes an obligation once the promisee has satisfied the conditions of the commitment (e.g., 'A groomed/supported B, so now B must support A'), and a permission from the viewpoint of the promisee to engage in some activity (e.g., 'A may engage in this fight because B will support A in return for A's grooming/support') (Politzer & Nguyen-Xuan, 1992). The negative interactions have the structure of a threat as in 'If A intervenes against B, B will intervene against A'.

This appreciation of obligation structures is also imbued with a 'machiavellian' sophistication in that individuals prefer to groom and support individuals of higher rank than themselves. This preference presumably is due to the fact that support from higher-ranking individuals during agonistic encounters has greater effect than support from lower-ranking individuals. For example baboons, macaques, and vervet monkeys form matrilineal hierarchies in which any female is dominant to all the females that are subordinate to her mother, and she is subordinate to all

the females that are dominant to her mother (Chapais, 1992; Cheney & Seyfarth, 1990; Prud'Homme & Chapais, 1993). During agonistic encounters, support is typically given to the higher-ranking females who in turn intervene in conflicts when they themselves are dominant to the target of the aggression. By aiding higher-ranking females, lower-ranking females form strong alliances based on reciprocal obligations that enable them to move up in rank.

Modelling research based on game theory has repeatedly shown that reciprocity (reciprocal altruism) can emerge as an evolutionarily stable strategy only if the participants are capable of recognizing individuals so that those who cheat may be excluded from future transactions (Axelrod,1984; Axelrod & Hamilton, 1981; Maynard Smith, 1982; Trivers, 1971). In practice, this means that using reciprocity as a competitive strategy requires both parties to be capable of monitoring the contribution of the other so that the collaboration may be discontinued if too large an imbalance is detected. Evidence suggests that some species of non-human primates are indeed capable of this sort of monitoring. Male Papio anubis baboons who refuse to assist other males in abducting females are less likely to receive aid than males who do (Alcock, 1984, p. 486). Similarly, Chimpanzees retaliate against individuals who are reluctant to share food (i.e., show a low rate of food distribution relative to others) either by directly aggressing against them when they themselves request food (de Waal, 1989) or by misinforming or failing to inform them about the location of food (Woodruff & Premack, 1979). Perhaps the most well-known case is that reported by de Waal (1992) in which a subordinate male terminated his long-term alliance with an alpha male in response to the alpha male's increasingly frequent refusals to support him in contests with another male over access to estrus females. Responsiveness to departures from reciprocity are less pronounced among macaques and stump-tail monkeys, who show a greater reluctance to retaliate against higher-ranking individuals than do chimpanzees (de Waal, 1992). Since rank changes typically occur when lower-ranking individuals challenge higher-ranking ones, the dominance hierarchies formed by chimpanzees (who are willing to challenge higher-ranking individuals) tend to be more dynamic than those of macaques and monkeys (who are unwilling to challenge higher-ranking individuals).

The data on coalition and alliance formation among several species of non-human primates show quite clearly a capacity for reasoning about obligations, and in particular, reciprocal obligations. This capacity is most pronounced in chimpanzees, who show a marked capacity for cheater detection. Daily interactions within a dominance hierarchy also require detecting and responding appropriately to other deontic structures, most notably permissions, prohibitions, threats, and warnings. Individuals in positions of high rank (authority) determine who may and who may not engage in which activities when, and they punish transgressors. In order to dominate resources, therefore, an individual must have the capacity to recognize violations of *permissions* and *prohibitions*, not just obligations.

For example, dominant males monopolize reproduction opportunities by aggressing against or threatening to aggress against females and subordinate males who are caught socializing or consorting (Cheney & Seyfarth, 1990, p. 227). Because of the high risks involved in such forbidden liaisons, females and subordinate males often engage in deception, such as concealing their trysts behind obstacles and suppressing their copulation cries; subordinate males also hide their erections behind their hands when their courtships are interrupted by dominant males (Kummer, 1988; de Waal, 1988). Deceptions of this kind have also been observed for hiding other forbidden behaviors, such as stealing food, failing to share food, or grooming forbidden individuals (see Whiten & Byrne, 1988b for numerous examples.) For example, one baboon spent twenty minutes inching behind a rock so that a dominant male could not see her grooming a subordinate male. These complex permission and prohibition structures constitute 'social norms' that are respected by subordinates and aggressively enforced by those who dominate them (Hall, 1964; Aruguete, 1994).

To summarize, the capacity to reason deontically – and particularly to recognize the need to detect violations of deontic structures – appears to be present in the reasoning architecture of many species of non-human primates. This capacity is directly related to reproductive success since much of this reasoning is directed toward dominating reproductive and food resources. This suggests that the changes in primate reasoning architecture that allowed for deontic reasoning preceded the emergence of the hominid line, and may be a primitive in the human reasoning architecture. Consistent with this interpretation is evidence that this type of reasoning emerges early in human development, that is, that young children show a "preparedness" to reason deontically.

Experimentally, this has been demonstrated by observing an early emerging tendency to adopt a "violation detection" strategy when faced with problems of a deontic content. Cummins (in press) reported that children as young as three years of age (the youngest tested so far) adopt of violation-detection strategy when reasoning about deontic rules, a strategy they do not adopt when reasoning about indicative rules. Harris and Nuñez (in press) found that 3- and 4-year-old children were better at identifying the instances that violated a deontic rule than an indicative rule. Moreover, they gave coherent justifications for their decisions, appealing to conditions that constituted violation of the deontic rule. In contrast, they typically gave irrelevant justifications ('It's just that one') or were unable to justify their choices on the indicative task. This suggests that young children grasp the full meaning of deontic tasks better than they do indicative tasks. Reference to social rules appear in children's justifications of their own behavior as early as 24 months of age (Dunn, 1988). And by the age of three, children are selective in their distribution of altruistic acts, preferring to aid those who have aided them in the past, indicating a preparedness to detect violations of reciprocal obligations (Smith, 1988). The ease and speed with which young children learn about, detect, understand, and reason about deontic situations is most consistent with the existence

of an innate domain-specific reasoning architecture that is evoked when a situation with deontic content is encountered.

The tendency to adopt a violation-detection strategy with problems of deontic content not only emerges early in development, it is also baldly apparent in the reasoning of adults (see Cummins, 1996, for a review of this literature.) The clearest examples are based on the Wason card selection task, a task unique not only in its simplicity but in its ability to generate robust content effects (Wason, 1968). This task consists of asking reasoners which of four cards must be turned over in order to test a particular conditional rule (p -> q). The four cards correspond, respectively, to the antecedent of the conditional (p), its consequent (q), and the denial of each (not-p, not-q). For example, consider the following problem: A friend relates to you the observation that in Arizona 'If you go to Phoenix, you travel by train.' In front of you are four cards that have a person's destination on one side and his or her means of transportation on the other. Your task is to indicate all and only those cards that must be turned over in order to test whether or not your friend was telling the truth. Your choices are 'Phoenix', 'Tucson', 'Train', and 'Car'. If you are like the vast majority of people, you selected 'Phoenix' and 'Train', that is, p and q.

Now consider the following case. You are to pretend that you work for the Arizona transportation bureau, and it is your job to enforce a new law aimed at reducing air pollution due to car emissions. The law is 'If you go to Phoenix, you must travel by train.' You're shown the same four cards, and are asked to indicate all and only those cards that must be turned over in order to determine whether or not the rule is being followed. If you're like most people, it seems apparent now that 'Phoenix' and 'Car', that is, p and not-q must be turned over.

The travel problem is an example of an indicative rule, and the most frequently observed response pattern (p and q) constitutes seeking rule-confirming evidence. The law problem is an example of a deontic rule, and the most frequently observed response pattern (p and not-q) constitutes seeking rule violations. Notice that seeking rule violation is also appropriate in the indicative case; if the 'Car' card is turned over to reveal 'Phoenix', a violation of the rule has been detected, and the rule has been incontrovertibly proved false. Despite this, the rates of violation-seeking range from 0% to about 30% on indicative rules and from 60% to 100% for deontic rules. This pattern has been observed among reasoners of varying educational backgrounds (Cheng et al., 1986), and on other reasoning tasks, such as conditional arguments (Fillenbaum, 1978, Thompson, 1994), paraphrasing (Fillenbaum, 1975 and 1976; Thompson & Mann, 1995), and equivalence judgments (Fillenbaum, 1976).

Finally, experiments that test people's reactions to cheating, as opposed to merely competing, show quite clearly that reneging on a promise to cooperate is reacted to more strongly and more negatively than is competition alone (Rabbie, 1992; Weg & Smith, 1993). For example, Weg and Smith (1993) gave subjects the opportunity to win money in transactions based on the Prisoner's Dilemma. The subject's task was to decide whether to betray his or her collaborators and win a

fixed amount of money, or to trust them and possibly win more or less than the fixed amount. Subjects showed a greater willingness to trust, and a greater unwillingness to forgive betrayals of that trust, than would have been predicted by rational choice theory. These results are consistent with the evocation of a reasoning strategy based on reciprocal obligations and cheater detection – the sort of strategy that is the core of coalition and alliance formation in primate dominance hierarchics.

Numerous proposals have been put forth to explain the indicative-deontic distinction. The first is pragmatic reasoning schema theory (Cheng & Holyoak 1985 and 1989; Cheng *et al.*, 1986). According to this theory, adults excel at deontic reasoning because deontic concepts constitute classes of frequently-encountered situations from which collections of domain-specific, goal-oriented rules are induced. One such schema, the permission schema, details the relationship between actions and preconditions, such as 'If the precondition is satisfied, then the action may be taken.' While accounting nicely for the robust domain-specific content effects seen in human reasoning, this theory does not explain the ease with which children comprehend and reason about deontic contents relative to other types of familiar contents (Girotto *et al.*, 1988, 1989; Light *et al.*, 1989; 1990).

A second theoretical explanation is social exchange theory, which analyzes deontic reasoning in terms of cost/benefit analysis and cheater detection (Cosmides, 1989; Cosmides & Tooby, 1994). These strategies are proposed to be innate, having been selected for during the evolution of our species in order to reason effectively about social exchange (cooperative action for mutual benefit). But if deontic reasoning emerged with the first hominids and is specific to the domain of social exchange, it is not clear why other species of primates apparently reason so effectively in deontic contexts. It also does not explain why permissions produce as robust an effect as reciprocal obligations, since it is not clear how a permission can be analyzed in terms of cooperative action for mutual benefit.

A third theory explains the deontic effect in terms of the construction and manipulation of models based on subjective utility (Manktelow & Over, 1991 and 1995), while a fourth theory models performance on the selection task in terms of optimal data selection using decision theory (Oaksford & Chater, 1994). According to these theories, human reasoning is optimally adapted to the environment, or domain, to which it is applied. In the deontic domain, this means maximizing subjective utility; in other domains, it means maximizing some other function. These proposals do not make clear, however, whether these reasoning strategies are learned or reflect something about the structure of mind. If the former, the question still remains how these strategies are learned and why they (as opposed to others) are learnable without direct, explicit instruction. If the latter, the question still remains how these strategies ended up in our architecture, that is, were they selected for or are they side-effects of other functions that were selected for? In either case, they must be somehow related directly or indirectly to solving the problem of maximizing reproductive success, otherwise it is not clear how they became part of the cognitive apparatus.

In contrast to this proposals, the argument offered here traces the capacity for deontic reasoning to selective pressure favoring the evolution of reasoning strategies that determine survival within dominance hierarchies, and hence impact directly on reproductive success. This explanation is also consistent with the empirical observations that the capacity for deontic reasoning is apparent in the social interactions of species other than our own, and why it emerges early in human development. It combines the evolutionary emphasis of social exchange theory with the specific domains identified by pragmatic schema theory (i.e., permission, obligation, precaution, and warning). Most importantly, it generalizes and deepens the evolutionary account by positing a direct relationship between domain specific reasoning architecture and reproductive success.

Acknowledgements

References

Alcock, J. (1984), *Animal Behavior: An Evolutionary Approach*, Sunderland, Ma: Sinauer Assoc.

Aruguete, M. (1994), 'Cognition, Tradition, and the Explanation of Social Behavior in Non-Human Primates', [Review of *Social Processes and Mental Abilities in Non-Human Primates*]. *American Journal of Primatology*, 33, 71–74.

Axelrod, R. (1984), *The Evolution of Cooperation*. New York: Basic Books.

Axelrod, R., & Hamilton, W.D. (1981), 'The Evolution of Cooperation'. *Science*, 211, 1390–1396.

Baillargeon, R. (1987), 'Object Permanence in 3 1/2- and 4 1/2-Month-Old Infants'. *Developmental Psychology*, 23, 655–664.

Baillargeon, R. (1994), 'How Do Infants Learn about the Physical World?', *Current Directions* in *Psychological Science*, 3, 133–140.

Bertram, B.C.R. (1976), 'Kin Selection in Lions and Evolution', in P.P.G. Bateson and R.A. Hinde, eds., *Growing Points in Ethology*, Cambridge: Cambridge University Press

Braine, M.D.S. (1978), 'On the Relation between the Natural Logic of Reasoning and Standard Logic', *Psychological Review*, 85, 1–21.

Braine, M.D.S., & O'Brien, D.P. (1991), 'A Theory of If: a Lexical Entry, Reasoning Program, and Pragmatic Principles', *Psychological Review*, 98, 182–203.

Bryant, P.E., & Trabasso, T. (1971), 'Transitive Inference and Memory in Young Children'. *Nature*, 240, 456-458.

Bygott, J.D., Bertram, B.C.R., & Hanby, J.P. (1979), 'Males Lions in Large Coalitions Gain Reproductive Advantage', *Nature,* 282, 839–841.

Campos, J.J., & Stenberg, C. (1981), 'Perception, Appraisal, and Emotion: the Onset of Social Referencing', in M. Lewis and L. Rosenblum, eds., *Infant Social Cognition: Empirical and Theoretical Considerations*, Hillsdale, NJ: Erlbaum.

Caraco, T., & Wolf, L.L. (1975), 'Ecological Determinants of Groups Sizes of Foraging Lions', *American Naturalist*, 109, 343–352.

Carey, S. (1985), *Conceptual Change in Childhood*, Cambridge, Ma: MIT Press.

Chapais, B. (1988), 'Rank Maintenance in Female Japanese Macaques: Experimental Evidence for Social Dependency', *Behavior*, 104, 41–59.

Chapais, B. (1992), 'Role of Alliances in the Social Inheritance of Rank among Female Primates', in A. Harcourt and F.B.M De Waal, eds., *Cooperation in Contests in Animals and Humans*, Oxford: Oxford University Press.

Cheney, D.L., & Seyfarth, R.M. (1990), *How Monkeys See the World*, Chicago: University of Chicago Press.

Cheng, P.W., & Holyoak, K.J. (1985), 'Pragmatic Reasoning Schemas', *Cognitive Psychology*, 17, 391–416.

Cheng, P.W., & Holyoak, K.J. (1989), 'On the Natural Selection of Reasoning Theories', *Cognition*, 33, 285–313.

Cheng, P.W., Holyoak, K.J., Nisbett, R.E., & Oliver, L.M. (1986), 'Pragmatic vs Syntactic Approaches to Training Deductive Reasoning', *Cognitive Psychology*, 18, 293–328.

Clark, E. V. (1973), 'Non-Linguistic Strategies and the Acquisition of Word Meanings', *Cognition*, 2, 161–182.

Clutton-Brock, T.H. (1988), 'Reproductive Success', in T.H. Clutton-Brock, ed., *Reproductive Success*, Chicago: University of Chicago Press.

Clutton-Brock, T.H., & Harvey, P.H. (1976), 'Evolutionary Rules and Primate Societies', in P.P.G. Bateson & R.A. Hinde, eds., *Growing Points in Ethology*, Cambridge: Cambridge University Press.

Cook, M., & Minetka, S. (1989), 'Observational Conditioning of Fear to Fear-Relevant and Fear-Irrelevant Stimuli in Rhesus Monkeys', *Journal of Abnormal Psychology*, 98, 448–459.

Cosmides, L. (1989), 'The Logic of Social Exchange: Has Natural Selection Shaped How Humans Reason? Studies with the Wason Selection Task', *Cognition*, 31, 187–276.

Cosmides, L., & Tooby, J. (1994), 'Beyond Intuition and Instinct Blindness: Toward an Evolutionarily Rigorous Cognitive Science', *Cognition*, 50, 41–77.

Cox, J.R., & Griggs, R.A. (1982), 'The Effects of Experience on Performance in Wason's Selection Task', *Memory & Cognition*, 10, 496–502.

Cummins, D.D. (1995), 'Naive Theories and Causal Deduction', *Memory & Cognition*, 23, 646–658.

Cummins, D.D. (1996), 'Evidence For the Innateness of Deontic Reasoning', *Mind & Language*, 11, 160–190.

Cummins, D.D. (In Press), 'Evidence of Deontic Reasoning in 3- and 4-Year-Olds', *Memory & Cognition*.

Cummins, D.D., Lubart, T., Alsknis, O., & Rist, R. (1991), 'Conditional Reasoning and Causation', *Memory & Cognition*, 19, 274–282.

Darwin, C. (1859), *Origin of Species*. Murray: London

Dasser, V. (1985), 'Cognitive Complexity in Primate Social Relationships', in R.A. Hinde, A.N. Perret-Clemont, & J. Stevenson-Hinde, eds., *Social Relationships and Cognitive Development*: Oxford: Clarendon Press.

Datta, S.B. (1983a), 'Relative Power and the Acquisition of Rank', in R.A. Hinde, ed., *Primate Social Relationships*, Oxford: Blackwell.

Datta, S.B. (1983b), 'Relative Power and the Maintenance of Rank', in R.A. Hinde ed., *Primate Social Relationships*, Oxford: Blackwell.

Datta, S.B. (1983c), 'Patterns of Agonistic Interference', in R.A. Hinde ed., *Primate Social Relationships*, Oxford: Blackwell.

Dewsbury, D.A. (1982), 'Dominance Rank, Copulatory Behavior and Differential Reproduction', *Quarterly Review of Biology*, 57, 135–159

Dunbar, R.I.M. (1992), 'Neocortex Size as a Constraint on the Behavioral Ecology of Primates', *Journal of Human Evolution*, 20, 469–493.

Dunbar, R.I.M. (1993), 'Coevolution of Neocortical Size, Group Size, and Language in Humans', *Behavioral and Brain Sciences*, 16, 681–735.

Dunn, J. (1988), *The Beginnings of Social Understanding*, Oxford: Basil Blackwell

Evans, J.St.B.T. (1989), *Bias in Human Reasoning*, Hillsdale, N.J.: Lawrence Erlbaum, Inc.

Fedigan, L. (1983), 'Dominance and Reproductive Success in Primates', *Yearbook of Physical Anthropology*, 26, 91–129.

Fillenbaum, S. (1975), 'If: Some Uses', *Psychological Research*, 37, 245–260.

Fillenbaum, S. (1976), 'Inducements: On Phrasing and Logic of Conditional Promises, Threats, and Warnings', *Psychological Research*, 38, 231– 250.

Fillenbaum, S. (1978), 'How to Do Some Things with If', in J.W. Cotton, & R.L Klatzky, eds., *Semantic Factors in Cognition*. Hillsdale, NJ: Erlbaum.

Garcia, J., & Koelling, R. (1966), 'Relation of Cue to Consequence in Avoidance Learning', *Psychonomic Science*, 4, 123–124.

Gigerenzer, G., & Hug, K. (1992), 'Domain-Specific Reasoning: Social Contracts, Cheating, and Perspective Change', *Cognition*, 43, 127–171.

Gillan, D.J. (1981), 'Reasoning in the Chimpanzee: II. Transitive Inference', *Journal of Experimental Psychology: Animal Behavioural Processes*, 7, 150–164.

Girotto, V., Light, P., & Colbourn, C.J. (1988), 'Pragmatic Schemas and Conditional Reasoning in Children', *Quarterly Journal of Experimental Psychology: Human Experimental Psychology*, 40, 469–482.

Goodall, J. (1986), *The Chimpanzees of Gombe*. Cambridge: Belknap Press.

Griggs, R.A., & Cox, J.R. (1983), 'The Effects of Problem Content and Negation of Wason's Selection Task', *Quarterly Journal of Experimental Psychology*, 35a, 519–533.

Hall, K.R.L. (1964), 'Aggression in Monkey and Ape Societies', in J. Carthy and F. Ebling, eds., *The Natural History of Aggression*, London: Academic Press, pp. 51–64.

Hall, K.R.L., & Devore, I. (1965), 'Baboon Social Behavior', in I. Devore, ed., *Primate Behaviour*, New York: Holt, Rinehart, & Winston, pp. 53–110.

Harcourt, A.H. (1988), 'Alliances in Contests and Social Intelligence', in R.W. Byrne & A. Whiten, eds., *Machiavellian Intelligence*, Oxford: Oxford University Press, pp. 131–152.

Harcourt, A.H., & De Waal, F.B.M. eds. (1992), *Coalitions and Alliances in Humans and Other Animals*, Oxford: Oxford University Press.

Harcourt, A.H., & Stewart, K.J. (1987), 'The Influence of Help in Contests on Dominance Rank in Primates: Hints from Gorillas', *Animal Behaviour*, 35, 182–190.

Harris, P.L., & Nuñez, M. (In Press), 'Understanding of Permission Rules by Preschool Children', *Child Development*.

Hausfater, G. (1975), 'Dominance and Reproduction in Baboons (*Papio Cynocephalus*): a Quantitative Analysis', *Contributions in Primatology*, 7, 1–150.

Hilgard, E.R., & Bower, G.H. (1975), *Theories of Learning*, Englewood Cliffs, NJ: Prentice–Hall.

Hilpinen, R. (1971), *Deontic Logic: Introductory and Systematic Readings*, Boston: Reidel/Kluwer.

Hilpinen, R. (1981), *New Studies in Deontic Logic*, Boston: Reidel/Kluwer.

Keil, F.C. (1994), 'Explanation, Association, and the Acquisition of Word Meaning', *Lingua*, 92, 169–196.

Kummer, H. (1988), 'Tripartite Relations in Hamadryas Baboons', in R.W. Byrne & A. Whiten, eds., *Machiavellian Intelligence*, Oxford: Oxford University Press, pp. 113–121.

Leboeuf, B.J. (1974), 'Male-Male Competition and Reproductive Success in Elephant Seals', *American Zoologist*, 14, 163–176.

Leslie, A.M., & Keeble, S. (1987), 'Do Six-Month-Old Infants Perceive Causality?', *Cognition*, 25, 265–288.

Light, P., Blaye, A., Gilly, M., & Girotto, V. (1989), 'Pragmatic Schemas and Logical Relations in 6-to 8-Year-Old Children', *Cognitive Development*, 4, 49–64.

Light, P., Girotto, V., & Legrenzi, P. (1990), 'Children's Reasoning on Conditional Promises and Permission', *Cognitive Development*, 5, 369–383.

Manktelow, K.I., & Over, D.E. (1991), Social Roles and Utilities in Reasoning with Deontic Conditionals', *Cognition*, 39, 85–105.

Manktelow, K.I., & Over, D.E. (1995), 'Deontic Reasoning', in S.E. Newstead & J. St. B. Evans, eds., *Perspectives on Thinking and Reasoning*. Englewood Cliffs, NJ: Erlbaum.

Marr, D. (1982), *Vision: a Computational Investigation into the Human Representation and Processing of Visual Information*, San Francisco: Freeman.

Maynard Smith, J. (1982), *Evolution and the Theory of Games*. Cambridge: Cambridge University Press.

McCann, T.S. (1981), 'Aggression and Sexual Activity of Male Southern Elephant Seals, *Mirounga Leonina*', *Journal of Zoology*, 195, 295–310.

McGonigle, B.O., & Chalmers, M. (1977), 'Are Monkeys Logical?' *Nature*, 267, 694–694.

McNally, R. J. (1987), 'Preparedness and Phobias: a Review', *Psychological Bulletin*, 101, 283–303.

Murphy, G.L., & Medin, D.L. (1985), 'The Role of Theories in Conceptual Coherence', *Psychological Review*, 92, 289–316.

Nishida, T. (1983), 'Alpha Status and Agonistic Alliance in Wild Chimpanzees *(Pan Troglodytes Schweinfurthii), Primates*, 24, 318–336.

Oaksford, M., & Chater, N. (1994), 'A Rational Analysis of the Selection Task as Optimal Data Selection', *Psychological Review*, 101, 608–631.

Packer, C. (1977), 'Reciprocal Altruism in Olive Baboons', *Nature*, 265: 441–443.

Piaget, J. (1952), *The Origins of Intelligence in Children*, New York: International University Press.

Piaget, J. (1972), *The Child's Conception of the World*, Totowa, NJ: Littlefield, Adams.

Politzer, G., & Nguyen-Xuan, A. (1992), 'Reasoning about Conditional Promises and Warnings: Darwinian Algorithms, Mental Models, Relevance Judgments, or Pragmatic Schemas?', *Quarterly Journal of Experimental Psychology*, 44A, 401–421.

Prud'homme, J., & Chapais, B. (1993), 'Aggressive Interventions and Matrilineal Dominance Relations in Semifree-Ranging Barbary Macaques', *Primates*, 34, 271–283.

Rabbie, J.M. (1992), 'The Effect of Intragroup Cooperation and Intergroup Competition on In-Group and Out-Group Hostility', in F. de Waal and A.H. Harcourt, eds., *Coalitions and Alliances in Humans and Other Animals*, Oxford: Oxford University Press, pp. 175–208.

Rescorla, R.A., & Wagner, A.R. (1972), 'A Theory of Pavlovian Conditioning: Variations in the Effectiveness of Reinforcement and Nonreinforcement', in A. Black & W.F. Prokasy, eds., *Classical Conditioning: Current Research and Theory*, New York: Appleton-Century-Crofts.

Rips, L.J. (1983), 'Cognitive Processes in Propositional Reasoning'. *Psychological Review*, 90, 38–71.

Rips, L.J. (1994), *The Psychology of Proof*, Cambridge, MA: Bradford/MIT Press.

Riss, D.C., & Goodall, J. (1977), 'The Recent Rise to the Alpha-Rank in a Population of Free-Living Chimpanzees', *Folia Primatologica*, 27, 134–151.

Robinson, J.G. (1982), 'Intrasexual Competition and Mate Choice in Primates', *American Journal of Primatology*, 1 (Supplement), 131–144.

Rumain, B., Connell, J., & Braine, M.D.S. (1983), 'Conversational Comprehension Processes Are Responsible for Reasoning Fallacies in Children as Well as Adults: If Is Not the Biconditional', *Developmental Psychology*, 19, 471–481.

Sawaguchi, T., & Kudo, H. (1990), 'Neocortical Development and Social Structures in Primates', *Primates*, 31, 283–289.

Schaller, G.B. (1972), *The Serengeti Lion*, Chicago: University of Chicago Press.

Selander, R.K. (1972), 'Sexual Selection and Dimorphism in Birds', in B. Campbell, ed., *Sexual Selection and the Descent of Man*, Chicago: Aldine.

Seligman, M.E.P. (1970), 'On the Generality of the Law of Learning', *Psychological Review*, 77, 406–418.

Seligman, M.E.P. (1971), 'Phobias and Preparedness', *Behavior Therapy*, 2, 307–320.

Seligman, M.E.P., & Hager, J.L., eds. (1972), *Biological Boundaries of Learning*, New York: Appelton-Century-Crofts.

Seyfarth, R.M. (1976), 'Social Relationships among Adult Female Monkeys', *Animal Behavior*, 24, 917–938.

Seyfarth, R.M., & Cheney, D.L. (1984), 'Grooming, Alliances, and Reciprocal Altruism in Vervet Monkeys', *Nature*, 308, 541–543.

Silk, J.B. (1987), 'Social Behavior in Evolutionary Perspective', in B.B. Smuts, D.L. Cheney, R.M. Seyfarth, R.W. Wrangham, and T.T. Struhsaker, eds., *Primate Societies*, Chicago: University of Chicago Press.

Smith, P.K. (1988), 'The Cognitive Demands of Children's Social Interactions with Peers', in R.W. Byrne & A. Whiten, eds., *Machiavellian Intelligence: Social Expertise and the Evolution of Intellect in Monkeys, Apes, and Humans*, Oxford: Oxford University Press, pp. 94–110.

Smuts, B. (1985), *Sex and Friendship in Baboons*, Hawthorne: Aldine Press.

Soja, S.N., Carey, S., and Spelke, E.S. (1991), 'Ontological Categories Guide Young Children's Inductions of Word Meaning: Object Terms and Substance Terms', *Cognition*, 38, 179–211.

Spelke, E.S. (1994), 'Initial Knowledge: Six Suggestions', *Cognition*, 50, 431–445.

Starkey, P., Spelke, E.S., & Gelman, R. (1990), 'Numerical Abstraction by Human Infants', *Cognition*, 36, 97–127.

Stein, R.A. (1976), 'Sexual Dimorphism in Crayfish Chelae: Functional Significance Linked to Reproductive Activities', *Canadian Journal of Zoology*, 54, 220–227.

Thompson, V.A. (1994), 'Interpretational Factors in Conditional Reasoning', *Memory & Cognition*, 22, 742–758.

Trivers, R.L. (1971), 'The Evolution of Reciprocal Altruism', *Quarterly Review of Biology*, 46, 35–57.

Tutin, C.E.G. (1979), 'Mating Patterns and Reproductive Strategies in a Community of Wild Chimpanzees *(Pan Troglodytes Schweinfurtii)'*, *Behavioral Ecology and Sociobiology*, 6, 29–38.

Uehara, S., Hiraiwa-Hasegawa, M., Hosaka, K., & Hamai, M. (1994), 'The Fate of Defeated Alpha Male Chimpanzees in Relation to Their Social Networks', *Primates*, 35, 49–55.

Vandell, L., & Wilson, K.S. (1987), 'Infant's Interactions with Mother, Sibling, and Peer: Contrasts and Relations between Interaction Systems', *Child Development*, 58, 176–186.

De Waal, F. (1982), *Chimpanzee Politics*. Baltimore. Johns-Hopkins University Press.

De Waal, F. (1988), 'Chimpanzee Politics', in R.W. Byrne, & A. Whiten, eds., *Machiavellian Intelligence*, Oxford: Oxford University Press, pp. 122–131.

De Waal, F. (1989), 'Food Sharing and Reciprocal Obligations among Chimpanzees', *Journal of Human Evolution*, 18, 433–459.

De Waal, F. (1992), 'Coalitions as Part of Reciprocal Relations in the Arnhem Chimpanzee Colony', in A.H. Harcourt and F. De Waal, eds., *Coalitions and Alliances in Humans and Other Animals*, Oxford: Oxford University.

Wason, P.C. (1968), 'Reasoning about a Rule', *Quarterly Journal of Experimental Psychology*, 20, 273–281.

Wason, P.C., & Johnson-Laird, P.N. (1972), *Psychology of Reasoning: Structure and Content*, London: Batesford.

Wason, P.C., & Shapiro, D. (1971), 'Reasoning and Mental Representation', *Quarterly Journal of Experimental Psychology*, 36a, 597–610.

Watts, C.R., & Stokes, A.W. (1971), 'The Social Order of Turkeys', *Scientific American*, 224, 112–118.

Weg, E., & Smith, V. (1993), 'On the Failure to Induce Meager Offers in Ultimatum Games', *Journal of Economic Psychology*, 14, 17–32.

Whiten, A., & Byrne, R.W. (1988), 'The Manipulation of Attention in Primate Tactical Deception', in R.W. Byrne & A. Whiten, eds., *Machiavellian Intelligence*, Oxford: Oxford University Press, pp. 211–224.

Woodruff, G., & Premack, D. (1979), 'Intentional Communication in the Chimpanzee: The Development of Deception', *Cognition*, 7, 333–362.