Gaze Following and Joint Visual Attention in Nonhuman Animals

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Key Words: gaze following; joint visual attention; theory of mind; nonhuman animal

Abstract

In this paper, studies of gaze following and joint visual attention in nonhuman animals are reviewed from the theoretical perspective of Emery (2000). There are many studies of gaze following and joint visual attention in nonhuman primates. The reports concern not only adult individuals but also the development of these abilities. Studies to date suggest that monkeys and apes are able to follow the gaze of others, but only apes can understand the seeing-knowing relationship with regards to conspecifics in competitive situations. Furthermore, recently, there are some reports of ability to follow the gaze of humans in domestic animals, such as dogs or horses, interacting with humans. These domestic animals are considered to have acquired this ability during their long history of selective breeding by humans. However, we need to clarify social gaze parameters in various species to improve our knowledge of the evolution of how we process others' gazing, attention, and mental states.

Introduction

Studies of the early precursors of theory of mind have focused largely on infants' understanding of other individuals' visual behavior. Caron, Kiel, Dayton, and Butler (2002) pointed out that commanding of the bulk of the attention is the phenomenon of gaze following, which emerges in the latter part of the first year. From the comparative point of view, a number of studies have addressed the question of the extent to which a variety of animal species share with humans the ability for gaze following. This area of research also aims to increase understanding of how these abilities develop in the course of evolution.

In the present paper, current studies focusing on gaze following behavior in nonhuman animals is reviewed. Gaze following research with humans has been part of a general investigative effort into the developmental origin of theory of mind. From a comparative perspective, primatologists were among the first to address the issue as an offshoot of a broader evolutionary interest in whether mental-state attribution is unique to humans (Povinelli, 1993). Over the last ten years or so, many experimental attempts to explore whether nonhuman animals have gaze following abilities have been conducted.

The review begins by proposing a definition of gaze following in the context of social gaze according to Emery's perspectives (Emery, 2000). Next several lines of evidence for the ability to gaze follow in nonhuman primates are provided, not only in apes but also in monkeys. The following section describes studies that have attempted to demonstrate gaze following in domestic animals. These latter studies are very interesting because they may provide a clue for considering selection pressures on domestic animals, especially dogs, during the process of domestication for specific skills relating to social cognition and communication with humans (Hare et al., 2002). The next section discusses the development of gaze following in nonhuman primates form the perspective of comparative developmental cognitive science. The ability to understand the "seeing-knowing relationship" in chimpanzees and corvids is discussed in the next section. Appreciation of the seeing-knowing relationship is one of the most central propositions in theory of mind. The final section of the review draws conclusions based on the current studies of gaze following in nonhuman animals.

Definition of social gaze

Gaze following was defined as “looking where someone else is looking” by Corkum & Moore (1995). This was actually used by Butterworth as the definition of joint visual attention (Butterworth & Jarrett, 1991). However, many researchers claimed that joint visual attention is not simply simultaneously looking at the same objects. For example, Tomasello (1995) claimed that joint visual attention is not just a geometric phenomenon concerning two lines of visual attention.

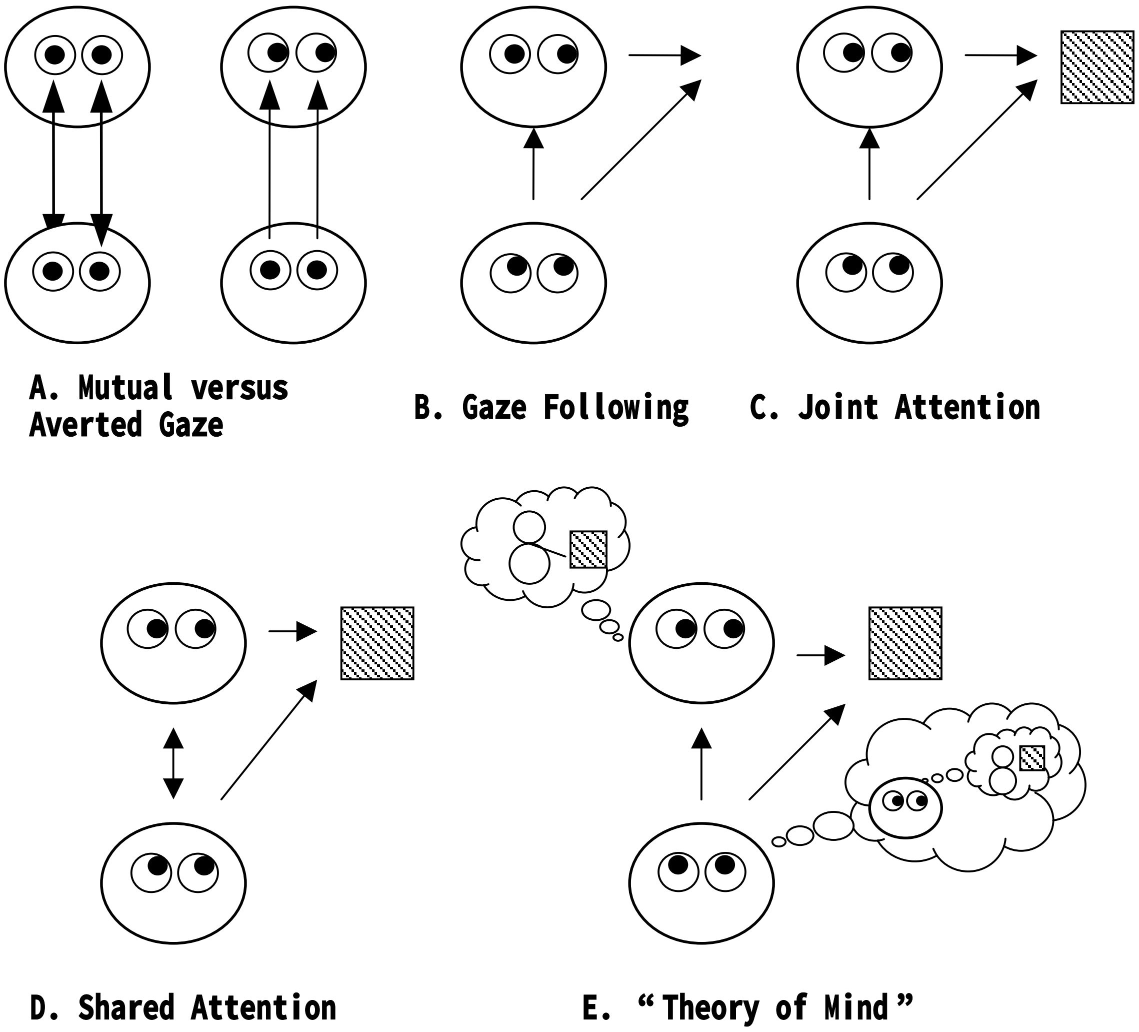

Figure 1　Schematic representation of each type of social gaze (From Emery, 2000)

Recently Emery (2000)　proposed that social gaze leads to theory of mind (see Figure 1). I adopt this classification in this paper. Mutual Gaze (Figure 1A) occurs when attention of individuals A and B is directed to each other. Averted gaze occurs when individual A is looking at B, but the latter’s focus of attention is elsewhere (see also Figure 1A). Gaze following occurs when individual A detect that B’s gaze is not directed towards him, and follows the line of sight of B to a point in space (Figure 1 B). Joint visual attention is the same as gaze following except that there is a focus of attention, such as an object (Figure 1C). Shared attention is a combination of mutual attention and joint visual attention, where the focus of individual A and B’s attention is on the object of joint focus and each other (i. e. “I know you are looking at X, and you know I am looking at X”, Figure 1D). According to Emery’s classification, shared attention differs from joint visual attention slightly. In the previous literature, the two terms were employed interchangeably. However, Emery points out that shared attention is a more complex form of communication requiring that individuals A and B each have knowledge of the direction of the social partner’s attention. Figure 1E shows mental state attribution or theory of mind. This uses a combination of the previous A-D attentional processes and higher-order cognitive strategies to determine that an individual is attending to a particular stimulus because they intend to do something with the object, or believe something about the object (cited from Emery, 2000).

In this paper, gaze following behavior is considered, because a number of interesting studies of gaze following behavior and joint attention in nonhuman animals have been published. Gaze following and joint attention is very important for social animals because they reveal an adaptive social-cognitive skill for vicariously detecting food, predators, and important social interactions among group mates.

Gaze following and joint attention in nonhuman primates

Determining the precise direction of another's attention may be an important ability for nonhuman primates. Itakura (1996) tested 11 species of nonhuman primates in a gaze monitoring task to examine whether they would look where the experimenter looked or pointed. The species were brown lemur, black lemur, squirrel monkey, brown capuchin, white-faced capuchin, stump-tailed macaque, rhesus monkey, pig-tailed macaque, tonkean macaque, chimpanzee, and orangutan. The procedure was as follows: the experimenter stood in front of the subject, and tried to obtain eye contact with vocalization. Then the experimenter turned to look behind the subject, to the left or right, in silence, with or without pointing. Itakura (1996) found that only chimpanzees and an orangutan reliably followed experimenter pointing and head + eye cue. No other species showed performance above chance level. He also reported that there was a strong correlation between the percentage of correct responses and the maximum duration that the subject attended to the experimenter.

In a gaze monitoring task similar to Itakura's (1996), Povinelli and Eddy (1996) found that chimpanzees followed the experimenter's eye movements alone. In a subsequent experiment, an opaque barrier was positioned to prevent the chimpanzee seeing the end-point of the experimenter's line of sight in a gaze monitoring task. The experimenter used head and eyes to look at an object out of sight of the chimpanzee. The chimpanzees' response – trying to look around or over the barrier, suggests that they postulated that something was behind the barrier.

Tomasello, Hare and Agnetta (1999) tested chimpanzees with different types of barrier, such as a piece of gutter, board, different room, and wall. They reported that chimpanzees looked around the barrier more when the experimenter had done so, compared to when the experimenter had looked in a different direction. In their next experiment, Tomasello et al. (1999) found that the chimpanzees looked at a distracter object, but continued to follow the experimenter's gaze onto the target. This was a very important finding, suggests that chimpanzees do not just follow gaze reflexively onto the first object that comes within view, but track another individual's gaze geometrically to the specific location and object being attended to.

Anderson, along with colleagues (1995) is one of the pioneers of this area in nonhuman primates. They used an experimenter-given cues paradigm, which is a sort of object-choice task. This paradigm, in which the subjects must use a variety of cues to find the location of hidden food, has been used to assess the ability of animals to use human-given facial and gestural cues in a object-choice task. Anderson, Sallaberry, and Barbier (1995) tested whether capuchin monkeys (*Cebus apella*) could use human gestures in this paradigm. The human's behavioral cues were pointing, gaze, and pointing + gazing. Capuchin monkeys were able to utilize pointing or pointing + gaze cues. Anderson, Montant, and Schmit (1996) tested rhesus monkeys using the same paradigm. They reported that rhesus monkeys could use pointing or pointing + gaze much like capuchin monkeys.

Itakura and Anderson (1996) trained a capuchin monkeys with slightly modified paradigm of experimenter-given cues task.

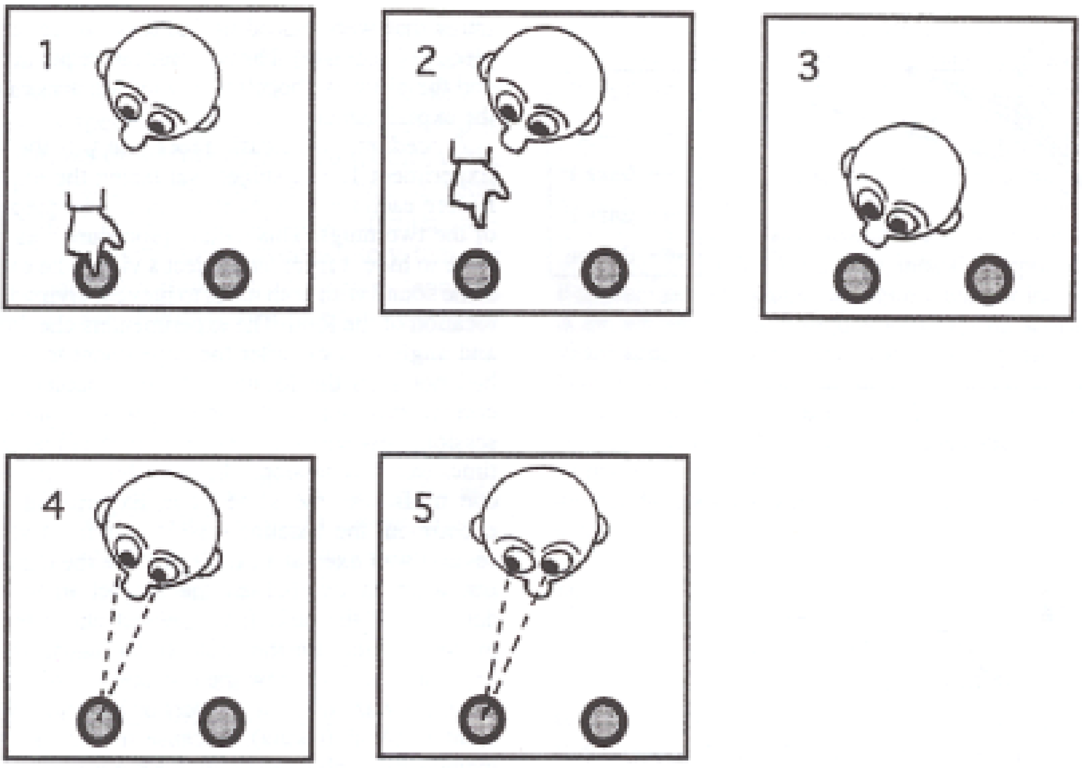

Figure 2 Schematic representation of each condition. (1) Tap, (2) Point, (3) Gaze 1, (4) Gaze 2, (5) Glance (Itakura & Tanaka, 1998)

There were five phases of training. At first, the experimenter stood in front of the subject, and when he was sure that the subject was looking into his face, the experimenter provided behavioral cues as follows: 1) Tap: the experimenter gazed at and tapped the correct stimulus with the forefinger during the stimulus presentation. 2) Point: the experimenter gazed and pointed to the correct stimulus with the index finger during stimulus presentation. 3) Gaze 1: the experimenter's head and eyes were approximately 15 cm from the discriminanda, but oriented towards the correct one. 4) Gaze 2: the experimenter gazed at the correct stimulus during stimulus presentation as in phase 3, but from a distance of about 60cm. 5) Glance: the experimenter glanced at the correct object without head movement during stimulus presentation. The result of this experiment was that the subject learned to use all of the experimenter-given cues, with the exception of glancing.

Itakura and Tanaka (1998) also found that chimpanzees, an orangutan, and human infants could all use gaze cues, pointing, and a glance cue to locate hidden food or a toy by using exactly the same paradigm as Itakura and Anderson. Their chimpanzees had lots of experiences of face to face experiments with humans, and the orangutan was a show-orangutan in the zoo (an animal trainer trains this orangutan to do some performance everyday life) , i.e., these were enculturated subjects. This may be an important factor. Itakura, Agnetta, Hare and Tomasello (1999) also reported that chimpanzees attempted to use social cues to locate hidden food. In the first experiment, the subject chimpanzee was exposed to a local enhancement cue (the informant approached and look at the correct target where food was hidden) and a gaze + point cue (the informant gazed and manually pointed to the correct target). Each cue was provided by both humans and chimpanzees. In the second experiment, the subject chimpanzee was exposed to a gaze direction cue in combination with a vocal cue (the human informant gazed at the hiding location and made one of two types of vocalization: a 'food bark' or human word-form. The results were as follows: 1) all subjects were quite skillful with the local enhancement cue, no matter whether a human or chimpanzee provided it; 2) few subjects were skillful with the gaze + point cue, no matter whether this came from a human or chimpanzee (most of these having been raised in infancy by humans); and 3) most subjects were skillful when the human gazed and vocalized at the hiding location, with little difference between the two types of vocal cue, with slightly better performance with food bark.

Povinelli et al. (1999) have also used a similar paradigm to test chimpanzees. They found that the chimpanzees were not able to use the experimenter's gestural cues to locate hidden food when using eye movements alone. Peignot and Anderson (1999) also found that captive gorillas used pointing and/or head + gaze cues to find hidden food, but they did not use eyes alone as a cue.

Inoue, Inoue, & Itakura (submitted) reported that a white-handed gibbon (*Hylobates lar*) could use an experimenter's pointing, gaze, and glance to locate hidden food. It is very interesting that the gibbon also could use human's glance as a cue. They explained this result by enculturation, because the subject had had extensive interaction with humans since a very young age.

Effects of humans' eye movements alone gaze following may be influenced by the degree of enculturation, in other words, how much interaction the subjects have had with humans, because the most positive data (Itakura and Tanaka, 1998; Inoue, Inoue, & Itakura, submitted) are from highly enculturated subjects.

Gaze following ability is shown not only in great apes but also some macaques can follow their conspecifics' gaze cues. There was conflicting evidence for attention following in monkeys (Anderson et al., 1995, 1996, Itakura & Anderson, 1996, Itakura, 1996). However, in all of these studies in mokeys, the stimulus for attention following was the experimenter. If the stimulus was a conspecifics, attention following was observed. For example, Tomasello, Call, and Hare (1997) demonstrated that five species of non-human primate (rhesus monkeys, stumptailed monkeys, pigtailed monkeys, sooty mangabeys, and chimpanzees) were able to follow conspecifics' gaze cues. Emery, Lorincz, Perrett, Oram, and Baker (1997) also found that rhesus macaques watching the gaze cues of another rhesus monkey on the video looked at the specific location on the video screen. Then how do we explain the difference between humans' gazing cue and conspecifics' gazing cue? Tomasello et al. (1998) considered that studies in which monkeys do not follow the human gaze may reflect more of a motivational problem. They claim that primates are much more interested in where conspecifics are looking than in where humans are looking. However, we do not have certain evidence of this yet.

To summarize this section, many species of nonhuman primates follow the gaze of humans and conspecifics, and they are able to use behavioral cues from humans or conspecifics to locate hidden food in an experimenter-given cues paradigm.

Gaze following and joint attention in domestic animals

Primate species have been a main focus of the comparative study of cognition, because we assume that primates share many cognitive abilities with humans due to their recent shared evolutionary descent with humans (McKinley& Sambrook, 2000). Furthermore, the effects of enculturation are presumed to be emphasized in species with a greater degree of behavioral plasticity, such as great apes. If we consider of combination of these two factors, it seems possible that a domestic animal whose evolution has been largely shaped by humans, such as a dog, should have ability similar to those of enculturated great apes. Several studies report on the ability to follow human's gaze in domestic animals.

Miklosi, Plogardi, Topal, & Csanyi (1998) demonstrated that domestic dogs have an ability to follow gaze by using experimenter-given cues based on those originally described in Anderson et al. (1995, 1996), but closer to those of Itakura and Anderson (1996) or Itakura and Tanaka (1998), modified to suit the species under investigation and the particular circumstances. The behavioral cues from the experimenter were pointing, bowing, nodding, head-turning, and glancing. 1) Pointing. The common pointing gesture was used. The experimenter pointed briefly toward the correct container after which his/her arm returned to the resting position at the thigh. During the pointing gesture the experimenter faced the dog. 2) Bowing. The bow was presented by bending the upper torso approximately 30 degree from the vertical in the direction of the target container, during which the experimenter looked to towards the correct pot. 3) Nodding. The experimenter turned his/her head in the direction of the baited pot and nodded once, looking towards the baited one. 4) Head-turning. The experimenter turned his/her head in the direction of the baited pot. 5) Glancing. During this behavioral cue the experimenter was kneeling. The experimenter's head remained still, facing the dog, and only the eyes were moved in the direction of the baited pot. The results showed that the domestic dog is capable of using various directional behavioral cues from humans to find hidden food. The dogs were also able to generalize from one person to another familiar person presenting the same behavior as cues.

Hare and Tomasello (1999) reported that dogs could use either local enhancement cues or gaze, body orientation and pointing cues simultaneously, given by either humans or conspecifics. They used 10 dogs as subjects. The results were as follows: 8 of 10 responded correctly to human-local enhancement cues; 5 of 10 responded correctly when given human-gaze and pointing cues; 6 of 10 responded correctly when given conspecific-local enhancement cues and 4 of 10 responded correctly when given conspecific-gaze and pointing cues. Dogs appear to utilize conspecific cues as a throwback to their history as pack hunters (see Emery, 2000).

McKinley and Sambrook (2000) also demonstrated that domestic dogs and horses used some behavioral cues in an experimenter-given cue paradigm. They used sixteen domestic dogs and four horses as subjects. In the experimental phase with dogs, cues were given as follows: 1) Point: the experimenter pointed towards the correct location twice, keeping her head oriented forward. 2) Head: the experimenter knelt on the ground and turned her head towards the correct location, back towards the dog, then back to correct location and held it there, keeping her eyes looking directly ahead throughout. 3) Gaze: the experimenter pointed straight ahead and moved her eyes to gaze the correct location.

In the experimental phase with horses, cues were given as follows: 1)Touch: the experimenter squatted behind the two buckets then touch the correct location. The experimenter also moved her hand up and down because the movement is important to the equine visual system. 2) Point: this resembled the dogs' cue except that again the experimenter moved her hand up and down until the subject chose one of the buckets.

The results of dogs experiment showed that the dogs were very skillful in using pointing as a cue to locate hidden food. This supports the results from previous studies. Dogs could also use the humans' head orientation and gaze (eye movements alone) as a cue. This also supported the conclusion of a previous study. A new finding was that some dogs appeared to respond to eye gaze alone as a cue. Two dogs were significantly more likely to choose the object experimenter was looking at. Hare et al. (in press) found that two dogs were able to use pointing alone and combined head orientation and eye movement to find the location of hidden food. However, they could not use eye direction alone as a cue. McKinley and Sambrook (2000) explained the discrepancy between the previous study and their study in terms of saliency of cues. In the experiment by Hare et al. (1998), the experimenter's gaze cues were given from a standing position while in the experiment of McKinley and Sambrook (2000) the experimenter sat on the ground, close to the subject's height. This might have made the cue more salient. Notwithstanding this point of divergence, dogs clearly show some kind of sensitivity to humans' eye movements.

In the case of horses, the results were mixed. Two of the subjects were able to find hidden food when they were given the experimenter's touching cue, but only one horse could use the pointing cue. There were individual differences (McKinley and Sambrook, 2000).

Most recently, Hare, Brown, Williamson & Tomasello (2002) reported on the domestication of gaze following behavior in dogs. They found that wolves raised by humans do not show a comparable ability to read human communicative signals indicating the location of hidden food, whereas domestic dog puppies only a few weeks old, even those that have had little human contact, do show these skills. Hare et al. (2002) concluded that during the process of domestication, dogs have been selected for a set of social-cognitive abilities that enable them to communicate with humans in unique ways.

To summarize this section, some domestic animals can follow humans' or conspecifics' gaze and pointing. The animals, such as dogs, who have been domesticated to live in human society, might have been skilled to be sensitive human gestural cues in long history of domestication. Unfortunately there are no studies of the propensity for gaze following by non-primates species in Japan.

Developmental perspective

In the previous two sections, I surveyed studies of gaze following in nonhuman animals. In this section I approach gaze following as a developmental pathway in human infants. In humans, gaze-following behavior emerges between 3 and 18 months of age. By 14-18 months of age, infants follow the gaze of adults by using eye cues only, and by 18-24 months, they are capable of understanding the referential aspect of visual attention of others. Then to what extent do nonhuman animals develop such ability? . Is it important from the perspective of comparative cognitive development? There are a few studies which address this issue.

Okamoto et al. (2002) investigated the development of this ability longitudinally by using an experimenter-given cues paradigm, which described before, in a chimpanzee. One male chimpanzee was tested regularly from 6 months to 13 months of age. There were four types of experimenter's gestural cues, such as tap, point, head turn, and glance. The subject chimpanzee reached the criterion for tap condition around 8 months, point condition around 9 months, and head turn condition around 10 months. By 13 months, the subject reached the criterion for glance condition. The results suggested that the chimpanzee showed reliable gaze following behavior in response to the experimenter's behavioral cues, including simple glancing by the end of 13 months. Also, the authors reported that the chimpanzee's gaze following behavior is controlled by the "social" properties of the experimenter-given cues and not only by the stimulus enhancing or local enhancing peripheral properties. There were two conditions in the experiment, one was an incongruent point condition and the other was a incongruent head turn condition. In the former condition, the experimenter gazed at and pointed to the target object with an index finger from the side of other object (they called it 'distracter'). In the latter condition, the experimenter oriented head and eyes toward the target object from the side of the distracter object. The authors' hypothesis was that if the chimpanzee infant's responses were based on stimulus enhancement the subject would choose the object closer to the experimenter (distracter). However, the results showed that the subject looked significantly more often at the socially cued object in both the incongruent point condition and incongruent head turn condition. These results suggest that the infant chimpanzee employed the social cues presented by the experimenter. This is a very important finding.

Ferrari, Kohler, Fogassi, & Gallese (2000) demonstrated that pig-tailed macaques would follow the gaze of the experimenter and that there are developmental stages such ability, revealed through cross sectional studies. The subjects were 11 pig-tailed macaques. Their ages ranged from 2 to 16 years. In the experiment, the subjects were tested in three experimental conditions: head/eyes, eye, and trunk. In the head/eyes condition, the experimenter turned the head 70 degree up, down, left or right, with the eyes always aligned with the head. In the eye condition, the experimenter oriented the eyes up, down, left and right to the extreme position of the orbit. In the trunk condition, the experimenter turned his trunk 60 degree to the left or right. The results showed that gaze following in pig-tailed macaques dramatically improves with age. Compared with adults, juvenile monkeys showed a marked difference in head-gaze following, because they were unable to understand the direction of another's gaze by employing eyes cues alone. Ferrari et al. (2000) proposed that the orientation of the head and eyes together is the first feature that triggers a shift in visual attention, suggesting that in young macaques head-and eyes orientation together provides more salient signals to the direction of another's gaze than eyes alone.

There is another developmental study of gaze following in nonhuman primates. Tomasello, Hare, and Fogleman (2001) investigated the development of gaze following behavior in chimpanzees and rhesus macaques. However, they used a different method than the experimenter-given cues paradigm. The general procedure was as follows: there were two types of trials. In experimental trials, the experimenter looked straight up into the air, moving both head and eyes but the experimenter's body remaining facing the subjects. In control trials, the experimenter looked directly at the subjects. The results show that both rhesus macaques and chimpanzees began to follow gaze quite reliably during infancy. Rhesus infants began to follow the direction of the human experimenter's gaze at the end of the early infancy period, at about 5.5 months of age. On the other hand, chimpanzees did not reliably follow the human's gaze until 3-4 years. Following these experiments, Tomasello et al.(2001) exposed both rhesus monkeys and chimpanzees of different ages to humans gazing into the air (towards no precise target) for many trials in succession. They tried to discover whether gaze following is a relatively fixed and unchangeable response in rhesus macaques and chimpanzees, or whether at some developmental point it is subject to modification by learning. The results showed that rhesus and chimpanzee infants and juveniles never habituated to the procedure. They continued to follow the human's gaze into the air, whereas adult rhesus and chimpanzees habituated quickly. They pointed out that it was only adults who consistently began to ignore the human's looking into empty space in both species. The authors concluded that in the period between infancy and adulthood individuals of these two species come to integrate their gaze-following skills with their more general social-cognitive knowledge about other animate beings and their behavior. The inconsistency of the age of emergence of reliable gaze following in chimpanzees between Okamoto et al. (2002) and these data (Tomasello et al., 2001) may due to the difference in methodology. Okamoto et al. (2002) trained a chimpanzee infant to use the human's behavior as a cue, whereas Tomasello et al. (2001) used a simple gaze following paradigm. However, the discrepancy remains to be fully explained.

To summarize this section, there are developmental stages in gaze following behavior of nonhuman primates just like as human infants. For example, human infants understand pointing and head orientation at first, and then understand glancing. Nonhuman primates reviewed here seem to show same order of the development as the human infants. Of course performances may be dependent on the nature of the tasks presented, but basically the nonhuman primates showed very similar pattern to human infants.

Understanding of seeing-knowing relationship

One of the most important and central questions in the study of social cognition in nonhuman animals is what individuals know about the psychological processes of other individuals (Brian et al., 2000). Now there is strong experimental evidence that many nonhuman animals, especially nonhuman primate species, reliably follow the gaze direction of conspecifics or human experimenters. These evidences may allow us to postulate the possibility that they understand that the direction of another's gaze implies that that animal is seeing something. Understanding of 'seeing-knowing' relationship is to understand that the eyes are the source of knowledge. However, there are fewer controlled studies of their understanding of 'high level' psychological process of others (see Brian et al., 2000).

Brian, Call, Agnetta, and Tomasello (2000), using an ingenious paradigm, found that chimpanzees know what another chimpanzees see and does not see. In the series of experiments, a subordinate chimpanzee and a dominant chimpanzee were placed in competition over two pieces of food. In all experimental situations, dominant chimpanzees obtained almost all of the foods to which they had good visual and physical access. However, subordinate chimpanzees succeeded in obtaining foods quite often in the situations in which they had better visual access to the food than the dominant chimpanzees, for example, when the food was located so that the dominant chimpanzee could not see it and the subordinate chimpanzee could see. Brian et al (2000) concluded that their results suggest that chimpanzees know what conspecifics can and cannot see, and that they use this knowledge to devise effective social-cognitive strategies in naturally occurring food competition situations.

Hirata and Matsuzawa (2001) also found the possibility that chimpanzees understand conspecifics' knowledge in a competitive situation. In their experiment, a human experimenter hid a piece of food in one of five containers in an outdoor enclosure. One chimpanzee (called witness) could see where the food was hidden, while another chimpanzee (witness-of witness) could not see the baited procedure directly but could observe the witness chimpanzee watching the baiting procedure. Then two chimpanzees were then released into the enclosure. The authors observed interesting behavior in these chimpanzees. The witness-of-witness chimpanzee developed tactics to forestall the witness chimpanzee. The witness chimpanzee misled the witness-of witness by taking a route to an empty pot. Hirata and Matsuzawa (2001) concluded that the flexible changing of tactics to obtain food suggests the possibility that witness-of-witness chimpanzee understood the witness's knowledge of the location of baited food.

Kuroshima, Fujita, Fuyuki, and Masuda (2002) found that capuchin monkeys could be trained to understand the relationship between seeing and knowing in a similar paradigm to that used by Povinelli, Nelson, and Boysen (1990). Capuchin monkeys were trained to choose the container which was tapped by the trainer who saw the baiting procedure and who therefore knew where the food was, but not for a trainer who did not see and did not know the location of food. The results show that the capuchin monkeys were able to learn to understand that "seeing is knowing." This is the first report of such ability in non-ape primates.

A similar ability was reported not in only primates but also in birds of the corvid family. Emery and Clayton (2001) found that scrub jays with prior experience of pilfering another bird's caches subsequently re-cached food in new cache site during recovery trials, but only when they had been observed caching. Although there are no reports of corvid's ability on gaze following or joint attention, this result suggests the possibility that these birds understand something about the seeing-knowing relationship.

In summary, some of great apes, monkeys, and possibly even birds seem to be able to understand the relationship between seeing and knowing in competitive situations.

Conclusion

Gaze following ability may allow non human primates to get salient information about the location of objects, and also to engage in complex forms of social cognition, such as visual-perspective taking, deception, empathy and theory of mind (Emery, 2000). In this paper, I have reviewed the gaze following behavior, joint attention, and understanding of the seeing-knowing relationship in non-human species. Now we have amassed considerable evidence that not only nonhuman primates follow the gaze of human experimenters or conspecifics, but also that domestic animals such as dogs and horses can do this to a certain extent. In particular, chimpanzees seem to understand the seeing-knowing relationship and other's knowledge.Also, some corvids have shown the possibility that they recognize the seeing-knowing relationship, though there are no data on their gaze following or joint visual attention. Table 1 reviews the performance of each species surveyed in this paper in each type of social gaze as classified by Emery (2000).

Table 1 Reviews of the performance of each species surveyed in this paper in each type of social gaze. P：positive evidence, ?: not tested or controversial evidence

Species	gaze following	joint attention	shared attention	seeing-knowing relationship	
Macaques	**P**	**P**	**?**	**?**	
Capuchin monkey	**P**	**P**	**?**	**P**	**(trainable)**
Gibbon	**P**	**P**	**?**	**?**	
Chimpanzee	**P**	**P**	**?**	**P**	
Orangutan	**P**	**P**	**?**	**?**	
Gorilla	**P**	**P**	**?**	**?**	
Dog	**P**	**P**	**?**	**?**	
Horse	**P**	**P**	**?**	**?**	
Jay	**?**	**?**	**?**	**P**	**(possible)**

The problem is that we do not know yet how to best evaluate the phenomenon of shared attention in nonhuman animals. In the case of human infants, referential looking or showing behavior is the evidence for shared attention. However, there are no reports of such behavior in nonhuman animals, even in nonhuman primates yet (except one evidence reported by Gomez (1991) in gorilla). We need to consider new paradigm to clarify this issue for future studies. Of course we may infer that chimpanzees would show shared attention because they seem to have ability to understand the seeing-knowing relationship, if shared attention is necessary for the emergence of understanding of the seeing-knowing relationship.

Tomasello et al. (1999) suggested two possibilities, namely "low-level" and "high-level" models of gaze monitoring. In the low-level model, organisms have a tendency to look in the direction that others are looking. In the high-level model, on the other hand, an organism comes to understand that when other individuals look in a direction they are seeing something; in other words, they have some kind of mental experience (Tomasello et a., 1999). According to Emery's classification, shared attention seems to be critical. Considering the data from previous studies, the use of gaze within a mentalistic context seems to be limited to humans and possibly some of the great ape, however, we do not have enough data to state this conclusively. Future studies will provide the evidence necessary before drawing strong conclusions.

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