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Theory and Method in Developmental Research

The Development of Mentalistic Gaze Understanding

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Very young infants are sensitive to and follow other people's gaze. By 18 months children, like chimpanzees, apparently represent the spatial relationship between viewer and object viewed: they can follow eye-direction alone, and react appropriately if the other's gaze is blocked by occluding barriers. This paper assesses when children represent this relationship as psychological in nature. Studies examining sensitivity to gaze, gaze following, and explicit judgement of gaze direction are reviewed. The evidence suggests that neither infants nor chimpanzees represent gaze as psychological. It is concluded that mentalistic gaze understanding develops from the age of 3 years. Copyright © 2006 John Wiley & Sons, Ltd.

Key words: joint attention; gaze detection; theory of mind

INTRODUCTION

There is intense current interest in how the understanding of others' gaze develops. The locus of gaze determines the content of one's visual representation of the surroundings. Eye-direction is critical in judging this, although head-direction and body posture are often good approximations. Understanding others' visual attention often allows inferences about an individual's knowledge and beliefs about the environment. Understanding of gaze is thus important for understanding representational mental states: not only seeing, but also knowledge, belief, and so on.

Several theorists have proposed that gaze understanding is a precursor to understanding belief (e.g. Gopnik *et al*., 1994; Baron-Cohen, 1995). This proposal rests on the premise that gaze is understood in mentalistic terms by the end of infancy. Mentalistic understanding of gaze is broadly defined here as the ability to represent a relationship between the eyes and an object, and represent the relationship as being representational in some way, for example, as attentional, or 'seeing' (e.g. Baron-Cohen, 1995, p. 42).

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The aim of this paper is to review evidence of when children develop a mentalistic understanding of gaze. Non-human primate abilities are also considered: chimpanzees share many of the psychological abilities of 2-year-olds, yet there is evidence that their gaze understanding is non-mentalistic.

There are two types of relevant evidence. Firstly there are behaviours we would normally interpret as showing mentalistic understanding. If an organism can predict another's behaviour, this may draw on a concept of mental states underlying the behaviour. However, it may also be based on abstraction of behavioural regularities, without recourse to additional mentalistic concepts. Distinguishing between these cases is very difficult (Povinelli and Vonk, 2004). Nevertheless, drawing the minimum necessary conclusions can be informative.

A more convincing type of evidence is failure to do something that an individual with the postulated mentalistic understanding would be expected to do. A special case of this is verbal judgement of eye-direction. Although ability to make such judgements could be based purely on looking behaviour, inability would suggest lack of mentalistic understanding.

It is always possible that individuals understand gaze in mentalistic terms in an implicit sense. This review is limited to understanding that can be shown in behaviour, but the possibility of explicit understanding arising from earlier implicit understanding is considered in the discussion.

PERCEPTION OF DIRECT GAZE

The most basic gaze perception ability is the ability to distinguish direct from averted gaze. Newborn infants may prefer faces with open eyes and direct rather than averted gaze (Farroni *et al*., 2002), although other studies have found no discrimination of direct gaze until 4 months old (Samuels, 1985; Vecera and Johnson, 1995). Before 4 months infants respond socially principally to adults' head direction; after they respond preferentially to eye-direction (Caron *et al*., 1997). At around this age, infant chimpanzees also prefer open-eyed and direct gaze human faces (Myowa-Yamakoshi *et al*., 2003).

These behaviours might indicate gaze understanding—in this case, between the self and the viewer (e.g. Baron-Cohen, 1995; Vecera and Johnson, 1995). This conclusion is too strong, however. Infants may simply be sensitive to the surface properties of an important stimulus. This ability is shared with many animals: sensitivity to being looked at is of obvious adaptive significance (Baron-Cohen, 1995; Emery, 2000).

Other evidence suggests that children cannot make explicit judgements about direct gaze until considerably later. Baron-Cohen and Cross (1992) found that 3-year-olds were only 75% correct at judging which of two people was looking at them (chance baseline being 50%). Bruce *et al*. (2000) and Doherty and Anderson (1999) found similar results. In the latter study even 2-year-olds performed well when head- and eye-direction were congruent, indicating that they understood the task and difficulties are specific to eye-direction. Thayer (1977) found that even 6-year-olds were poor at judging whether they were being looked at. Thus despite precocious sensitivity to direct gaze, there is no evidence that children represent it as a mentalistic relationship between themselves and the viewer until 3 years of age or later.

PERCEPTION OF GAZE DIRECTION

Non-Human Primates

Few animals other than humans need to follow eye-direction. Most mammals are quadrupeds and do not move their head and eyes independently. Therefore, body and head direction both reliably indicate the direction of attention, and are more salient than eye-direction (Emery, 2000). Chimpanzees move their eyes independently of head and body more than other non-human primates, but this tendency is far greater in humans (Kobayashi and Kohshima, 2001).

It is perhaps not surprising therefore that monkeys show limited ability to follow eye-direction (see Emery, 2000, for a review). Captive chimpanzees, however, will spontaneously turn in the direction of a human head or eye movement (Povinelli and Eddy, 1996a). More interestingly, if a head turn terminates at a barrier between the chimpanzee and the experimenter, chimpanzees try to look at the experimenter's side of the barrier (where his line of sight terminates) rather than follow the line through the barrier (Povinelli and Eddy, 1996a). Monkeys do not take occluding barriers into account (Kummer *et al*., 1996).

However, chimpanzees' understanding of the significance of looking behaviour is questionable. For example, Povinelli and Eddy (1996b) found that chimpanzees were no more likely to solicit food from an experimenter who could see them than one who could not (because he or she was blindfolded, for example). Other research shows chimpanzees are sensitive to the experimenter's attentional status (Leavens *et al*., 2004), but not that they make this discrimination on the basis of eye-direction. There is debate about whether chimpanzees can use experimenter eye-direction to select which of two containers are baited (Itakura and Tanaka, 1998; Povinelli *et al*., 1999).

This suggests several possible levels of gaze understanding. Prosimians may not follow head-direction (Anderson and Mitchell, 1999). Monkeys do follow head-direction, but there is limited evidence that they follow eye-direction. Chimpanzees follow eye-direction and expect gaze to terminate at an object. This suggests that for chimpanzees, another's gaze is not simply directing their attention; it is creating an expectation of visual experience in a specific direction. Chimpanzees appear to represent gaze as a spatial relationship between the eyes and an object. However, their failure to adapt their behaviour based on what the experimenter can see or is looking at suggests that they do not understand this relationship in any psychological way. They may be aware that there is a relationship, but have no idea what the nature of this relationship is. This rudimentary understanding would still be a valuable asset. The next section examines whether human infants have any more sophisticated understanding than this.

Children

Following Head and Eye Turns

Infants follow adults' gaze shifts from 3 months onwards (Scaife and Bruner, 1975; D'Entremont *et al*., 1997; Hood *et al*., 1998). By 18 months, infants will follow gaze out of their own visual field (e.g. Butterworth and Jarrett, 1991), and reliably follow eye-movements alone (Corkum and Moore, 1995). This indicates a tendency to orient on the basis of gaze cues.

Evidence for representing a spatial relationship between the eyes and an object arises around 12 months. Woodward (2003) habituated children to an actor looking to one side at an object. Twelve-month-olds dishabituated to the actor looking at a new object on the same side, but not to the actor looking at the same object on the other side. This suggests that they encoded the relationship between actor and object, rather than only surface features of the events. Younger children did not dishabituate.

Butler *et al*. (2000) looked at 14- and 18-month-old children's tendency to follow another's head turn to an object when the object was occluded from the adult. Eighteen-month-olds tended not to follow an adult's head turn to a target when it was occluded by an opaque barrier, but did so if the occluder was transparent. Fourteen-month-olds looked less often when there was an opaque barrier, but less often still when the occluder was transparent.

The literature suggests that infants represent a spatial relationship between object and viewer. The relationship is between the viewer and the first object in their line of sight, and can extend through apertures. This understanding develops shortly before 18 months, roughly when children start to track gaze to the space behind them, which also suggests that children are beginning to expect gaze to terminate at an object (Butterworth and Jarrett, 1991). Prior to this age, gaze following may be a conditioned response (Moore, 1999). By 18 months, however, human infants have apparently similar gaze understanding to chimpanzees. Available literature on infant gaze following does not warrant any stronger conclusion.

Gaze Judgment

O'Neill (1996) suggests infants conceive of attention in terms of engagement, a non-mentalistic concept roughly corresponding to involvement in a situation/activity. Engagement is best signalled by broad stable cues, such as posture, demeanour, and head direction (McGuigan and Doherty, 2002). Eye-direction, by contrast, is transient, constantly changing, and difficult to distinguish, particularly in humans. However, it is critical in determining what someone is attending to. The ability specifically to judge eye-direction may therefore indicate the transition from an understanding of engagement to a mentalistic understanding of gaze. Most evidence suggests children cannot judge eye-direction until about 3 years, the same time they can judge whether someone else is looking at them.

The following studies all involved judgement of eye-direction with head facing forward.[1] Masangkay *et al*. (1974) found that most 3-year-olds but not 2-year-olds were able to consistently identify which of the four objects an experimenter was looking at. Lee *et al*. (1998) found that although 3-year-olds were above chance at judging what a person in a picture was looking at, performance was poor. Even with the inclusion of eye-movement, 2-year-olds' eye-direction judgement was not above chance on this task or only exceeded chance when feedback was given. Doherty and Anderson (1999) found that most 3- and 4-year-olds, but no 2-year-olds could say which of the four objects a schematic drawing face was looking at. Performance was no better with a real person (see also Doherty *et al*., 2004). When a congruent head turn was included, however, even 2-year-olds performed near ceiling, indicating understanding of the task.

[1] But see Doherty and Anderson (2001) for concerns about people's ability to move the eyes without detectable head movements.

The only claim of good performance on gaze judgment for children under 3 years comes from Lempers *et al*. (1977). This study has been taken to demonstrate that infants have adult-like gaze understanding. Lempers *et al*. found impressive competencies in children from 11 to 37 months on a range of gaze tasks. However, they did not report their results in detail. Data presented were based on children's 'best response', where tasks generally comprised a single trial but were administered 'several times'. Success on some tasks was assumed if children were deemed successful on 'harder' tasks without the former being administered. Given the lack of clear information, it is impossible to know whether Lempers *et al*.'s results differed from chance.

Finer-grained judgements seem to be even harder. Some joint attention studies included more than one target to the correct side (e.g. Butterworth and Jarrett, 1991), but involved head turns and large gaze deviations (60°). The few studies of fine-grained gaze judgements suggest that development continues beyond 4-years. Leekam *et al*. (1997) found that only 45% of normal 4-year-olds passed a fine-grained gaze task requiring judgement of which of three rods was being fixated. Doherty *et al*. (2004) carried out a similar experiment with a live experimenter. Only children of 6-years made correct judgements on more than 50% trials where objects were separated by 10° of visual angle; 3-year-olds were not above chance on either 10° or 15° trials.

The evidence therefore suggests that explicit judgement of eye-direction is a novel skill that arises about the age of 3 years, and then improves gradually over the next few years.

DISCUSSION

The available developmental evidence warrants the conclusion that human infants achieve a level of understanding equivalent to adult captive chimpanzees. They can represent a spatial relationship between the eyes and an object. There is doubt over whether chimpanzees understand this relationship in any mentalistic way. There is no good reason to believe that infants have a better understanding. The poor performance of 2- and some 3-year-olds when judging eye-direction, either at targets or at the viewer, suggests that children lack a key component of adult mentalistic understanding of gaze until 3 years.

This is later than is typically assumed. If gaze understanding is a precursor to theory of mind, it is a very immediate precursor. Doherty and Anderson (1999) compared the ability to judge eye-direction and to pass a false belief task in preschool children. Performances were equivalent, and were positively correlated ($r = 0.40$, $p = 0.02$, prior to age-partialling). Psychological understanding of gaze may arise as part of more general theory of mind abilities. The contemporaneous development of apparently mentalistic understanding in distinct sub-domains (i.e. gaze and belief), suggests that development is more conceptual than simple abstracting of behavioural regularities (Povinelli and Vonk, 2004).

Another possibility is that earlier gaze understanding is mentalistic, but implicit and not available to judgement. Some process such as 'Representational Redescription' (Karmiloff-Smith, 1992) might explain the development from implicit to explicit gaze understanding. If so, explicit judgement ability should develop rapidly, since it would be based on translation of a sophisticated existing implicit ability rather than relearning. The gradual improvement in gaze judgement accuracy from chance at 3 years suggests that this is not the case.

Nor is there presently any evidence to suggest implicit gaze understanding prior to 3 years.

The functional distinction between gaze following and gaze judgement suggests that two systems may be in operation. Adult humans apparently use two systems for determining gaze direction: one based on the relative luminance of the iris and sclera (see Ando, 2002); and the other based on analysis of the geometry of the eyes (Ando, 2002; Jenkins and Langton, 2003). Due to poor visual acuity, infants may be limited to the luminance-based system. At 3 months, when infants start to follow gaze, their acuity is insufficient to resolve the edges of the eye, iris or pupil (Banks and Salapatek, 1981). However, they are able to perceive contrast at very low spatial frequencies; this contrast sensitivity would be sufficient to perceive the difference in luminance between the iris and the sclera from a viewing distance of 50 cm. The luminance-based system is computationally much simpler, at the cost of some accuracy (e.g. in uneven lighting conditions). If there is an innate gaze processing mechanism, it probably operates on luminance cues.

Adults' use of two systems might therefore involve one that is innate, fast and approximate, and another learned, more computationally difficult but more accurate. The learned system is probably the basis of gaze judgments, and begins to operate at 3 years. Until this age, the luminance system may be sufficient for children's requirements.

In conclusion, human infants, like chimpanzees, are sensitive to being looked at from an early age, and rapidly develop the abilities to follow head-direction then eye-direction. From perhaps 12 month onwards, these abilities are based on representation of a relationship between the head and/or eyes and an object. This relationship, however, does not appear to be understood in a mentalistic way. The earliest reliable evidence of psychological understanding of gaze comes from children's explicit judgement of eye-direction, which they can do from about 3 years.

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