Theory of Mind

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Abstract The ability to attribute mental states to oneself and others is fundamental to human cognition and social behavior. Research on the development of a Theory of Mind in childhood indicates a two-step developmental sequence of desire-understanding and belief-understanding in preschool age. There is ongoing debate about the significance of recent findings on Theory of Mind in infancy. Neuroimaging studies of Theory of Mind reasoning in adults provide some support for a specific Theory of Mind network. This claim is contested, however, and many relevant studies have not yet been done. There is no hard evidence for a Theory of Mind (and an understanding of belief) in non-human primates, but there is evidence for a lower-level perception-goal psychology in some animals.

1 Introduction

A Theory of Mind is the ability to attribute mental states (thoughts, knowledge, beliefs, emotions, desires) to oneself and others. This common-sense mentalism is a powerful tool in our everyday predictions and explanations of human action. In developmental psychology, the child's conceptual understanding of the mental domain has been the focus of much research in the last 25 years (see Flavell 2004; Sodian 2005; Sodian and Thoermer 2006; Wellman 2002; for reviews). A critical test for the ability to represent mental states independently of reality is an understanding of *false* belief, since the ascription of true beliefs does not require a differentiation of beliefs from reality. Wimmer and Perner (1983) conducted the first systematic investigation of false belief understanding in children and found that children begin to correctly predict a story figure's mistaken action based on a false belief around the age of 4 years. In their classic "Maxi task" (1983) a doll named

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Maxi is presented to the child and the experimenter tells the child that Maxi places his chocolate bar in the green cupboard. Maxi then goes to the playground. While he is away, a doll representing Maxi's mother wants to bake a cake. So she takes the chocolate out of the green cupboard, breaks off a piece and instead of putting it back into the green cupboard, puts it in the blue cupboard. The experimenter then describes how Maxi returns and his mother goes away again. After that, the child has to answer several questions. The memory questions relate to the child's understanding of the story. Basically all children are able to answer these correctly. However, the critical false belief question, relating to where Maxi will search for the chocolate, is the one that 3-year-olds generally do not pass. However, 40–80% (depending on the test condition) of 4- to 5-year-olds answer correctly that Maxi will search for the chocolate in the green cupboard. In contrast, younger children tend to make reality-based action predictions and fail to attribute false beliefs to other persons, as well as to themselves. Their general assumption is that Maxi will search for the chocolate in the blue cupboard. The nature and theoretical interpretation of this developmental phenomenon has attracted great interest in the past 25 years. More recently, Theory of Mind has also become a focus of neuroimaging research (see Amodio and Frith 2006; Saxe et al. 2004, for reviews). Furthermore, Theory of Mind development has been found to be related to the development of other cognitive functions such as language, memory, self-control, and time-representation (e.g., Astington and Jenkins 1999; Bischof-Köhler 2000; Perner et al. 2007; Perner and Lang 1999). Therefore, it is no longer possible to review all relevant lines of research in a brief chapter. In the following sections, we will briefly summarize developmental and neurocognitive Theory of Mind research, and then focus on the relation between Theory of Mind and language acquisition. Theory of Mind is not only an area of developmental psychology, but has also, from the start, focused on the question of whether non-human primates and other animals have mindreading abilities. We will conclude with a brief overview of recent progress in comparative Theory of Mind research.

2 Development of a Theory of Mind

Theory of Mind has also been described as a belief–desire psychology, since we rely on these two basic concepts in our everyday predictions and explanations of human action.

In child development, desire reasoning precedes belief reasoning by about one and a half years. Even18-month-old infants have a limited ability to reason non- egocentrically about people's desires, and by the age of two and a half years children make correct use of desire terms and grasp causal relations between desires and emotional outcomes. For example, they understand that people are happy when they get what they have desired (Bartsch and Wellman 1995).

In contrast, false belief understanding emerges only at the age of about 4 years. Three-year-olds and younger children fail to understand that a person's mental representation of reality can differ from reality, and they fail to understand how such

misrepresentations arise from false or incomplete information. Other conceptual distinctions that require an understanding of representational diversity are the appearance reality distinction, and the ability to understand that the same entity can be perceived differently from two different visual perspectives (Level 2 perspective taking). These distinctions are mastered in close conjunction with belief understanding around the age of 4 years (Flavell and Miller 1998). Consistent with the view that Theory of Mind development progresses as a two-step developmental sequence, Wellman and Liu (2004) found that tasks designed to assess children's understanding of desires, knowledge and beliefs form a Guttman scale. A meta-analysis of over 500 studies of false belief understanding showed that belief understanding is a robust developmental phenomenon. Although facilitating task conditions lead to success in children below the age of 4, there is still a clear developmental trend between the ages of about two and a half and 4 years (Wellman et al. 2001). Young children's difficulty with false belief tasks cannot be attributed to language demands, since non-verbal tasks have been shown to be equally difficult as verbal ones (Call and Tomasello 1999; Sodian et al. 2006); nor can it be attributed to inhibitory demands, since the developmental trend persists in tasks with low inhibitory demands, for instance tasks requiring an explanation for a mistaken action (Moses and Flavell 1990). There is evidence for a specific deficit in understanding *mental* representations in normally developing 3-year-olds and in autistic children (Leslie and Thaiss 1992; Perner et al. 1987).

An *implicit* understanding of belief precedes an explicit one by about 6 months (Clements and Perner 1994); also 36-month-olds take other people's false belief into account in communication (Carpenter et al. 2002). Recent eye-tracking studies have found evidence for belief-based anticipatory looking in infants as young as 24 months (Southgate et al. 2007), and 18 months (Neumann et al. 2008). Looking-time studies indicate that 13- and 15-month-old infants expect belief-based actions (Onishi and Baillargeon 2005; Surian et al. 2007). There is ongoing debate about whether these findings indicate that infants possess a Theory of Mind or whether they should be explained by lower-level heuristics, such as smart encoding or behavioral rules (e.g., Perner and Ruffman 2005). There is, however, undoubtedly, a rich understanding of goal-directed action in infancy, beginning around the age of 6 months (Woodward 1998). Around their first birthday, infants conceive of people as intentional agents (Tomasello 1999), paying attention to what other people are attending to and predicting their behavior from a variety of communicative cues. Infants use their intention-reading abilities in inferring others' goals even when the goal-directed action failed (Meltzoff 1995), in responding to bids for cooperation (Warneken and Tomasello 2006), and in distinguishing between unwillingness and inability of an adult to comply with their requests (Behne et al. 2005). Infants also encode what others see and do not see independently of their own visual access to an object (Luo and Baillargeon 2007; Sodian et al. 2007), and they use their knowledge of what others have seen in communication (Moll et al. 2007). Thus, recent research on infants' social understanding indicates that the preschooler's Theory of Mind is based on a rich understanding of intentional action in infancy. Longitudinal findings indicate that there is, in fact, a specific relation, on an individual level,

between infants' social information processing and preschoolers' Theory of Mind (Aschersleben et al. 2008; Thoermer et al. submitted; Wellman et al. 2004).

Later developments in children's understanding of the mind include second order false belief understanding around the age of 6 years, an increasingly powerful understanding of the mind as an active interpreter of information (Chandler and Carpendale 1998), which entails the notion of interpretive frameworks, rather than just simple beliefs. A nascent understanding of interpretive frameworks can be found even in 6-year-olds who understand the role of social prejudice in interpreting a target action (Pillow 1991). However, a full and explicit understanding of the role of theories or interpretive frameworks in interpreting natural phenomena develops slowly through adolescence and is not even present in all adults (Bullock et al. 2008). Later Theory of Mind development also includes elementary knowledge about thinking (Wellman et al. 1996). During the early preschool years, thinking is construed as an internal activity, representing a real or imagined content. However, an understanding of ongoing, constructive mental activity, and an intuitive idea of the stream of consciousness emerges only around the age of 8 years (Flavell 2003; Flavell and O'Donnell 1999). At this age, children understand that a person, seemingly unoccupied from the outside, e.g., just sitting on a bench, can still be preoccupied with mental activity on the inside.

3 Theories

There are several types of explanation for the development of children's knowledge about the mind. To date, the most dominant approach in philosophy and psychology is the so called Theory theory (Bartsch and Wellman 1995; Gopnik and Wellman 1994; Perner 1991; Wellman and Gelman 1998). Theory theorists offer an everyday, informal framework of related concepts as an explanation for mentalistic understanding. The developmental steps in these frameworks are analogous to the shift in scientific explanatory frameworks (Carey 1985). Bartsch and Wellman (1995) have described some of these critical steps, by arguing that 2-year-olds first develop a "desire psychology," basing their predictions about human behavior solely on desires. While desires remain the dominant explanations for people's behaviors at the next developmental stage, 3-year-olds begin to take beliefs into account and make use of a "desire-belief psychology." Finally, the relationship between beliefs and desires shifts and 4-year-old children understand that beliefs can be seen to "frame" desires and equally motivate human thought and behavior.

Perner (1991) developed an influential three stage model on children's developing representational skills. At the first stage, infants possess "primary representations," where they are limited to perceive things in current reality, e.g., a banana is a banana for them. During their second year of life, children entertain "secondary representations," which enable them to take "primary representations" and go beyond reality to model hypothetical situations, e.g., they pretend during child play that a banana represents a pistol. The third step is "metarepresentation." According to Perner (1991) older children's correct answers on false belief paradigms like the "Maxi task" (Wimmer and Perner 1983) are evidence of a true representational

understanding. To grasp the concept of false belief the child has to understand the difference between reality and a person's (false) concept about reality, but also that this false concept is believed to be true by the person. Thus, the child has to represent the representation of a representation. Theory theorists acknowledge that experiences play a major formative role in children's theory of mind.

Simulation theorists (Goldman 1992; Gordon 1986; Harris 1992) state that practice in role-play improves children's mentalising abilities, as children are enabled to understand other's mental states through role-taking and simulation processes.

Putting more emphasis on social experiences than cognitive theories of Theory of Mind, Carpendale and Lewis (2004) have introduced a social-constructivist approach. The basic idea is that, when socially interacting with other persons, children construe a Theory of Mind (Chapman 1991). Around the end of the first year of life, dyadic mother–infant face-to-face interactions are followed by triadic interactions between mother, child and object, allowing the child a gradual and cumulative acquisition of important mentalising abilities.

In contrast, other developmentalists (e.g., Carlson et al. 1998; Hughes 1998) believe that children's age-dependent improvement in a set of higher-order cognitive abilities, so-called executive functions, accounts for children's developing Theory of Mind skills.

As an example, until they are 4 years old most children fail the "windows task" devised by Russell et al. (1991). In this task the child is required to instigate a false belief in the experimenter. First, two boxes with transparent windows are presented, so that the child sees the chocolate reward in one of the boxes. Children are then required to infer the rule that when pointing at the empty box they can fool the experimenter and thus save the reward for themselves. They also have to realize that even though they know something to be false, someone else can be tricked into believing it to be true. Still, according to the executive function idea, younger children continually fail false belief tasks, as they lack the inhibitory control to suppress a prepotent response to the cognitively salient reality; in this case the reward in the box.

Modularity theorists (Baron-Cohen 1995; Leslie 1994; Scholl and Leslie 1999) postulate an acquisition of Theory of Mind through neurological processes. According to them, the maturation of a succession of domain-specific and modular mechanisms (Fodor 1983) enables organisms to deal with animate versus inanimate and agent versus nonagent objects. While the nature of these basic hard-wired mechanisms is not determined by experience, theorists in this field do not neglect the possibility that experience might trigger its operation and that its expression could be influenced by performance factors.

As the following section shows, neuroimaging studies have provided new insights into the existence of a brain region specialized in Theory of Mind.

4 Neural Correlates

A reliable set of brain regions has been connected with false belief reasoning, the marker test for Theory of Mind, including the medial prefrontal cortex (mPFC) (e.g., Goel et al. 1995; Sabbagh and Taylor 2000) and/or the right and left temporo-parietal

junction (TPJ) (Saxe and Kanwisher 2003). The few brain imaging studies with children have implicated activation of the mPFC (Kobayashi et al. 2007; Ohnishi et al. 2004), TPJ, inferior parietal lobule (Ohnishi et al. 2004) and ventral prefrontal cortex (Liu 2006). Evidence for a distinct Theory of Mind system would require a) increased brain activity for any task or stimulus eliciting the attribution of mental states and b) specialized processes, specifically devoted to Theory of Mind. This domain-specific interpretation of Theory of Mind would be challenged by the involvement of other processes like inhibitory control, language, executive function or recursion, serving a whole range of cognitive functions (domain-general processes). While developmental theorists (e.g., Wellman and Liu 2004) point out that Theory of Mind is to be understood as a complex ability consisting of more concepts than false belief, so far few neuroimaging studies have taken this into account. One study by Sommer et al. (2007) has compared true to false belief understanding. The results indicate that some Theory of Mind network regions, especially the right TPJ, are recruited only for false, not true belief attribution in adults. In line with Apperly et al. (2005) the results stress the importance of developing new tasks to isolate the distinct neural underpinnings of different mental concepts. Furthermore, fMRi studies, investigating the patterns of association and dissociation of deficits in patients with brain lesions and autistic children provide unique information concerning a distinct Theory of Mind network. Reviewing 20 years of data on lesion patients and children with autism, Stone and Gerrans (2006) argue that it may not be necessary to assume a separate Theory of Mind mechanism, since there is empirical evidence that Theory of Mind abilities do not solely depend on higher order cognitive processes or metarepresentation per se, but on their developmental and "online" interaction with low level precursor mechanisms like gaze processing and emotion recognition. This could explain why some studies show evidence that toddlers with autism have deficits in joint attention skills, but not always early deficits in executive function (Griffith et al. 1999; Rutherford and Rogers 2003). The fact that deficits in autistic children are not always apparent when they are tested by a computer rather than a person (Ozonoff 1995), hints at some indispensable input from lower order social domains to provide for intact higher order processes like executive function.

5 Theory of Mind and Language

Since it is not only Theory of Mind undergoing profound developmental changes during the first 5 years of life, but also children's language skills, and since Theory of Mind and language development have been found to be closely associated (Astington 2000), there is controversy about whether it is language ability that constrains Theory of Mind or vice versa (see Milligan et al. 2007, for a review). It has been shown that children's Theory of Mind assists them in their word learning (e.g., Baldwin 1991). In more complex communicative situations, adults' mentalizing ability was found to enhance the efficacy of shared understanding in conversation

(Krych-Appelbaum et al. 2007). For the reverse influence, it has been shown that parents' language about mental states facilitates children's later Theory of Mind and emotion understanding (e.g., Slaughter et al. 2007; Taumoepeau and Ruffman 2006). A longitudinal study by Astington and Jenkins (1999) provided evidence that early language ability predicts later Theory of Mind performance, while other studies (deVilliers and Pyers 2002; Slade and Ruffman 2005), have found the relation to be bi-directional. As a consequence, researchers' positions on the coevolution of language and Theory of Mind are fairly widespread. According to Ruffman (2000), since children's early Theory of Mind -components are of an implicit nature manifesting in children's overt behavior, rather than being insights they can consciously reflect and verbalize, it is statistical learning abilities (Saffran et al. 1996) that account for individual differences in early, nonverbal false belief understanding. Once this implicit understanding is in place, the first children to develop explicit understanding are those with better language skills because language provides the terms and means for refining implicit intuitions. Recent behavioral (Newton and deVilliers 2007) and neuroimaging studies (Kobayashi et al. 2007, 2008) of Theory of Mind development, indicating that adults process Theory of Mind more verbally than children, support this view. Interestingly, studies investigating the consequences of late acquired aphasia (especially loss of grammatical skills), suggest that a mature Theory of Mind functions even in the absence of syntactical structures and thus the neural bases of adult Theory of Mind and language might be largely distinct (Varley and Siegal 2000). As an example, an aphasia patient (Apperly et al. 2006), could still solve first and even second-order nonverbal Theory of Mind tasks. However, studies with autistic and normally developing children (Astington and Jenkins 1999; Lohmann and Tomasello 2003; Slade and Ruffman 2005; Tager-Flusberg and Sullivan 1994) indicate that comprehension of syntax is related to mentalising abilities. Accordingly, while syntax seems to be critical for developing a Theory of Mind, the structure and expression of mature, nonverbal belief reasoning might not depend on linguistic cues.

6 Theory of Mind in Other Species and Robots

Since Premack and Woodruff's (1978) seminal publication "Does the chimpanzee have a Theory of Mind ?" there has been a lively debate, especially in comparative psychology, whether and to what extent non-human animals can be credited with a Theory of Mind. Here again, a differentiated view on the different components of a Theory of Mind and its precursors seems crucial.

One of the building blocks for a Theory of Mind is the human infant's ability to follow gaze (see Emery 2000 for a review). While chimps are quite prolific gaze-followers their performance in respect to pointing, another important social cue, is mixed. While Call et al. (2000) and Barth et al. (2005) report positive responses to pointing and gazing, others found the responses to pointing to be very weak or not existing at all (i.e. Povinelli et al. 1997). Furthermore, other animals like ravens,

which are not as closely related to humans as chimps, follow a person's gaze into distant space (Bugnyar and Heinrich 2006). Though, in the *object choice-task* ravens, unlike chimpanzees (i.e. Call et al. 2000; Barth et al. 2005), do not rely on gaze cues to detect hidden food (Schloegl et al. 2007), indicating an ill-conceived understanding of the social function of gaze.

Another important precursor of Theory of Mind is intention understanding. With a paradigm Gergely et al. (2002) first tested on preverbal infants, Buttelmann et al. (2007b) found that like human infants, chimpanzees imitated an irrational action (switching a light on with one's head) more often, when it seemed necessary (the model's hands were blocked) compared to when it appeared as an act of free choice. Thus, to some extent, great apes seem to understand the intentionality and rationality of others' actions.

For the concept of "seeing" in chimps, Povinelli and Vonk (2003) suggest a behaviouristic rather than a mentalistic interpretation, while researchers from Tomasello's lab (Tomasello et al. 2003) advocate the idea that some mental states, "seeing" among them, can be understood to some extent by chimps. Karin D'Arcy and Povinelli (2002) found that, though chimpanzees in competitive feeding situations approach hidden food more often, this was independent of whether the food was behind a barrier blocking the rival's view or behind a barrier but in clear sight of a rival. Their results support the idea that chimps, while having competitive strategies, do not reason about what their conspecifics see or do not see.

An experiment by Bugnyar and Heinrich (2005) adds to the discussion by showing that ravens were able to know what other birds, competing about food with them, had or had not seen. While the authors conclude that ravens are candidates for the concept "see," they stress that they cannot rule out the possibility that the animals might have learned about another bird's viewpoint in relation to its later competitive behavior through foraging. Thus, they do not infer a full-fledged mentalistic understanding in ravens.

In a clever series of two studies, Buttelmann et al. (2007a) investigated whether chimpanzees use facial, emotional cues to infer the core concept of desire. In the first experiment, great apes were found to base their food- choice on the experimenter's emotional expression. In the second experiment, the chimpanzees first saw the experimenter lifting a cup and expressing a corresponding emotion of liking or disgust towards its content. Subsequently the animals' view was blocked. Without having visual access as to which cup exactly the experimenter has lifted, the animals saw the happy-looking experimenter eating food out of one of the containers. After that the chimpanzees could choose one of the cups for themselves. Chimpanzees more often chose the cup the experimenter had expressed disgust towards, obviously inferring that this would be the one still containing food. Thus, chimpanzees seem to understand other's desires and based on that, can make some action predictions; in this case that the experimenter had eaten the food he desired. It is yet to be investigated whether chimpanzees understand the subjective quality of desires and, like 18-month-old human infants, differentiate between their own and another person's desire (Repacholi and Gopnik 1997).

Call and Tomasello (2008) recently reviewed 30 years of research and concluded that while chimpanzees can infer the goals and intentions of others and grasp the concepts of perception and knowledge, there is no evidence that they possess any false belief understanding comparable to humans. As a consequence, while Bartsch and Wellman (1995) have proposed a belief-desire-theory for human's Theory of Mind, they propose a perception-goal philosophy for the primate's understanding of the mental world.

The field of Theory of Mind will further emerge and seek input from other disciplines. While philosophers, neuroscientists and ethologists have jointly contributed to Theory of Mind research, robotics is a newly emerging area adding to the field. To build a humanoid robot that can participate in social interaction, scientists in robotics have to address the same issues as researchers of social cognition. The benefit could be bi-directional though. Scassellati (2002), who has performed research in this area at the MIT Artificial intelligence lab, points out several advantages of applying robotics as a tool for cognitive science. As an example, the validity and predictive powers of theoretical models of a Theory of Mind could be tested against each other by manipulating the robot in a controlled and detailed way, while maintaining the same setting and testing paradigms as with human subjects. By varying internal model parameters, one could systematically study environmental effects on each step of Theory of Mind development. Furthermore, a humanoid robot could be subjected to controversial testing, which would be unethical, expensive or too dangerous to perform on human subjects.

As a first step, Scassellati (2002) has discussed the module theories of Leslie (1994) and Baron-Cohen (1995) in the realms of robotics. More concretely, he has developed initial implementation details of basic mind reading skills in robots (e.g., tracking human faces and eyes and differentiating inanimate from animate objects). What thus unites researchers of infant social cognition and researchers constructing humanoid robots is that both fields are based on a careful conceptual analysis and profound theory building as prerequisites for critical empirical examinations.

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