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Nonverbal components of Theory of Mind in typical and atypical development

Dora Kampis*, Dóra Fogd, Ágnes Melinda Kovács

Department of Cognitive Science, Cognitive Development Center, Central European University, Budapest, Hungary

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ABSTRACT

To successfully navigate the human social world one needs to realize that behavior is guided by mental states such as goals and beliefs. Humans are highly proficient in using mental states to explain and predict their conspecific's behavior, which enables adjusting one's own behavior in online social interactions. Whereas according to recent studies even young infants seem to integrate others' beliefs into their own behavior, it is unclear what processes contribute to such competencies and how they may develop. Here we analyze a set of possible nonverbal components of theory of mind that may be involved in taking into account others' mental states, and discuss findings from typical and atypical development. To track an agent's belief one needs to (i) pay attention to agents that might be potential belief holders, and identify their focus of attention and their potential belief contents; (ii) keep track of their different experiences and their consequent beliefs, and (iii) to make behavioral predictions based on such beliefs. If an individual fails to predict an agent's behavior depending on the agent's beliefs, this may be due to a problem at any stage in the above processes. An analysis of the possible nonverbal processes contributing to belief tracking and their functioning in typical and atypical development aims to provide new insights into the possible mechanisms that make human social interactions uniquely rich.

Everyday social interactions, from communication to joint actions such as playing football require monitoring what other people see, know and believe. Although such inferences seem to be a basic characteristic of our adult interactions, it is unclear what cognitive systems are involved in these processes, how they mature, and whether young children are able to grasp others' intentional states with a facility that is similar to adults.

The fundamental capacity to infer other people's mental states is usually termed as Theory of Mind (ToM) or mentalizing. ToM enables us to represent others' goals, beliefs and intentions, to predict and interpret their actions based on these mental states, and to plan our own reactions accordingly. Importantly, human behavior is governed by what one believes about the reality, which may or may not coincide with the true state of affairs. Research from the last 30 years targeting the development of ToM has led to a systematic investigation of reasoning about others' false beliefs. Instances of unexpected location change (when an object initially seen in location A is moved to location B in absence of a protagonist; Wimmer & Perner, 1983) proved to be a good test case. In these so-called standard ToM tasks, until about the age of four, typically developing children fail to take into account the protagonist's false belief when asked to make a verbal prediction regarding the protagonist's actions. Based on such data it was proposed that in typically developing children ToM abilities emerge around the age of four (Wellman, Cross & Watson, 2001).

* Corresponding author.
E-mail address: kampis_dora@phd.ceu.edu (D. Kampis).

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Research from the last ten years seems to uncover a different picture regarding the development of ToM abilities. If we measure children's spontaneous responses (e.g., their looking patterns) instead of asking them direct questions about a protagonist's beliefs and her consequent behavior, even young infants show sensitivity to others' mental states. Infants as young as 15 months were found to expect a protagonist to search for an object at the location where she (falsely) believes it to be hidden (Onishi & Baillargeon, 2005). Following this finding, a paradigm shift took place, which entailed switching from 'explicit' tasks involving verbal reports to non-verbal or 'implicit' measures. These implicit measures have in common that they target behavioral or neural correlates of representing mental states. In infants, a frequently used measurement is comparing looking time patterns to expected and unexpected outcomes that do or do not match infants' expectations based on the beliefs they ascribe to someone. Other non-verbal or implicit tasks involve assessing anticipatory gaze, where participants' expectations (about what an actor might do based on her belief) are measured before the actual behavior takes place. Some tasks in turn involve more active measurements such as probing whether infants adjust their helping behavior depending on another person's belief (e.g., when a protagonist tries to retrieve an object from a location about which he has a false belief, infants retrieve the object for him from the correct location instead). Such implicit ToM measurements have at least two obvious advantages. First, they do not overtly prompt participants to reflect on others' mental states, and thus tap on mentalizing processes that are spontaneously triggered by social interactions. Second, they provide a better means to investigate social cognition in populations with limited linguistic abilities and less efficient executive control functioning. Implicit tasks, unlike the standard explicit ToM tasks, rely much less on such orthogonal capacities (Scott, He, Baillargeon, & Cummins, 2012).

The implicit-explicit distinction is at the core of recent two-system proposals of ToM, which assume that only the explicit system involves representing others' mental states, and the implicit system relies on encoding simple object-agent-location relations (Apperly & Butterfill, 2009; Rakoczy, 2012). However, there are reasons to assume that implicit and explicit mentalizing rely on the same core mechanisms. Recent neuroimaging evidence suggests that implicit and explicit inferences about other people's traits activate the same mentalizing areas, and ERP studies reveal that goal and trait inferences triggered by implicit and explicit instructions have a similar early timing (for a review see Van Overwalle & Vandekerckhove, 2013). With regard to inferences in belief reasoning, neuroimaging data (involving fMRI, Kovács, Kühn, Gergely, Csibra, & Brass, 2014; or NIRS, Hyde, Betancourt, & Simon, 2015) suggest that the temporo-parietal junction that is regularly involved in explicit tasks is also activated during implicit belief processing.

In the present paper we will use this latter, unitary view of ToM as starting point. Although we will focus on processes involved in implicit mentalizing, we believe that these core processes are likely common between implicit and explicit ToM. We aim to provide a fine-grained analysis of ToM and discuss three sets of component processes that may capture different steps involved in mentalizing (see also Kovács, 2015 for a different analysis). In such an approach explicit access to mental state representations can be considered as one of the final steps involved in ascribing a mental state to another agent. Crucially, failure on a ToM task can therefore result from a problem at one (or more) of the preceding stages.

In the following parts we will examine three sets of processes contributing to ToM reasoning. In this analysis, we will address only those aspects of ToM that entail understanding others' epistemic states, specifically belief reasoning, as a case study. Other kinds of mental states, such as emotional states, are outside the scope of the present inquiry. We will target mechanisms that can be tackled using implicit, non-verbal measures investigating inferences about what other agents see, know or believe. First, we will focus on studies that investigate how infants identify social agents and their focus of attention. Preference for biological motion and face-like configurations, and spontaneous gaze following are fundamental capacities that guide our attention to relevant aspects of the physical and social world from early on. These capacities enable us to detect *potential* mental state holders and *potential* mental state contents. The processes discussed in this initial part do not entail mental state attributions *per se,* nevertheless their early onset and intact and efficient functioning may play an important role in successful mentalization. Second, we will discuss processes that likely build on the ability to detect potential mental state holders and mental state contents, and that result in forming and sustaining representations of others' beliefs. Finally, successful mentalization also entails a third set of processes involved in integrating the represented mental states into inferential schemas that allow to predict others' actions and to modify our own behavior accordingly. We will discuss how these three sets of processes develop, and how they might build upon each other.

In addition to reviewing studies targeting these non-verbal ToM components in typical development, we will discuss findings from atypical development suggesting that some of these processes may function differently. Specific aspects of social cognition, in particular explicit Theory of Mind performance has been found to be impaired in certain populations, as children with various neurodevelopmental disorders often show lower performance on the verbal ToM tasks than their typically developing peers. For instance, children with autism spectrum disorder (ASD) seem to have problems with such tasks even at a much later age compared to typically developing children; a performance that was taken as a core signature for specific social deficits (Baron-Cohen, Leslie, Frith, 1985; Leslie & Frith, 1988). ASD is a neurodevelopmental disorder characterized by severe and persistent deficits in reciprocal social interactions and social communication, as well as mild to profound intellectual disability in approximately half of the individuals (American Psychiatric Association, 2013). Difficulties on explicit ToM tasks were also found in children with Williams syndrome (Tager-Flusberg & Sullivan, 2000; Van Herwegen, Dimitriou &, Rundblad, 2013), a genetic disorder entailing relatively spared linguistic capacities and excessive sociability on the one hand, but severe impairment in visuo-spatial abilities, a general intellectual disability, and difficulties in social interactions and pragmatic use of language on the other hand (Martens, Wilson, & Reutens, 2008).

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Children with other neurodevelopmental disorders, such as Prader-Willi syndrome or Fragile X syndrome also display lower performance on verbal ToM tasks than typically developing controls (Cornish et al., 2005; Lo, Siemensma, Collin & Hokken-Koelega, 2013). Fragile X syndrome is a heritable intellectual disability, which is accompanied by attentional deficits, hyperactivity and elevated social anxiety, manifested for example in avoidance of eye contact and unusual social behavior (Cornish, Sudhalter & Turk, 2004; Lesniak-Karpiak, Mazzocco, & Ross, 2003). Prader-Willi syndrome is a genetic disorder characterized by mild to moderate intellectual disability, disruptive behavior and disturbed social relations (Dykens & Kasari, 1997; Jauregi, Laurier, Copet, Tauber, & Thuilleaux, 2013). Although some aspects of social cognition appear to be affected in both Prader-Willi and Fragile X syndrome, studies targeting ToM abilities in these populations usually rely on explicit verbal measurements that are outside the scope of the present analysis. Furthermore, it is unclear what conclusions could be drawn from these explicit or verbal ToM tasks given the potentially limited linguistic or executive control abilities observed in these populations (Cornish et al., 2004; Rhodes, Riby, Fraser, & Campbell, 2011; Russo et al., 2007) might mask their underlying abilities. The majority of the studies, which investigated ToM in atypical development measuring nonverbal or spontaneous responses targeted ASD or Williams syndrome. Thus, in the following parts we will mainly focus on findings from these two populations.

Targeting the non-verbal assessments of the components of Theory of Mind enables us to investigate social cognition in typically developing infants and children, as well as children with neurodevelopmental disorders. An analysis of the steps contributing to mentalizing might help to better understand the development of such capacities, as well as the underlying causes of the social deficits observable in specific populations. Identifying differential functioning of one or more of these capacities in atypical development, in turn, can give us insights about how these processes may function, interact and build upon each other.

1. Identifying potential mental state holders and mental state contents

Theory of Mind traditionally refers to the capacity to ascribe mental states to others with certain contents (e.g. Sally believes her toy is in box A). To form such representations, it is essential to identify (1) who might be a potential mental state holder, and (2) what are the potential mental state contents. Not surprisingly, the potential mental state holders are social agents, and thus a fast identification and special attention to agents also implies special attention to mental state holders. Hence, in rather simplistic terms, tracking potential mental state holders may emerge ‘for free’ from processes that direct humans’ attention to other social agents. We don’t aim to fully cover the ways through which agents may be detected, as the goal of the present section is to highlight that detecting mental state holders and contents can be seen as part of the mentalizing process and their disrupted functioning might impair mental state attribution.

1.1. Detecting agents (potential mental state holders)

Detecting potential mental state holders can be achieved in different ways, such as looking for agents that are ‘like us’ (i.e., other people; Meltzoff, 1995) or identifying agents based on their specific characteristics, such as biological motion (Schlottmann & Ray, 2010), contingent reactivity (Deligianni, Senju, Gergely, & Csibra, 2011), internal source of energy (Leslie, 1994), or rational goal-directed behavior (Király & Gergely, 2003).

As most agents relevant to us are humans, paying special attention to other people can be of crucial importance. Indeed, even neonates show signs of preference for face-like configurations (Johnson, Dziurawiec, Ellis, & Morton, 1991; Hoehl & Peykarjou, 2012), enabling them to allocate attention to people around them. In contrast to typically developing children, children with autism spectrum disorder (ASD) do not seem to prefer faces to non-social stimuli (Wilson, Brock & Palermo, 2010), although some studies find this only with non-social stimuli from the specific areas of interests often found in autism (such as vehicles or clocks; Sasson & Touchstone, 2014). Findings regarding face recognition abilities in ASD are mixed, overall pointing to a specific deficit in utilizing the eye-region for the discrimination of faces rather than a general impairment (Weigelt, Koldewyn, & Kanwisher, 2012). In line with this, some authors have found that children with ASD have a tendency to look more at the mouth of people rather than their eyes (Klin, Jones, Schultz, Volkmar, & Cohen, 2002), which seems to be related to their social-communicative impairments (Falck-Ytter, Fernell, Gillberg, & von Hofsten, 2010). Individuals with Fragile X syndrome also fixate significantly less to the eye and face-regions of people than age-matched typically developing controls, and show a decreased activation in response to faces in the those face-processing related brain regions that are also associated with social cognition (Holsen, Dalton, Johnstone, & Davidson, 2008).

In contrast, individuals with Williams syndrome have been shown to allocate higher amount of attention to faces and the eye region than controls when watching events involving people (Riby & Hancock, 2009; Porter, Shaw, & Marsh, 2010; but see: Hanley, Riby, Caswell, Rooney, Back, 2013 for an opposite pattern of results). Although individuals with Williams syndrome seem to have relatively spared face-processing abilities, e.g. they score in the normal range on standard tests of face-recognition (Bellugi, Lichtenberger, Jones, Lai, & St George, 2000); behavioral (Karmiloff-Smith et al., 2004) and electrophysiological studies (Mills et al., 2000) suggest that they rely on atypical face processing strategies. Evidence from infants with Williams syndrome who show a decreased face inversion effect also supports this possibility (D’Souza et al., 2015).

Detecting faces is not the only way to identify potential mental state holders, as humans can ascribe mental states not only to other people but also to a variety of other entities such as geometrical shapes (Heider & Simmel, 1944). One could identify

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agents through detecting biological motion, i.e. the configural invariants of living beings and their produced movements. A selective visual preference for upright biological motion can be observed right after birth (Simion, Regolin, & Bulf, 2008). This preference can increase the chance to gain experience with entities that qualify as mental state holders (even without recognizing them as such) that can, in turn, enable an early detection of potential mental state contents.

In contrast to typically developing infants, children with ASD seem to be less sensitive to cues that characterize agents. They often display a lower performance on tasks requiring detection of biological motion (Blake, Turner, Smoski, Pozdol, & Stone, 2003; but see Moore, Hobson, & Lee, 1997), and unlike typically developing children they do not prefer to look at intact biological motion compared to phase-scrambled motion (Annaz, Campbell, Coleman, Milne, & Swettenham, 2012). Such differences can be observed even in 2-year-old toddlers with ASD, who display no preference for upright compared to inverted motion of point-light agents (Klin, Lin, Gorrindo, Ramsay, & Jones, 2009). Furthermore, although typically developing 14- to 42-month-olds prefer social stimuli to geometric images, toddlers with ASD show the opposite pattern, which was found to be predictive of a later ASD diagnosis (Pierce, Conant, Hazin, Stoner, & Desmond, 2011). Adults with high-functioning autism (HFA) are often found to show comparable performance to controls on tasks that require identification of biological motion (Murphy, Brady, Fitzgerald, & Troje, 2009, but see Kaiser, Delmolino, Tanaka, & Shiffrar, 2010). However, despite the similar performance, individuals with HFA show different neural signatures in such tasks (McKay et al., 2012).

Other atypical populations do not seem to display such differences in how they perceive biological motion. For instance, in contrast to children with ASD, children and adolescents with Williams syndrome demonstrate intact (Reiss, Hoffman, & Landau, 2005) or even superior biological motion perception capacities (Jordan, Reiss, Hoffman, & Landau, 2002), despite being impaired in their general ability to detect form-from-motion. These findings are in line with the view that some social-perceptual aspects of social cognition are preserved in Williams syndrome (Tager-Flusberg & Sullivan, 2000).

Detecting potential mental state-holders can be considered the first step that might later lead to mental state representations. A reduced preference for biological motion and face like configurations, in turn, could result in less attention to social agents, which could lead to less efficient tracking of their mental states discussed in the following sections. Such differences might be the starting point of – or at least one factor contributing to – the social deficits observed in atypical development.

1.2. Detecting what agents attend to (potential mental state contents)

Besides a preferential attention to agents (who happen to be potential mental state-holders), one should also be able to follow social agents' focus of attention and infer what they may see, in order to be able to figure out which aspects of the environment they may have mental states about. Following a person's gaze, or engaging in joint attention with her enables us to know what she can – and is likely to – attend to, and thus form a representation of. If one fails to encode the target of attention of a social partner, she will inevitably fail to ascribe mental states about that object to that person. Next we will discuss processes that can play a role in identifying others' focus of attention.

Humans seem to be extremely sensitive to the gaze of their conspecifics and the potential information it may carry. Even neonates prefer to look at faces with direct gaze compared to averted gaze (Farroni, Csibra, Simion, & Johnson, 2002). At 9–10 months infants follow gaze reliably (Corkum & Moore, 1995) and expect gaze shifts to be referential (i.e., directed at objects in the environment; Senju, Csibra & Johnson, 2008).

Some aspects of gaze processing appear to be preserved in individuals with ASD. According to a recent review children with ASD can accurately judge eye-gaze direction, they are sensitive to whether someone is looking at them (Itier & Batty, 2009), and follow gaze automatically (Pruett et al., 2011; but see Gillespie-Lynch, Elias, Escudero, Hutman, & Johnson, 2013 for lower performance in younger, 2 to 6-year-old children).

However, there are reasons to believe that individuals with autism may process eye-gaze differently from typically developing children, analogously to the differences observed in processing biological motion. Whereas typically developing children detect direct gaze faster than averted gaze, children with ASD are equally fast for both (Senju, Yaguchi, Tojo, & Hasegawa, 2003). Further, in typical populations directional social stimuli (gaze cuing) result in orienting even if participants voluntarily try to refrain from it, as opposed to non-social directional cues (arrows) (Langton & Bruce, 1999). However, in children with autism such directional social stimuli do not have a distinct effect (Senju, Tojo, Dairoku, & Hasegawa 2004). In line with this, brain regions that were found to be related to detecting averted gaze in the typically developing group, showed similar activation in response to arrows in children with ASD (Vaidya et al., 2011). These findings suggest that individuals with ASD may process gaze differently from their typically developing peers, which could either be a result, or a cause of a decreased appreciation of the referential aspect of gaze.

Despite a possibly higher attention to the eye region discussed earlier, individuals with Williams syndrome are less accurate in judging eye-gaze direction (Mobbs et al., 2004) and in identifying the target of other agents' attention, as indexed by fewer gaze-shifts to the location where an agent is looking (Riby, Hancock, Jones, & Hanley, 2013). To explain such findings, it has been proposed that in Williams syndrome the difficulty to focus on the relevant objects in a situation (and thus correctly interpret gaze cues) could be related to problems with disengagement from faces (Riby & Hancock, 2009). Alternatively, difficulties in judging gaze direction might stem from impairment in visuo-spatial cognition that is well documented in Williams syndrome (Martens et al., 2008). This latter possibility is supported by findings indicating atypical neural activation during gaze processing in the brain regions associated with visual cognition (Mobbs et al., 2004). In addition, preschool aged children with Williams syndrome are less successful in using gaze cues to infer the location of a hidden object (John & Mervis, 2010) than typically developing infants at 18 months of age (Behne, Carpenter, & Tomasello, 2005). Based

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on this, it was proposed that children with Williams syndrome might have difficulties in understanding the communicative intent behind gaze cues (John & Mervis, 2010). Atypical gaze processing has been also found in other neurodevelopmental disorders, such as Fragile X syndrome. Children and adults with Fragile X show decreased accuracy in judging the direction of gaze compared with age-matched controls, and show different brain activation patterns during these tasks, compared to typically developing participants (Garrett, Menon, MacKenzie, & Reiss, 2004).

In sum, although in typically developing children the ability to detect and follow gaze develops early and is mastered quite well, children with atypical developmental pathways diverge in their behavior from their peers. In typical populations eye gaze is treated as a distinguished cue for detecting socially relevant targets in the environment, however, in participants with autism it seems to be treated as just one of many directional cues. If an individual with autism does not note to which object another person's gaze is directed at, this could influence the efficient tracking of others' mental state contents. Similarly, atypical gaze processing in children with Williams syndrome or Fragile X syndrome may lead to less efficient tracking of others' mental states in a given situation.

Infants' sensitivity to object-directed gaze, and joint attention, specifically attending to an object together with a person and checking back and forth between the object and the person's face, emerge roughly at the same age (Carpenter, Nagell, Tomasello, Butterworth, & Moore, 1998); and both have been suggested to be the basis of human social learning (Tomasello, Carpenter, Call, Behne, & Moll, 2005), and precursor to ToM (Baron-Cohen & Ring, 1994). In line with this, joint attention around 1.5 years was found to be associated with explicit ToM abilities at the age of four (Charman et al., 2000). In consequence, the findings discussed in this section concerning gaze following abilities may be related to some of the fundamental building blocks of mentalizing and the differential functioning of these capacities could therefore affect the efficient tracking of others' mental states.

2. Representing others' visual perspective and mental states

So far we have focused on processes that may be involved in detecting aspects of one's social and physical environment necessary for forming representations about other agents' mental states. Crucially, whereas the abilities to identify *potential* mental state holders (agents) and *potential* mental state contents (e.g. objects or events) are needed to represent certain objects or events *as the content* of the agent's mental state and *as attributed to the agent*, the latter are consequences of a further processing step. In other words, we cannot represent others' beliefs without detecting agents and what they might attend to; but we can represent these agents and the objects they attend to without attributing them a belief-representation about these objects.

Once one can identify an agent and the target of her attention, one will be able to calculate her mental representations. Infants seem to understand that others' visual perspective influences their respective behavior from their first year. At 6 months they interpret an agent's reaching as a preferential choice depending on the agent's visual access (Luo & Johnson, 2009), and at 12 months they understand that an agent's referential communication can be mistaken if her visual access is blocked (Sodian & Thoermer, 2004).

Spontaneously taking the visuo-spatial perspective of an agent and representing *whether* someone can see an object (Level-1 perspective taking; Flavell, Everett, Croft, & Flavell, 1981) seems to be present in early infancy and is intact in adults with ASD (Schwarzkopf, Schilbach, Vogeley, & Timmermans, 2014; Zwickel, White, Coniston, Senju, & Frith, 2011). However, Level-2 perspective taking (i.e., representing *how* someone sees an object) was proposed to rely on more sophisticated processes and to emerge later in development. By the age of three, typically developing children can compute another person's visual perspective in a Level-2 task, yet comparing the other's perspective to their own is still challenging (Moll, Meltzoff, Merzsch, & Tomasello, 2012). School-aged children with ASD have difficulties on tasks where they have to select the correct picture which fits the viewpoint of a doll, placed in different positions around a turntable compared to language matched, much younger typically developing controls (Hamilton, Brindley, & Frith, 2009). Adults with Williams syndrome also demonstrate difficulties when they have to judge how an array of objects appears from a different, imagined viewpoint (Broadbent, Farrant & Tolmie, 2014). Some studies have argued that such problems in visual perspective taking in Williams syndrome have an independent developmental trajectory from the difficulties they have in other spatial tasks such as mental rotation (Hirai et al., 2013). Other studies however have found that even when individuals with Williams syndrome performed similarly to their chronological-age matched peers in a visual perspective taking task, their performance was predicted by their scores on a mental rotation task, whereas that of typically developing children was predicted by a task involving body posture judgments (Pearson, Marsh, Ropar, & Hamilton, 2015). This again points to the possibility that similar performance in such tasks might be achieved through different strategies in typically and atypically developing populations.

One way to characterize visual perspective taking is detecting the 'line of sight' of a person, specifically determining whether there are obstacles between the person and an object, which does not necessarily involve ascribing a mental content to the agent. However, an interference effect observed in situations when the other person's visual perspective and one's own perspective differs (Samson, Apperly, Braithwaite, & Andrews, 2010) can only be explained by a competition between two representations: the representation of what the agent sees and one's own representation. Therefore, representing what an agent sees should be considered as mental state ascription: it entails attributing to the agent a representation about the reality. In accordance with this, recent neurophysiological evidence suggests that 8-month-old infants display the same neural signatures when they themselves represent the continued existence of an occluded object, and crucially, also when they could attribute such representations to another person (Kampis, Parise, Csibra & Kovács, 2015).

Assessing whether a child can attribute a representation to another agent about the true state of affairs (i.e., true beliefs), however, is challenging because in such cases the child's own reality representation matches a potentially ascribed mental content (Dennett, 1978). To overcome this challenge, the false belief tasks were developed. Research involving various versions of this task has shown that at 1.5-2-year-old infants anticipate the location where an agent will search based on her false belief (Southgate, Senju, & Csibra, 2007), around one year of age they look longer (reflecting their surprise) if an agent acts inconsistently with her beliefs (Onishi & Baillargeon, 2005; Surian, Caldi, & Sperber, 2007), and even at 7 months their reactions are influenced by another agent's beliefs (Kovács, Téglás, & Endress, 2010). Such results indicate that young infants represent the other agent's mental states (most typically beliefs, but see Luo, 2011, for preference attribution based on the person's belief in 10-month-olds).

Unlike typically developing infants, 6-to–8 year old children with ASD and adults with Asperger syndrome do not seem to spontaneously anticipate others' actions based on their false beliefs (Senju et al., 2010; Senju, Southgate, White & Frith, 2009). Recently, using the anticipatory looking paradigm of Southgate et al. (2007), it was found that 3-year-old siblings of children with ASD do not show such false belief based anticipations either, independently from their later diagnosis, pointing to possible genetic bases for such differential functioning (Gliga et al., 2014).

Although nonverbal paradigms aim to capture early ToM abilities in an intuitive way, most of these studies have targeted the participant's behavior in the observer's position. According to a recent proposal a challenge to the early mentalizing capacities is whether infants can inferentially integrate these mental state representations (Rakoczy, 2012) and modify their spontaneous behavior accordingly. Whereas the paradigms targeting looking time or anticipatory looking behavior already seem to suggest that belief-representations are integrated into infants' predictions regarding others' actions, in the next section we will discuss studies that target how these are reflected in children's active behavior and are used in social interactions.

3. Mental state representations and their role in social interactions

The ability to represent others' mental states has various functions from understanding to solving coordination/cooperation problems of varying complexity, and learning to navigate in the social world (Tomasello, 2008). The benefits of being able to ascribe mental states would be restricted if we could not utilize them when interacting with others (Liszkowski, 2013), although these interactions can also be seen as a trigger for belief computation and not only as their 'output' or implementation.

Infants not only show an understanding of others' goals and beliefs, they also incorporate these into their behavior and react to initiations of interactions accordingly. There is a set of convincing evidence showing that 12-month-olds are able to correctly infer the referential intention of an adult. For instance, they assume that an adult is likely to point at (and request) an object she has previously interacted with (Liszkowski, Carpenter, Striano, & Tomasello, 2006).

Other studies suggest that 17-month-olds respond to object requests according to the person's belief: they retrieve the object from the correct, rather than the pointed-to location when the agent has a false belief about the location of the object (Southgate, Chevalier, & Csibra, 2010). Similarly, if a person is looking for an object she has put in one of two boxes, 18-month-olds respond to this person's request for help based on what she believes about the boxes; they open the box that actually contains the object, rather the one she tries to open, if she has not seen the location swap (Buttelmann, Carpenter, & Tomasello, 2009). Similar helping behavior dependent on the protagonist's belief was observed in an unexpected-identity task as well (Buttelmann, Suhrke, & Buttelmann, 2015). Furthermore, 18-month-old infants anticipate another person's actions based on her false beliefs and point to correct her belief even before she initiates her action (Knudsen & Liszkowski, 2012).

In contrast to the findings that young infants seem extremely efficient in tracking other's beliefs in such situations, in some cases even adults show difficulties in inferring the intended referent of an agent's requests (Keysar, Lin, & Barr, 2003). Children with ASD perform similarly to controls on such tasks (Begeer, Malle, Nieuwland, & Keysar 2010), and they can also distinguish knowledgeable from ignorant partners in a competitive context even though they fail the standard false-belief tasks (Peterson, Slaughter, Peterson & Premack, 2013). Yet when they need to initiate interactions, children with ASD perform worse if they need to warn a confederate that she has a mistaken belief about the situation (Begeer, Rieffe, Meerum Terwogt, & Stockmann, 2003), and demonstrate fewer attempts to re-engage the partner in a joint activity (Liebal, Colombi, Rogers, Warneken, & Tomasello, 2008). This suggests that, some aspects of these abilities are present in children with ASD: when prompted to make a decision, they know whether a partner has sufficient knowledge in a situation and they respond to a request appropriately. However, they do not seem to initiate cooperative actions unless asked to do so. This is in line with findings showing lack of spontaneous belief ascription but successful performance on some explicit tasks: it is possible that individuals with ASD can use alternative routes to make inferences about others' beliefs and knowledge, but do not do so spontaneously (Senju et al., 2009).

Social interactions are the driving force and one of the most substantial outcome of tracking others' mental states. Even very young infants seem to successfully participate in interactions that rely on mentalizing abilities, but specific situations requiring the initiation of interactions or explicit pondering of others' beliefs might posit a challenge to atypical populations and even to healthy participants.

4. Concluding remarks

In the present paper we aimed to analyze specific processes that contribute to successful mentalization. We have focused on processes involved in: (1) identifying potential mental state-holders and mental state contents, (2) representing others' mental states, (3) using such mental states in interactions; and discussed their functioning in typical and atypical development. We believe that success on the tasks discussed in the last section clearly implies that infants can attribute mental states to others. However, failures are less informative. If a child underperforms on such a task, this could be due to several reasons, such as failing to pay sufficient attention to the agent, failing to identify her target of attention or simply not being able or motivated (Chevallier, Kohls, Troiani, Brodkin, & Schultz, 2012) to integrate the other person's mental state in a behavioral prediction.

Other than the processes described here, there might be other sub-components that could posit a challenge on some populations. For instance, it is an open question how the relationship between an agent and their corresponding mental state is represented. There is recent evidence suggesting that infants might not always bind the mental state content to a specific agent (Kampis, Somogyi, Itakura, & Király, 2013), rather encode the agent as an 'agent-placeholder'. Similarly, the exact content of the mental states might not always be specified (only that the agent holds *some* belief – an 'empty' belief file), and could be added later when relevant information is encountered (Kovács, 2015). Furthermore, some kinds of belief contents might be represented differently than others. This possibility is supported by recent fMRI evidence, showing differential activation of the right temporo-parietal junction – a region crucial to mental state computation – during tracking of beliefs about the presence, but not the absence of an object (Kovács et al., 2014).

Looking at Theory of Mind through its different components has various advantages. First, one does not need to conceptualize ToM as an all-or-nothing ability incorporated into two separate (implicit and explicit) systems and relying on different representations. Rather, these two might build on the outcome of the same process that involves the components discussed in the present paper. Therefore what could differentiate between the two is that implicit access to mental state representations might be faster (and read out more simplified information) and might emerge earlier, whereas explicit access to such representations would be dependent on the development of language, metacognition, and communication. Second, from this viewpoint the contradictory findings on different verbal and nonverbal tasks – present both in typical and atypical populations – become consequences of the different demands of accessing and retrieving the same belief-representations. Finally, such a conceptualization of ToM processes enables a systematic investigation of the possible problems underlying the social difficulties of atypical populations, which in turn informs us about the cognitive mechanisms underlying Theory of Mind, and possibly leads to a deeper understanding of the scopes and limits of ToM capacities in humans.

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