Social cognitive and interactive abilities in autism

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Abstract: Autism is a neurodevelopmental condition characterized by difficulties in social perception, cognition, and interaction. Differences to non-autistic peers start appearing early in development and are associated with altered brain structure and functioning. This chapter begins with an overview of research on theory of mind and empathy, discussing how skills in these domains present in high-functioning autism. Findings indicate that, across development, a sizable portion of autistic people learns to compensate for specific difficulties. Yet, challenges in social interaction continue to impact their level of functioning in everyday life throughout adulthood. We describe how research has attempted to introduce more interactive experimental settings, and how this interactive turn has improved our understanding of autism in contexts closer related to real life. Finally, we discuss the Bayesian brain account of autism as a computational framework that explains social difficulties in terms of domain-general perceptual, cognitive, and biological mechanisms. We conclude by pointing to recent developments such as participatory research and the mining of larger longitudinal datasets as ways to make autism research more effective in improving autistic people's lives.

Keywords: autism, social cognition, social interaction, second-person neuroscience, mentalizing, empathy, Bayesian brain

Introduction

Autism spectrum disorder, henceforth referred to as autism in this chapter, is a neurodevelopmental condition. One of its hallmarks are difficulties in social cognition and interaction. Social cognitive abilities can be described as a set of skills that help us process other people's intentions, emotions, and more generally, mental states in order to understand their behavior. A wealth of experimental research has documented social processing difficulties in autism. Early on in development, autistic children lag behind age-matched peers in mastering abilities such as inferring others' mental states (Baron-Cohen, Leslie, and Frith, 1985; Senju et al., 2010) or following others' eye gaze (Charman, 2003). These differences can also be related to differences in brain structure and function (Hazlett et al., 2017), and may partially be compensated for across development (e.g., White et al., 2009). Despite these compensatory developments, autism is known as a lifelong condition. Many aspects of social functioning continue to be affected throughout adulthood and detrimentally impact quality of life in important ways (Kim and Bottema-Beutel, 2019). It has been questioned whether traditional ways of studying social cognitive abilities can succeed in explaining the difficulties autistic people face in everyday life. Crucially, real life requires the use of social abilities in an interactive context, in which we do not only have to process, but also quickly adapt to the social information available (Schilbach et al., 2012; Schilbach et al., 2013). This has brought about an interactive turn, shifting focus from individual cognition to interacting minds (cf. Frith and Frith, 1999; Schilbach, 2016; 2019). Resulting two-person accounts of autism research have strived to capture what happens when autistic people interact with other, autistic and non-autistic, people (Redcay and Schilbach, 2019). Another challenge in autism research has been to explain social difficulties within a more unified framework of the autistic brain. Here, the Bayesian brain account represents a novel attempt of relating social and nonsocial characteristics of autism to more general aspects of autistic perception (e.g., Bolis et al., 2017).

This chapter gives an overview of the theoretical frameworks and research findings that explain social interactive aspects of autism. Its focus lies on autism with no accompanying intellectual disability, often referred to as so-called high-functioning autism. First, we give a brief introduction to longstanding research on theory of mind. In the next section, we focus on different aspects of empathy. The third section of this chapter describes how social abilities can be studied in a more interactive context. The last section introduces the Bayesian brain account of autism. Finally, we outline several more recent developments in autism research that may shape the following decades.

Theory of Mind in Autism

Early attempts of explaining social cognitive difficulties in autism have focused on the question whether autistic children have a theory of mind (TOM). TOM, also referred to as mentalizing, describes the ability to cognize about own and others' mental states (cf. Premack and Woodruff, 1978). In acquiring a TOM, children gradually become aware how behavior is shaped by beliefs, intentions, and emotions. They learn to infer these states in others, and to predict how others behave on the basis of their inferences. An early indicator of TOM is children's awareness of others' false beliefs. Typically, developing children gradually improve their false belief understanding between 2.5 and 5 years of age, and are able to recognize that someone's thoughts deviate from the actual state of the world when they are 4–5 years old (see meta-analysis including more than 4000 children by Wellman, Cross, and Watson, 2001).

Autism and TOM: Evidence from Behavioral Studies

The first study with autistic children pointed to profound differences in their TOM development. Baron-Cohen and colleagues (1985) observed that 80% of autistic children ($n = 20$, mean age: 12 years) failed the so-called Sally-Anne-task, an explicit test of false belief understanding that at least 85% of children with Down's syndrome ($n = 14$, mean age: 11 years) and non-autistic children ($n = 27$, mean age: 4.5 years) could solve. Their findings inspired the mindblindness hypothesis, which proposes that autistic people show social and communicative difficulties due to a failure of attributing mental states to others (Baron-Cohen, 1995; Frith, 2001). Since then a number of findings has emerged confirming that autistic children are delayed in their development of a TOM (discussed in Baron-Cohen 2000; Happé, 1995). Although these delays are also seen in children and adolescents with high-functioning autism, verbal intelligence seems to counteract mentalizing difficulties. When autistic children reach a certain level of verbal skills, many of them manage to solve first-order false belief tasks (e.g., Happé, 1995; White et al., 2009). This may indicate an important confound, in that even children with preserved TOM abilities could fail at explicit tasks because they do not understand the words used.

There is mixed evidence on whether TOM abilities of autistic people continue to be affected in adulthood. One hypothesis is that autistic adults do struggle with more complex, or advanced, forms of TOM. Examples of complex TOM include the understanding of ambiguous, nonliteral remarks, sarcasm, and second-order TOM. Second-order false beliefs require inferences about mental states that address the mental state of a third person, e.g., he

falsely believes that she thinks. A study employing the Strange Stories task observed that autistic adults ($n = 18$) performed worse than non-autistic children and adults ($n = 49$) in finding appropriate explanations for other people's ambiguous statements (Happé, 1994; replicated by Jolliffe and Baron-Cohen, 1999). This was contradicted in a later study, finding no differences between autistic and non-autistic adults ($N = 38$) in a short form of the Strange Stories task, despite group differences at inferring thoughts and feelings in dynamic videotaped interactions (Ponnet et al. 2004). In a study with 63 children and 80 adults, autistic children performed worse at understanding stories conveying first- and second-order false beliefs, whereas autistic adults only showed difficulties with second-order false beliefs (White et al., 2009). However, a large study on children and adolescents ($N = 254$) did not observe any differences between autistic and non-autistic groups in the understanding of social stories requiring second-order TOM, comprehension of sarcasm and other advanced forms of TOM (Scheeren et al., 2013). In line with previous findings, Scheeren and colleagues observed that advanced TOM skills were associated with verbal abilities. This indicates that also the assessment of complex TOM may be confounded by differences in verbal abilities.

It has also been proposed that autistic people may struggle more with implicit rather than explicit mentalizing (e.g., Senju et al., 2009; for a detailed discussion of evidence see Sodian et al., 2015). This hypothesis argues that autistic people can learn to compensate for their explicit mentalizing difficulties, and that using compensatory strategies later allows them to infer others' mental states in a conscious and deliberate manner similar to how non-autistic persons may solve a math problem. However, compensatory strategies still fall short of permitting implicit inferences during spontaneous communication and interaction. This account is interesting in that it might explain why autistic people often succeed in TOM tasks despite experiencing difficulties in understanding others' intentions in real life. In a first, seminal study testing this account, Senju and colleagues (2009) tracked eye gaze of autistic ($n = 17$) and non-autistic ($n = 19$) adults during a nonverbal false belief task. They observed that non-autistic adults engaged in unprompted behavior that is typical for these situations: they spent more time looking at the correct solution. Autistic participants, on the other hand, showed no looking bias toward either solution. Intriguingly, no group differences were observed in an explicit version of this false belief task. These findings support the notion that autistic adults do not spontaneously infer others' mental states to anticipate their behavior. In another study, Senju and colleagues (2010) found evidence suggesting that this difference is already present at an early age. In contrast to their non-autistic peers ($n = 17$), autistic children ($n = 12$) with a mean age of 8 years did not display a looking bias indicative of spontaneous

false belief attribution, and also performed worse in an explicit false belief task. However, studies have raised doubts on the methods used to measure implicit TOM. For instance, a recent replication study could not replicate original results of four anticipatory-looking tasks (Kulke et al., 2018). Crucially, this failed replication also concerned the task used by Senju and colleagues (2009, 2010). Thus, answering the question of whether autistic people have greater difficulties with implicit TOM, will first require further advances in capturing implicit TOM.

Although not all studies discussed previously suggest universal TOM difficulties, a recent meta-analysis on social and nonsocial cognitive functioning in autism does indicate that TOM difficulties count as one of the most consistent research findings (Velikonja, Fett, and Velthorst, 2019). According to this analysis, autistic adults display the largest difficulties in studies of TOM ($n = 39$) and emotion processing ($n = 18$), with respective Hedges g estimates of -1.09 and -0.80.

Mentalizing and the Brain: The TOM Network

Neuroimaging studies assessing brain activation during TOM tasks have observed a pattern of involved regions that are typically referred to as the TOM, or mentalizing, network. The main hubs of this network are considered the medial prefrontal cortex (MPFC), bilateral superior temporal sulcus (STS), bilateral temporoparietal junction (TPJ), as well as a region spanning precuneus and posterior cingulate cortex (see reviews by Carrington and Bailey, 2009; Abu-Akel and Shamay-Tsoory, 2011). The relative involvement of these regions depends on what types and components of TOM are assessed. For instance, the TPJ seems to be particularly important for processing false beliefs (e.g., Saxe and Kanwisher, 2003) and is believed to have a role in distinguishing own and others' mental states. Abu-Akel and Shamay-Tsoory (2011) further contrast affective and cognitive TOM, considering dorsolateral prefrontal cortex and striatum as two contributing areas involved in executive and affective components of TOM, respectively. There is evidence that also processes considered "precursors" of TOM, such as pupil mimicry of an interaction partner (Prochazkova et al., 2018) and participation in gaze-based social interaction engage the TOM network (Redcay and Schilbach, 2019).

TOM and Brain Development

Development of TOM is connected to continuous functional and structural development of the brain. A recent study presented children ($n = 122$) and adults ($n = 33$) with movie scenes depicting others' mental versus bodily states (Richardson et al., 2018). Already, at the age of 3 years, mental and bodily state scenes distinctly engaged the TOM network and the pain network. Interestingly, this functional specialization of the two networks could also be seen in

children who still failed false-belief tasks. From ages 3–12, and with continuous TOM maturation, the two networks became increasingly anticorrelated.

Brain development in autism is altered early on, with studies detecting differences to typically developing peers within the first 2 years of life (for review of evidence see Lainhart, 2015). A compelling study of 148 infants with high and low familial risk of autism observed that those diagnosed with autism at 24 months showed higher brain volume overgrowth between 12 and 24 months (Hazlett et al., 2017). Brain volume overgrowth at that age was also associated with higher scores in the autism diagnostic observation schedule (ADOS) and in the communication and symbolic behavior scales (CSBS). A deep-learning algorithm, mostly stemming from measurements made as early as 6 months after birth, could predict autism diagnosis on the basis of hyperexpansive cortical surface area.

Autism and TOM: Evidence from Brain Imaging Studies

In one of the first studies on TOM-related brain activity, five male autistic adults underwent positron emission tomography (PET) imaging while reading stories requiring attributions of mental or physical states (Happé et al., 1996). Compared to a sample of six male non-autistic adults (Fletcher et al., 1995), autistic participants performed worse in answering questions about the TOM condition and did not show activation in the left medial frontal cortex during TOM processing. They also showed less pronounced activation differences between conditions in bilateral temporal poles and the left superior temporal gyrus. Another early PET study of 20 autistic and non-autistic adults used animated triangles to represent “interactions” requiring mental state attribution (Castelli et al., 2002). Compared to the control group, autistic participants performed worse at interpreting mental states and exhibited reduced activation during TOM-related processing in the basal temporal area, STS, and superior frontal gyrus. They also showed reduced connectivity between extrastriate regions, involved in early visual processing, and the STS. In a similar study using the Frith-Happé animations (White et al., 2011), autistic children ($n = 13$) performed worse than non-autistic peers ($n = 13$) at attributing mental and nonmental states to triangles, and exhibited reduced activation in the TOM network, the so-called mirror neuron system and the cerebellum (Kana et al., 2015). A wealth of neuroimaging studies has since emerged that has rendered a more complex picture of the TOM network in autism. In line with the findings discussed previously, several studies suggest that autistic individuals may recruit the TOM network in a less discriminate manner, distinguishing less between mental and nonmental states. For instance, contrasting inferences on intentions vs physical and emotional content, one study found less pronounced TOM-related activation differences in 18 autistic adults compared to 18 non-autistic controls

(Mason et al., 2008). Autistic participants also exhibited reduced functional connectivity within the TOM network—associated with structural differences in the corpus callosum—and between TOM and language processing regions. Although no behavioral results were reported, the authors interpreted this overall picture of neural differences as evidence for a less efficient use of the TOM network, suggesting that it might be related to connectivity differences spanning the whole brain. Using the animated triangle task, another study with autistic and non-autistic adults ($N = 24$) observed lower functional connectivity within the frontal and posterior parts of the TOM network in autistic participants, although there was no difference in behavioral performance (Kana et al., 2009). Less discriminate TOM-related activation was also observed in a study on the processing of opinion sentences (Lombardo et al., 2011). In contrast to controls ($n = 33$), autistic adults ($n = 29$) recruited the right TPJ in a comparable manner in response to mental and physical states. This lack of specificity was related to social difficulties as assessed by the Autism Diagnostic Interview-Revised (ADI-R). A recent magnetoencephalography (MEG) study indicates that reduced TOM-related activation can already be observed during childhood (Yuk et al., 2018). In that study, autistic and non-autistic children ($N = 41$) performed equally well in attributing true versus false beliefs. However, autistic children exhibited reduced activation of left TPJ, which coincided with increased activation of right inferior frontal gyrus. The authors suggest that inferior frontal activation may represent increased use of executive functioning as a compensatory strategy. Conversely, there are some studies that have observed greater involvement of the TOM network in autism. Wang and colleagues (2006) found that autistic children and adolescents ($n = 18$) were less accurate than their peers ($n = 18$) in an explicit task on irony comprehension, but showed greater activation in STS and inferior frontal gyrus during the processing of different cues. In a longitudinal study, White and colleagues (2014) compared autistic children who passed false belief tasks to those who did not. Both autistic groups ($n = 22$) showed increased TOM-related activation relative to their non-autistic peers ($n = 11$). These differences were observed at two time points 5 years apart, despite a large overall improvement in mentalizing performance.

Studies have found potential explanations for both hyper- and hypoactivation of the TOM network in autism. Increased TOM-related activation has typically been interpreted as more effortful processing, whereas reduced activation and intra- or interregional functional connectivity have been seen as indications for a lower propensity to engage in mentalizing, or lower efficiency. Finally, it has been suggested that greater involvement of regions outside the core TOM network, such as the inferior frontal gyrus, may point to alternative strategies used

by autistic people to compensate for mentalizing difficulties. These interpretations are partially supported by evidence linking brain activation to lower task performance or scores of social functioning, although several of the described studies did not find behavioral differences. Differences in neurocognitive functioning could also be seen when task performance was comparable, or in autistic people whose TOM seemed preserved. One potential explanation could be that brain imaging is sensitive to fine-grained differences in social processing that the tasks used in those studies do not capture.

Importantly, there are several studies observing no group differences in brain activation during TOM-related processing. Dufour and colleagues (2013) did not detect any differences in cortical activation between autistic ($n = 31$) and non-autistic ($n = 462$) adults during the processing of an explicit, verbal false belief task. Furthermore, a large recent study did not observe any group differences in brain activation between autistic ($n = 205$) and non-autistic ($n = 189$) children and adults during the processing of an animated shapes task (Moessnang et al., 2020). Considering the large sample size of the latter study, this casts doubt on a general hyper- or hypoactivation of the TOM network in autism. To determine whether there are reliable differences in TOM-related brain connectivity, additional studies with larger sample sizes will be needed.

In sum, research on TOM highlights difficulties, but also points to heterogeneity within the autistic population. It has been suggested that autistic people can learn to compensate for TOM difficulties but struggle to do so implicitly. Difficulties with implicit mentalizing would likely show in real-time interactions and impact one's ability to generate adequate responses, such as empathic behavior. The upcoming sections of this chapter will focus on how empathy and interactive behaviors present in autism.

Empathy in Autism

Some studies seem to suggest that empathy is impaired in autism (e.g., Baron-Cohen and Wheelwright, 2004; Lombardo et al., 2007). Indeed, autistic people often report to be less empathetic in psychometric instruments such as the empathy quotient (EQ: Baron-Cohen and Wheelwright, 2004) (e.g., Wheelwright et al., 2006; Lombardo et al., 2007; Johnson, Filliter, and Murphy, 2009) or the interpersonal reactivity index (IRI: Davis, 1983) (e.g., Lombardo et al., 2007; Demurie, De Corel, and Roeyers, 2011; however, for findings of comparable scores in self-reported emotional empathy see Rogers et al., 2007; Dziobek et al., 2008, and Thaler et al., 2018). Experimental research on empathy in autism has produced more diverging results.

An important limitation of self-reported empathy may be that individuals' answers depend on their introspective abilities (cf. Dziobek et al., 2008), a domain that autistic people tend to have difficulties with (Uddin, 2011). Disagreements on whether autistic people experience difficulties with empathy may also be related to the use of different conceptualizations of empathy (Decety and Jackson, 2004).

Theoretical Accounts of Empathy

Several definitions of empathy distinguish between cognitive and emotional, or affective, empathy (Davis, 1983; Shamay-Tsoory, Aharon-Peretz, and Perry, 2009). Cognitive empathy typically means to adopt the perspective of the other person and be aware of his or her emotions, while affective empathy is about producing an adequate emotional response. One hypothesis states that autistic people only show difficulties in the cognitive component, while affective empathy is preserved (e.g., Dziobek et al., 2008; Bird and Viding, 2014). The empathy imbalance hypothesis (Smith, 2009) and the intense world theory (Markram and Markram, 2010) propose that autistic people may even display heightened affective empathy, along with a general tendency for hyperarousal. Others have argued that difficulties experienced by autistic people may lie in precursors of empathy, such as emotion recognition and social information processing (Bird et al., 2013; Bird and Viding, 2014). Differences in self-other distinction, the process by which own emotional experiences are isolated from those of others (Decety and Lamm, 2006), have also been suggested to impact autistic people's understanding of others' emotional states (cf. Lombardo and Baron-Cohen, 2011).

Cognitive vs Affective Empathy

Support for a distinction between cognitive and affective empathy stems from studies contrasting autism with psychopathy. Individuals with psychopathic tendencies tend to have preserved TOM but show reduced affective empathy. The reverse seems to apply to autistic individuals. For instance, a study by Jones and colleagues (2010) compared boys with autism, psychopathic tendencies, conduct disorder, or no diagnosis (N = 96) in their empathic responses to hypothetical scenarios about other people's dismay. Boys with psychopathic tendencies were the only group reporting reduced fear responses, but performed well in a task assessing TOM. Conversely, autistic boys reported a typical level of affective responses, but experienced difficulties in the TOM task. Another study (Schwenck et al., 2012) observed lower cognitive empathy in autistic boys (n = 55) as opposed to lower affective empathy in peers with conduct disorder and a high number of callous-unemotional traits (n = 36). Findings in that study also indicated that empathic abilities improved with age within all

comparison groups ($N = 192$), pointing to similar development of empathy regardless of the presence of a diagnosis.

Hadjikhani and colleagues (2014) presented autistic adults and adolescents ($n = 38$) and matched controls ($n = 35$) with dynamic facial expressions of patients with shoulder pain. Although groups differed in self-reported empathy as assessed with the EQ, there were no group differences in brain activation during the video viewing. In the autistic group, self-reported emotional empathy was associated with activation in regions typically involved in emotion processing. Although no behavioral responses were assessed, the authors interpreted findings as support for preserved emotional contagion in autism. Other neuroimaging studies depicting others' pain also point to preserved emotional empathy (Krach et al., 2015) with potentially heightened affective arousal (Fan et al., 2014; Gu et al., 2015). Presenting videos of body parts getting hurt in physical accidents, Fan and colleagues (2014) observed elevated somatosensory area (SI/SII) activation and blunted activation in anterior insula (AI) in autistic male young adults ($n = 24$) compared to non-autistic peers ($n = 21$). In a second study with a similar sample ($N = 40$), they did not detect any group differences in mu suppression, indicating that sensorimotor resonance was preserved. Autistic participants showed heightened responses in N2 amplitude, indicating greater early affective arousal during empathic processing. Cortical and hemodynamic responses were modulated differentially by social complexity and individual pain sensitivity, highlighting modulatory roles of social understanding and sensory processing. Social complexity also modulated empathic responses of autistic adults in the study by Krach and colleagues (2015). When presented with more complex social scenarios, autistic male participants ($n = 16$) rated emotion intensity of others lower than non-autistic participants ($n = 16$), showed blunted pupil dilation, and reduced brain activation in AI and anterior cingulate cortex (ACC).

In sum, behavioral and neuroimaging data support the notion that autistic individuals show preserved, if not elevated, affective empathy. Findings showing a moderating effect of social-cognitive demands are in line with the proposal that it is difficulties in social information processing, rather than in empathy per se, that can impact empathic responses (Bird and Viding, 2014).

The Roles of Alexithymia and Social Information Processing

Bird and colleagues (2013) have argued that any difficulties in empathy seen in autism may stem from elevated levels of alexithymia. Alexithymia is characterized by difficulties in identifying and describing own emotions. Research indicates that alexithymic individuals also have difficulties judging others' emotions (Parker, Taylor, and Bagby, 1993; Lane et al.,

1996; Prkachin, Casey, and Prkachin, 2009; Uljarevic and Hamilton, 2013), and display reduced empathic responses (Moriguchi et al., 2007; Grynberg et al., 2010). While approximately 10% of the general population possess this trait (Salminen et al., 1999), the percentage of autistic people with alexithymia is presumed to be considerably higher. A recent meta-analysis of 15 studies with relatively small autistic samples ($N \leq 88$) has estimated prevalence to be at 49.93% (Kinnaird, Stewart, and Tchanturia, 2019).

First evidence for a role of alexithymia in empathy stems from a study that compared 36 autistic and non-autistic men with matched alexithymia levels. Bird and colleagues (2010) examined neural responses to watching a close companion receive electrical pain stimulation. Brain activation in an a-priori defined region of interest in AI was negatively associated with alexithymic traits. There was no difference in this correlation between autistic and non-autistic participants. The authors interpreted findings as supporting their hypothesis that autism does not impact affective empathy. In line with a previous study (Silani et al., 2008), affective empathy—in the form of self-reported unpleasantness—was neither affected by alexithymia nor autism. Another recent study assessed how 32 autistic and non-autistic adults with comparable alexithymia levels evaluated others' facial expressions of pain (Thaler et al., 2018). Viewing videos depicting patients' shoulder pain, both groups reported similar levels of unpleasantness, indicating comparable affective empathy. However, autistic participants underestimated actual pain intensities experienced by patients more than the control group. Results highlight that autistic people may experience difficulties in precursors of empathy that cannot be explained by alexithymia, such as the intensity of dynamic facial expressions. It has been argued that difficulties in social information processing—including deficits in emotion identification and TOM—could impact empathic behavior even when empathy per se is preserved (cf. Bird and Viding, 2014). Compelling evidence for how empathy and TOM are linked in real life stems from a study evaluating an 8-week training of TOM for autistic children (Holopainen et al., 2018). Empathic responsiveness was assessed via structural observations of video-recorded interactions between autistic children and experimenters. Compared to a waitlist control group ($n = 63$), those children who took part in the training ($n = 72$) showed increased empathic responsiveness after the intervention. Coll and colleagues (2017) have recently proposed a measurement framework that distinguishes problems with emotion identification from empathizing difficulties. Quantifying empathy as the extent to which a person shares the emotional state they believe the other person to be in, this framework accounts for the possibility that the empathizing individual misinterprets another's emotions. This argument is interesting because it may redefine what has been interpreted as

reduced empathic behavior in autism as more general difficulties in social information processing.

The Double Empathy Problem

When studying empathy and TOM in autism, it is important to consider the idea that social misunderstandings do not just happen within one person, but concern all interaction partners. Referring to this issue as the “double empathy problem,” Milton (2012) has argued that non-autistic people also struggle with taking the perspective and understanding the experiences of autistic people. This phenomenon has also been described as a “social interaction mismatch” (Bolis et al., 2017; see section “Autism as a Problem of Interpersonal Misattunement” for further details). Indeed, there is experimental evidence supporting this notion. For instance, in a study involving 27 autistic and non-autistic rating participants, autistic people’s posed facial expressions of emotions were recognized less well than those of non-autistic people (Brewer et al., 2016). Across a set of three studies (respective samples of 214, 37, and 98), non-autistic adults evaluated autistic children and adults appearing in videos of social interactions less favorably than they evaluated non-autistic peers (Sasson et al., 2017). Participants perceived autistic protagonists as less likeable and approachable, more socially awkward, and reported they would be less likely to socially engage or develop a friendship with them. Finally, in a study with 361 adolescents and adults, Cage, Di Monaco, and Newell (2018) observed that participants exhibited dehumanizing attitudes toward autistic people, expressed in a lower attribution of uniquely human character traits. The double empathy problem highlights the importance of investigating and reframing social-cognitive difficulties in autism as difficulties concerning all interaction partners, including autistic and non-autistic people.

Autism and Social Interaction

There is increasing interest in studying social abilities in settings that are interactive, and thus, more closely resemble real life (cf. Schilbach, 2016). The premise of this interactive turn is that being social is less about observing others and more about interacting with them. As discussed in this section, it seems that it is precisely this interaction that may often prove challenging.

Joint Attention in Autism

Research increasingly suggests that autism may best be described as a social interaction disorder that manifests in forming adequate behavioral responses during social encounters (cf. Schilbach, 2016). One important element of interactions is joint attention (JA), defined as the

process of coordinating attention with interaction partners to send and receive information about a third entity (e.g., other people, events, or objects). In contrast to dyadic interactions such as mutual gaze, JA has a triadic character, structured as a “referential triangle” between two agents and that third entity (Carpenter, Nagell, and Tomasello, 1998; Pfeiffer, Voogele, and Schilbach, 2013). Self-initiated or initiating JA (IJA) describes the process of making another individual follow one’s own gaze, whereas other-initiated or responding JA (RJA) entails following another person’s gaze to share a common referential target (Mundy and Newell, 2007). JA is vital for navigating spontaneous and unstructured settings. It is considered an important developmental precursor for other social and cognitive abilities. Typically developing children can follow other people’s gaze direction to a location outside of their visual field by 9 months of age, allowing them to communicate and interact with their environment before language development (Mundy and Newell, 2007). Up to the age of 18 months, toddlers will usually have developed a large repertoire of JA behaviors (Mundy et al., 2007). They then continue to refine these skills up to adolescence (e.g., Oberwille et al., 2016; also see review by Mundy, 2018). Social and communicative difficulties, including eye contact, gaze behavior, and response to name, are the most conclusive discriminators for autism around the age of 12–18 months (Stone, Ousley, and Littleford, 1997; Charman et al., 2000; Charman, 2003; Gotham et al., 2007). Early delays can also be observed in more domain-general areas of visual attention. For instance, a study with 104 infants with and without familial risk of autism observed that by 14 months, those later diagnosed with autism were less efficient in disengaging from visual stimuli (Elsabbagh et al., 2013). They also showed a less consistent development of speed and flexibility of visual orienting between 7 and 14 months of age. As these abilities are considered crucial in JA, it is unsurprising that autistic children show difficulties in both IJA and RJA (for reviewed evidence see Mundy and Newell, 2007; Mundy, Sullivan, and Mastergeorge, 2009). Studies indicate that deficits in IJA are more stable and universal, while RJA difficulties can disappear later in childhood. Importantly, early delays in IJA and RJA development correlate with later difficulties in language and social abilities (Sigman and McGovern, 2005; Toth et al., 2006; Anderson et al., 2007; Delinicolis and Young, 2007; Redcay et al., 2013). This highlights that it may be beneficial to include training in JA in early intervention programs for autistic children (Charman, 2003).

Autism and JA: Evidence from Brain Imaging Studies

During the last decade, research on JA has undergone remarkable developments in replacing purely observational tasks with socially interactive ones. Real-time gaze-contingent

experimental set-ups during functional magnetic resonance imaging (fMRI), for instance, have been used to account for the reciprocal nature of JA while exploring associated neural mechanisms (Schilbach et al., 2010, 2013; Oberwelland et al., 2016). A series of studies employing socially interactive tasks indicate that the JA network in typically developed adults involves the MPFC extending into the medial orbitofrontal cortex, the right posterior STS, and the right TPJ (Redcay, Dodel-Feder, and Pearrow, 2010; Schilbach et al., 2010; Pfeiffer et al., 2014; Bilek et al., 2015; Oberwelland et al., 2016). Aside from this general JA network, the ACC, ventral striatum, and amygdala, all of which are associated with motivation and emotion processing, seem to contribute to JA processes (Schilbach et al., 2010; Pfeiffer et al., 2014). These findings indicate that JA goes beyond the mere exchange of information and intentions. It appears that sharing attention with other people is associated with feelings of reward, and thus has a socio-communicative purpose in itself (Schilbach et al., 2010; Schilbach, 2015; Oberwelland et al., 2016). Findings of increased reward-based brain activation during social interaction have also been observed in children (Alkire et al., 2018). When they believed to be interacting with a peer rather than an artificial agent during mental- and nonmental state reasoning, they responded more quickly and reported greater enjoyment. Interactive context was associated with brain activation in the TOM network, cortical midline regions, bilateral insula, striatum, and amygdala.

In another study, Oberwelland and colleagues (2016) looked at the developmental trajectories of JA in 32 children and adolescents using an interactive task during a magnetic resonance imaging (MRI) scan. Overall, JA recruited a similar set of brain regions than in adults. There was, however, an interesting discrepancy between different types of JA, pointing to a more reward-associated role of IJA as compared to RJA. While activation during RJA was confined to regions involved in visual, attention, and social processing, IJA involved activation in a wider range of brain regions typically attributed to social cognition, decision-making, emotions, and motivational/reward processing. Only activation during IJA was significantly enhanced when participants interacted with a familiar rather than an unfamiliar partner. Regarding developmental effects, the authors found some evidence for a greater differentiation in the recruitment of TPJ with increasing age. Adolescents showed greater activation in bilateral TPJ during IJA, whereas in children, no difference between IJA and RJA could be observed.

Oberwelland and colleagues (2017) used the same task to investigate neural correlates of JA in a sample of 32 male children and adolescents with and without autism. Although there were no group differences in saccade behavior or overall accuracy during JA, non-autistic

participants showed greater brain activation during JA in two clusters associated with the so-called social brain, including temporal pole, STS, TPJ, and precuneus. Only within the non-autistic group, IJA was associated with frontal activation involving the MPFC. In autistic participants, self-related activation in that same frontal cluster was negatively associated with self-reported difficulties in social communication. Integrating this finding with previous results, the authors discuss that a lower involvement of frontal regions during IJA might reflect difficulties in self-other distinction (Schulte-Rüther et al., 2014) or in the disengagement of visual attention (Keehn, Müller, and Townsend, 2013). There were no group differences in the modulation of brain activation by familiarity of the interaction partner. Results indicate that, even in a simple and relatively controlled interaction, autistic children and adolescents show differences in their neural processing of JA.

Sensorimotor Interaction in Autism

One factor that may contribute to social interaction difficulties is sensorimotor processing. For instance, Dowd, Rinehart, and McGinley (2010) have argued that motor impairments seen in autism do not just happen in parallel, but exacerbate social interaction problems, and may be represented in overlapping neural circuits. Attempts have been made to go beyond visuospatial interaction and eye gaze, to study interacting bodies (Schilbach, 2016; Bolis et al., 2017; Zapata-Fonseca et al., 2018).

In one of the first studies to investigate sensorimotor interaction in autism, Zapata-Fonseca and colleagues (2018) implemented a minimalist experimental paradigm known as perceptual crossing (PC), modified from Lenay (2008). Ten dyads of autistic and non-autistic adults engaged in tactile-based interactions in a shared one-dimensional virtual space. Participants were connected to each other via a sensorimotor loop: they appeared as avatars in the virtual space, navigated a computer mouse with their dominant hand, and a Braille stimulator with the index finger of the other hand. Moving around in virtual space, both participants received sensory feedback via the Braille stimulator when they crossed each other, or when they interacted with objects serving as distractors. They were asked to click the computer mouse whenever they thought they had crossed the other person's avatar. With this setup, researchers could compare participants' abilities in social contingency detection. Interestingly, autistic participants performed equally well as control participants, showing comparable sensitivity to the other person's tactile properties. This indicates that, at least in a reductionist virtual environment as given in this paradigm, autistic individuals are able to detect an agent that responds to their actions and can discriminate between this agent-based movement and nonreactive, object-based movement. In discussing their unexpected finding, Zapata-Fonseca

and colleagues (2018) have raised important issues pertaining to computer-mediated interactions. Despite their dyadic and real-time features, virtual setups are typically far more reductionist than real-life encounters. They convey limited sensory input, and focus on a goal-oriented task that typically does not rely too much on social information. Conversely, real-time social interaction requires people to adapt to unexpected changes in environment as well as changing intentions of interaction partners. The authors argue that autistic people might benefit from a virtual setup, as it provides fewer potentially distracting or confusing sources of information.

Despite these issues, examining real-time social interaction within sensorimotor tasks appears to be a promising approach for gaining a better understanding of autism. Two-person psychophysiology and multilevel analysis of intersubjectivity could increase ecological validity (Bolis and Schilbach, 2018). It will also be important to compare other variations of dyads within larger samples, including autistic-autistic dyads.

Autism as a Problem of Interpersonal Misattunement

The hypothesis of interpersonal misattunement redefines autism and other psychiatric conditions not merely as disorders of the individual brain, but as cumulative misattunement between people (Bolis et al., 2017). Already at an early age, the level of synchronicity between an infant and their caregiver correlates with the development of subsequent communicative forms such as JA and language (Siller and Sigman, 2002; Bolis and Schilbach, 2018). Bolis and Schilbach (2018) distinguish two types of cumulative attunement that may be important for synchronizing interactions: propositional attunement (knowing what to do) and pragmatic attunement (knowing how to do something). They argue that autistic people, irrespective of verbal skills, may struggle with spontaneous interactions because they show less pragmatic attunement with others. Based on this hypothesis, interactions within homogeneous dyads, such as two autistic people, would be expected to appear smoother compared to heterogeneous dyads. As such, describing autism as a cumulative mismatch might potentially alleviate social stigma (Bolis et al., 2017). Clinical settings subscribing to this hypothesis could do this by prioritizing the coupling dynamics and “tuning” of interaction between people over the tuning of individual behavior. A preliminary evaluation of an autism-specific group psychotherapy focusing on these interactive elements suggests that autistic people benefit from a setting in which they interact with other autistic people (Parpart et al., 2018).

Studies on Autistic-Autistic Interaction

Some recent studies have started to investigate social interaction in autistic-autistic dyads. In a study with 52 autistic and non-autistic adults, Wadge and colleagues (2019) compared different dyad combinations in a game focused on reconstructing a geometric target using communication. They observed that autistic pairs and mixed pairs performed worse than non-autistic pairs at solving these problems. The difference was driven by a lower use of shared signals, pointing to less communicative alignment. Another study focused on the hypothesis that autistic people develop shared understanding in other ways than non-autistic people. To examine how this process might come about, Heasman and Gillespie (2018) analyzed dialogues in video-recorded interactions of 30 autistic adults playing video games. The authors identified two outstanding characteristics in these pair-wise interactions. First, participants made generous assumptions of common ground, in that they frequently shifted topics without introducing them to the other person. Second, participants had a low demand for coordination, in that they showed a high tolerance for misunderstandings or ignored turns. Interestingly, both factors seemed to have large beneficial effects in improving rapport and reciprocity. More support for the idea that autistic people exhibit differences, rather than deficits, in their interactional style stems from a recent study of 172 adults performing semi-structured interactions within varying dyad constellations (Crompton et al., 2020). Compared to non-autistic pairs and mixed pairs, external (non-autistic and autistic) raters perceived interactional rapport as highest in autistic pairs. In sum, these studies demonstrate how moving away from a deficit-oriented perspective may further enhance our understanding of autistic social interaction.

The Bayesian Brain Account of Autism

Autism is characterized by a diverse set of characteristics. Yet the most prominent autism theories, such as accounts of weak central coherence (Happé and Frith, 2006) and mindblindness (Baron-Cohen, 1995), are typically more well-suited to explaining specific features rather than the full phenotype. The Bayesian brain account may offer a more unifying theoretical framework of autism. More generally, this account can describe psychiatric and neurodevelopmental disorders in terms of how individuals adapt to changing environments using different sources of information (for a detailed discussion of clinical applications of Bayesian accounts, see Haker, Schneebeli, and Stephan, 2016). As such, it could also be useful in explaining strengths seen in autism, such as enhanced perceptual functioning (e.g., Bonnel et al., 2003; reviewed in Mottron et al., 2006). The Bayesian brain account views

social difficulties as rooted in more domain-general inferential processes and provides plausible hypotheses for how these differences are expressed on a biological level.

Bayesian Inference and Predictive Coding

According to Bayesian accounts of cognition and perception the human brain makes sense of the external world by continuously inferring what states of the environment are causing sensory inputs (Friston, 2010). In other words, the brain does not passively perceive the world, but actively strives to explain and predict it. The brain makes these inferences by relating current sensory input (observed data or likelihood) to what was previously learned about the environment (prior belief or prior). This process is formalized using Bayes' theorem: in graphical terms, the prior, likelihood, and posterior, can be represented as probability distributions. Applying this Bayesian brain account to autism, Pellicano and Burr (2012) have proposed that autistic individuals favor immediate sensory evidence over prior beliefs. They suggested that autistic prior probability distributions are broader, thus exerting a weaker influence on perception. Building on this hypothesis, autistic people may be less influenced by previous information because they expect their priors to be less precise (Friston, Lawson, and Frith, 2013; Lawson, Rees, and Friston, 2014).

To understand how Bayesian inference is instantiated in physiological processes in body and brain, it can be explained within a predictive coding framework (cf. Clark, 2013; Hohwy, 2014; Hohwy, 2017). In predictive coding terms, the means of prior probability distributions represent predictions, and the difference between predicted sensory input and actual sensory input is expressed in terms of prediction errors. Following the free energy principle, the brain attempts to minimize surprise by minimizing unexplained information, i.e., prediction errors. It can do so via two mechanisms—by acting in accordance with predictions (active inference), or by updating the internal model (perceptual inference) to improve future predictions. An example of perceptual inference would be learning to identify the position of crickets based on their auditory signals (cf. Skewes and Gebauer, 2016). An example of active inference would be directing eyes toward aspects that the brain predicts, resulting in more frequent saccades toward predicted content. Predictions and prediction errors are generated at different layers in the cortical hierarchy. Prediction errors are passed up in this hierarchy, while predictions are passed down. Biologically, these processes are instantiated by modulating postsynaptic gain in superficial pyramidal neurons (e.g., Feldman and Friston, 2010). Applying this framework to autistic perception, Van de Cruys and colleagues (2014) have proposed that prediction errors in autism have a higher expected precision and are less flexible.

As Palmer, Lawson, and Hohwy (2017) have pointed out, these Bayesian accounts of autism share the assumption that autistic people have a higher learning rate. Importantly, learning rates fluctuate depending on the weighting balance of predictions and prediction errors, a balance that responds to different sources of uncertainty at different hierarchical levels. For instance, learning rates decline when precisions of our sensory environment are more stable over time, and are augmented when conditions are more volatile (e.g., Behrens et al., 2007). Tracking these fluctuations in learning rates may provide important clues to how autistic people adapt to changing environments (e.g., see the following for a study by Lawson, Mathys, and Rees, 2017).

Autism and the Bayesian Brain

There is now emerging evidence from experimental studies putting the Bayesian brain account of autism to a test (also see discussion by Palmer, Lawson, and Hohwy, 2017). To assess how individuals weight priors, studies typically manipulate the expectations of participants using, for instance, contextual cues or illusions. The rubber-hand illusion is brought about by applying synchronous sensory stimulation to an individual's concealed hand and a rubber hand situated next to it. Watching the rubber hand being stimulated and feeling that stimulation on one's own hand helps create a sense of ownership for the rubber hand. When the rubber hand is moved, participants experience a drift in the estimated position of their own hand, and this effect can influence subsequent motor movements. Palmer and colleagues (2013) examined the effects of this illusion in a sample of 24 adults with high- and low-levels of autistic traits. They observed that participants with fewer autistic traits were more influenced by the illusion, displaying differences in proprioceptive drift and smoothness of grasping movements between conditions. Participants with more autistic traits exhibited no such differences between conditions, despite reporting subjective effects of the illusion. This indicates that they integrated contextual variation less into their perceptual decisions and actions, which could be explained by a lower expected prior precision. In a second study, Palmer and colleagues (2015) extended these findings by comparing the effects of this illusion in 15 autistic adults and 30 control participants with a high vs low number of autistic traits. All three groups reported a subjective experience of the illusion and showed comparable magnitudes of perceptual integration, including proprioceptive drift. However, an effect on the smoothness of grasp movements was only observed in control participants with a low number of autistic traits. Results indicate that both autism and autistic traits are associated with a lower integration of context, but highlight that this integration might particularly concern active inference in the form of motor movements.

One way of directly contrasting individuals' prior precisions and sensory precisions is to manipulate response criteria and discriminability in signal detection experiments. In a study with 29 adults, Skewes, Jegindø, and Gebauer (2015) introduced statistical contexts and sensory noise to assess how they influence perceptual decisions on visual orientation. They observed that participants with more autistic traits integrated statistical contexts less into their response criteria, indicating lower prior precisions. Conversely, there was no difference between people with high- and low-levels of autistic traits in the influence of sensory noise on discriminability, pointing to comparable sensory precisions. Skewes and Gebauer (2016) extended these findings in a signal detection study with 20 autistic and 23 non-autistic adults, focusing on auditory localization. Autistic participants responded less optimally to manipulations of statistical context and sensory noise, indicating a less efficient integration of prior information with sensory information.

Manning and colleagues (2017) were the first to test whether autistic children ($n = 34$) have higher learning rates than non-autistic children ($n = 32$) and adults ($n = 19$) under volatile circumstances. Contrasting stable and volatile reward probabilities in a learning task, they estimated learning rates with a reinforcement learning mechanism, applying a delta learning rule. They found no group differences in overall learning rates, nor in increases of learning rates in the volatile condition. Results indicate that proposed differences in precision weighting in autism might be more constrained than previously assumed. As the authors argue, differences may be confined to more complex forms of perceptual learning, such as a more continuous tracking of reward probabilities, or taking into account several types of information. As such, models that implement hierarchical layers may be better suited for capturing autism-related differences. Lawson, Mathys, and Rees (2017) used the hierarchical Gaussian filter (HGF: cf. Mathys et al., 2011) to examine expectations of volatility in 49 autistic and non-autistic adults. They observed that autistic participants showed less surprise in response to volatility changes, represented in less modulation of reaction times, error rates, and pupil dilation by expectedness. Autistic participants also showed a greater weighting of expectations about volatility, represented in increased updating of learning rates on volatility. Findings indicate that autistic people may overestimate how unstable their environment is, resulting in a less flexible weighting of prediction errors under uncertainty.

Despite these promising first findings, it should be noted that evidence for the Bayesian brain account of autism is still limited. Studies comparing Bayesian inference in different psychiatric and neurodevelopmental conditions will be important to determine in more detail in what parameters they differ from each other and how these differences relate to causes and

phenotypes (e.g., see Lanillos et al., 2020 for a comparison of Bayesian brain and other neural network models in schizophrenia vs autism).

Autism and Social Bayes

Some recent studies have tested the Bayesian brain account of autism in a social-cognitive context. One example for how weighting of social priors can be assessed is the direct gaze bias. It describes the phenomenon that people tend to perceive eye gaze as more direct when depicted eyes contain more perceptual noise. Under a Bayesian framework this can be explained by a greater reliance on priors during conditions of high uncertainty, and it would be expected to be reduced in the case of autism. Contrary to these predictions, a recent study indicates that the effect can also be seen in autistic individuals (Pell et al., 2016). Applying a more complex Bayesian hierarchical model, Sevgi and colleagues (2020) examined how autistic traits are associated with the weighting of social cues. In a study with 36 adults, the authors assessed participants' propensity to integrate eye gaze in a reward-based learning task. The task varied reward probabilities of eye gaze and a nonsocial cue, as well as the volatility of reward probabilities. Participants' responses were modeled using the HGF (Mathys et al., 2011). In line with a Bayesian brain account of autism, autistic traits were associated with poorer task performance, explained by a suboptimal integration of social cues during volatile phases. More specifically, people with more autistic traits tended to over-rely on gaze context when its accuracy was low. Chambon and colleagues (2017) built on signal detection experiments by Skewes, Jegindø, and Gebauer (2015), assessing prior and sensory precisions in inferences on social versus non-social motor intentions. The non-autistic control group ($n = 20$) responded more to manipulations of priors for social inferences. No such difference was seen in autistic participants ($n = 18$), supporting a Bayesian interpretation of attenuated social priors. Another recent study examined how 36 male autistic and non-autistic adults coded social prediction errors in the brain (Balsters et al., 2017). In a new false belief task, the researchers assessed social prediction errors by contrasting actual and expected outcomes of others' decisions. Autistic participants were less good at using reward probabilities to identify likely outcomes, and this difference was stronger for outcomes of another person or a computer-generated agent. As in previous studies, social prediction error was associated with activation of the gyral surface of the anterior cingulate cortex (ACCg), represented in a negative blood-oxygen level dependent (BOLD) response to others' unexpected rewards. Importantly, however, this ACCg response to social prediction error could not be observed in the autistic group. Results indicate that the magnitude of brain responses to social prediction errors may be attenuated in autism. Findings on social aspects

of Bayesian inference may explain how social communicative features such as difficulty responding to others or a reduced tendency to use gestures and other nonverbal signals, develop in autism. These communicative skills are typically acquired in interaction with others. Here, less efficient forms of inferential processing—in the form of attenuated social priors or attenuated neural processing of social prediction errors—would be expected to influence skill development. As can be seen from the discussed studies, the Bayesian brain account of autism is a promising theoretical framework that will need further testing and refinement.

General Outlook and Perspectives

This chapter gives an overview of theory and empirical findings on how social cognitive and interactive abilities develop differently in autism. To conclude, we would like to point out developments in this field that are expected to shape the next decades of autism research. First, it appears that the difficulties autistic people experience in real life happen primarily during interactions with others. Innovations in experimental settings increasingly allow researchers to study social functioning through a second-person rather than a third-person perspective (cf. Schilbach, 2015; Schilbach, 2016). One example of how these interactions can be targeted more directly is the use of mobile phone apps in research and interventions (Koumpouros and Kafazis, 2019). These apps could already prove useful in early childhood, facilitating early detection and intervention. Examples could be first screening tools helping parents recognize features warranting further diagnostic assessment, as well as self-guided trainings for parents of children with a confirmed diagnosis. Second, there has been some development in explaining autistic features within an overarching theory. The Bayesian brain account of autism describes these traits in terms of Bayesian inference, making plausible assumptions for underlying neurobiological mechanisms. A step forward will be to further integrate this framework with the view of autism as a social interaction disorder (cf. Bolis and Schilbach, 2018). Third, it will be important that theoretical advances are visible in the development of clinical and social interventions. A stronger focus will need to be put on social functioning in everyday life, including employment, access to support systems, and interpersonal relationships. A fourth issue apparent in the discussed studies is that sample sizes are often quite small. This may be an important reason for mixed and inconsistent evidence. To tackle this problem, open science methods will likely gain more relevance, as well as multicenter studies and databases with wider geographical and temporal scopes. One interesting example of a longitudinal, nationwide database is the Netherlands Autisme Register

(NAR) (Begeer et al., 2017). The NAR was created together with autistic stakeholders and is designed to provide feedback to its autistic members that is useful to them. One fifth and final issue concerns the question of how autism studies can benefit autistic people. An important study in the UK showed that autistic people and their families did not perceive research outcomes as leading to concrete improvements in their lives (Pellicano, Dinsmore, and Charman, 2014). To address this issue, attempts have been made to develop research processes in which autistic people take a more active part (e.g., Fletcher-Watson et al., 2018). These initiatives also seem highly relevant for studying social abilities, considering that they are tightly linked to autistic people's quality of life (Tobin et al., 2014; Kim and Bottema-Beutel, 2019) and tend to be one of their main priorities in psychotherapy interventions (e.g., Gawronski et al., 2011). As is also highlighted in emerging accounts such as the double empathy problem, autism researchers need to critically reflect on how they can best form an understanding of the perspectives of autistic people. To establish and improve this understanding, the lived experience of the autism community seems vital.

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