

**COMMENTARY****Autism 101 Commentaries**

# Research on social attention in autism and the challenges of the research domain criteria (RDoC) framework

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**Abstract**

The fuzzy nature of categories of psychopathology, such as autism, leads to significant research challenges. Alternatively, focusing research on the study of a common set of important and well-defined psychological constructs across psychiatric conditions may make the fundamental etiological processes of psychopathology easier to discern and treat (Cuthbert, 2022). The development of the research domain criteria (RDoC) framework is designed to guide this new research approach (Insel et al., 2010). However, progress in research may be expected to continually refine and reorganize the understanding of the specifics of these mental processes (Cuthbert & Insel, 2013). Moreover, knowledge gleaned from the study of both normative and atypical development can be mutually informative in the evolution of our understanding of these fundamental processes. A case in point is the study of social attention. This Autism 101 commentary provides an educational summary of research over the last few decades indicates that social attention is major construct in the study of human social-cognitive development, autism and other forms of psychopathology. The commentary also describes how this research can inform the Social Process dimension of the RDoC framework.

**Lay Summary**

Autistic people, like all people, display a lot of individual differences. This makes the category of “autism” difficult to define. Instead of trying to define autism as a distinct category it may be better to try to define a common set of important mental processes that contribute to all human differences including the difference we refer to as autism. However, defining that important set of mental processes can also be difficult. Ironically, sometimes the study of category, like autism, can reveal an important dimension of human mental development. This commentary describes how this is the case for research on the nature and development of social attention in autistic people. Once conclusion is that research with autistic people also has much to say about understanding human nature more broadly.

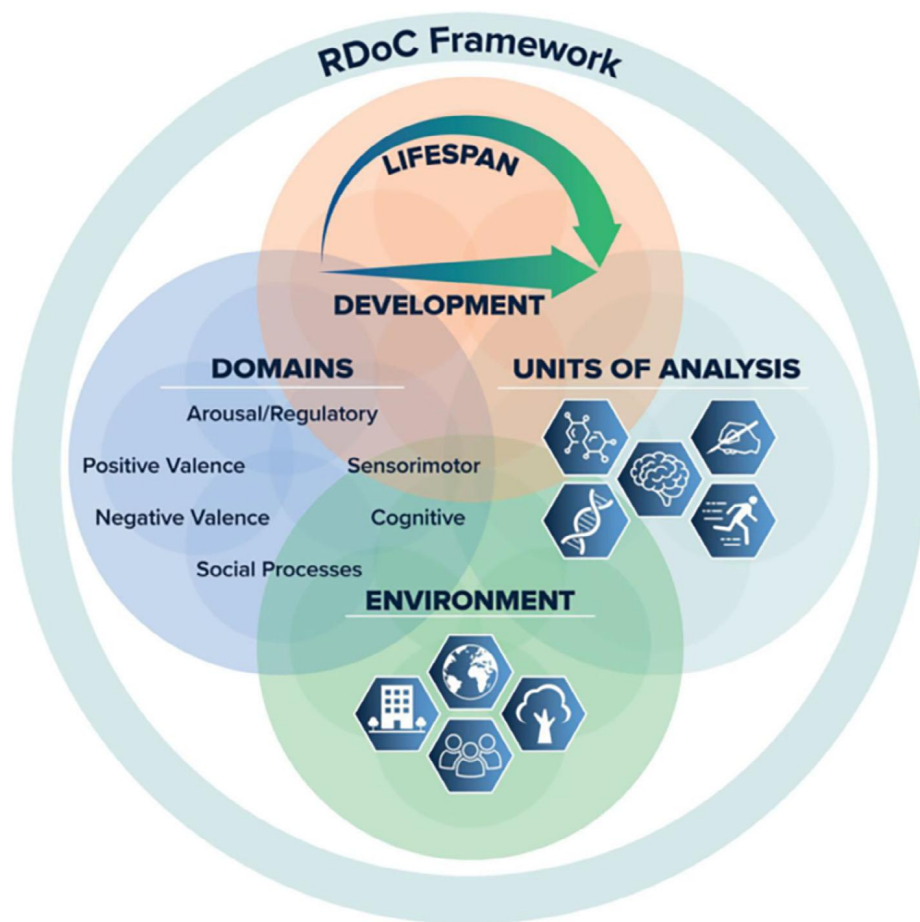
**KEYWORDS**

autism, eye contact effect, face processing, joint attention, psychopathology, research domain criteria, social orienting

**INTRODUCTION**

There are significant neurobehavioral and genetic commonalities between autism and other psychiatric conditions (Antshel & Russo, 2019; Baribeau et al., 2019; Hyman, 2019; Stergiakouli et al., 2017). There is also significant heterogeneity in the expression of autism across individuals and development (Georgiades et al., 2013; Lord & Jones, 2012; Warrier et al., 2022). These

observations, among others, challenge the validity of a categorical definition of autism. Alternatively, adopting a dimensional approach where psychiatric conditions may be best described in terms of varied patterns of disturbance across a common set of neurocognitive, motivation, sensory and psychophysiological constructs may be a more useful approach to the study of autism, and psychopathology more generally (Hollander et al., 1998; Hyman, 2021; Kim et al., 2019; Sanislow et al., 2010).



**FIGURE 1** An illustration from Sanislow et al. (2022, p. 656) of the main features of the RDoC framework including element that recognizes inclusion of the importance of development functions in interaction with domain construct, units of analysis and environment from. This figure was published in the public domain by the American Psychological Association in the *Journal of Psychopathology and Clinical Science*.

This type of dimensional approach is exemplified by the experimental research domain criteria (RDoC) framework of the National Institute of Mental Health in the USA (Cuthbert, 2022; Insel et al., 2010). The RDoC encourages research that would identify the fundamental set of biobehavioral mental process that contribute to symptoms across diagnostics groupings, with the goal of making the essential etiological processes of psychopathology easier to discern and treat (Cuthbert, 2022). To this end, the RDoC framers identified six primary biobehavioral dimensions for study, (1) cognitive systems, (2) behavioral approach systems, (3) behavioral avoidance systems, (4) arousal modulation systems, (5) sensory motor systems and (6) social process systems.<sup>1</sup> A set of hypothetical mental processes, or “constructs,” are also delineated within each biobehavioral dimension of the RDoC along with their operationally defining observable behavioral measures.

The measurable constructs of the RDoC have two essential attributes. First, they need to be characterized by compelling evidence of their measurement and construct validity as defined in psychological research (Cronbach & Meehl, 1955; MacCorquodale &

Meehl, 1948). Second, there needs to be strong evidence that the behavioral measures of a construct are theoretically and empirically associated with mechanisms of a biological system, such as a specifiable brain circuit (see pages 4–6, Cuthbert & Insel, 2013).

The creation of the current RDoC was a challenging task that was based largely on the knowledge acquired up through the first decade of the millennium (Insel et al., 2010). It has been successful in many ways, but also has several limitations (Cuthbert, 2022). One limiting factor, for example, is that the constructs of the RDoC “tended to represent ... adult dimensions rather than developmental functions” (p. 655) and there was “an insufficient degree of specification regarding constructs, paradigms and measures regarding developmental research” pertinent to psychiatric conditions (p. 654, Sanislow et al., 2022). This creates a significant problem for the application of the RDoC framework to the types of developmental psychopathology studies necessary to understanding the early onset of autism and other forms of childhood conditions. In recognition of this issue, the Sanislow et al. (2022) describe the need to move toward a new, more developmentally informed model of the RDoC framework, as is illustrated in Figure 1. Cuthbert and Insel (2013) also recognize that the nature of the dimensions and constructs of the RDoC “are always

<sup>1</sup>See <https://www.nimh.nih.gov/research/research-funded-by-nimh/rdoc/constructs/rdoc-matrix>

dependent upon the march of research to continually refine and evolve” (p. 4). However, another challenge to the ongoing validity of framework is that a process for updating the RDoC framework to allow it to evolve in response to advances in research has not been explicitly described (Cuthbert, 2022).

Revision of the social process systems dimensions of the RDoC may be expressly needed and significant for autism research for several reasons. The centrality of social symptoms to the diagnosis of autism makes research on the development of human social processes systems especially germane (Klin et al., 2002). Moreover, the study of social-emotional and social cognitive neuroscience processes has been rapidly evolving since 2010 (Carver & Johnson, 2018; Kliemann & Adolphs, 2018; Pan et al., 2022; Redcay & Schilbach, 2019). It seems likely that observations from this recent epoch of research could improve the conceptualization of the RDoC social process systems dimension. Second, many of the constructs of the social process systems, such as attachment and affiliation, social communication, and perception and understating of mental states, are associated with mental processes that begin in the first 2 years of life, which are thought to have significant cascading effects on subsequent phases of development (e.g., Csibra, 2003; Feldman, 2017; Fonagy et al., 2007). The study of some these mental processes has been crucial to research on the nature of the early onset of important individual differences social development that typify autism (e.g., Baron-Cohen, 1989; Chevallier et al., 2012; Mundy & Sigman, 1989; Sigman & Mundy, 1989; Vivanti & Messinger, 2021). Over the last 20 years these “clinical” studies in combination with related advances in basic research have catalyzed advances in the identification of pivotal aspects of the development of human social process systems over the last 20 years that are not well captured in the current RDoC framework. Thus, there has been a *vita* dynamic interplay between basic cognitive science and research focused on autism in defining the mental dimensions of human social process systems (Mundy, 2021) that has the potential to inform the next generation of the RDoC framework. A case in point is provided by evidence of the pivotal nature of research on measures of social attention in the study of autism (Mundy & Bullen, 2022) and psychopathology more generally (Tso et al., 2020) and the implications of this research for the refinement of the RDoC social processes systems dimension.

## THE HYPOTHETICAL CONSTRUCT OF SOCIAL ATTENTION IN AUTISM RESEARCH

Studies have long observed that differences in social attention were prominent in the development of autism and seemed to play an essential role in the social

phenotype (Dawson et al., 2004; Klin, 1991; Loveland & Landry, 1986; Mundy et al., 1986; Wetherby & Prutting, 1984). Subsequently, research and theory began to explicitly suggest that these types of social attention measures reflect constructs, or unobservable mental processes, that play an important role in the development of social cognition from infancy to adulthood (Baron-Cohen, 1994; Birmingham & Kingstone, 2009; Emery, 2000; Frischen, Bayliss, et al., 2007; Frischen, Smilek, et al., 2007; Klein et al., 2009; Mundy & Newell, 2007; Nummenmaa & Calder, 2009).

In current autism research social attention now most often refers to mental processes and underlying biobehavioral mechanisms involved in: (1) social orienting behaviors, or the motivation and mental processes involved in the prioritization of attention to social stimuli such as faces, eyes, biological motion, social sounds and speech, (2) gaze processing and joint attention, which involve motivation and cognitive processes attendant to coordinating attention with another person and, (3) the impact of social presence on behavior, such as the eye contact and audience effects, in which the perception and awareness of being the object of attention of another person impacts cognitive and emotional processes. The basic research and theory that has given rise to this tripartite definition has been detailed in numerous reviews (e.g., Birmingham & Kingstone, 2009; Braithwaite et al., 2020; Dawson et al., 2012; Freeth & Morgan, 2022; Itier & Batty, 2009; Klin et al., 2015; Mundy & Bullen, 2022; Mundy & Newell, 2007; Nummenmaa & Calder, 2009; Salley & Colombo, 2016; Senju & Johnson, 2009a, 2009b; Tomasello et al., 2005).

Some of the roots of social attention research can be found in the study of the prelinguistic precursors of infants’ understanding of interpersonal communicative reference that provides a cognitive foundation for subsequent language development (Baldwin, 1995; Bates et al., 1975; Bruner, 1995; Csibra, 2003). The literature on social attention was also informed by observations of the human tendency to prioritize attending to faces (Purcell & Stewart, 1988), and the study of the reflexive nature of spatial orienting in response to gaze direction cues (Friesen & Kingstone, 1998; Ristic et al., 2007), as well as how processing spatial directional cuing from gaze differs from processing of non-social directional cues (Frischen, Bayliss, et al., 2007; Frischen, Smilek, et al., 2007; Ristic et al., 2007). Social attention has also been studied in social psychology, especially under the rubric of audience effects or how being observed by other people effects behavior (Chevallier et al., 2014; Freeth & Morgan, 2022; Hamilton & Lind, 2016), as well a related developmental research on the eye contact effect or how eye contact impacts cognitive, stimulus valence, and a sense of affiliation (Becchio et al., 2008; Hietanen, 2018; Senju & Johnson, 2009a).

More recently, developmental studies of the infant siblings of children with autism have consistently



indicated that the atypical development of social orienting and joint attention are symptoms of the emergence of autism that can begin to be observed in infants between 6- and 12-months of age (e.g. Chawarska et al., 2013; Franchini et al., 2019; Jones & Klin, 2013; Stallworthy et al., 2022). In children 3 years of age or older observations of differences in social attention are associated with large group effects between children with autism, and children with developmental delays or children with neurotypical development (Dawson et al., 2004; Mundy et al., 1986). Consequently, they exhibit evidence of substantial diagnostic sensitivity and specificity, ranging from 0.82 and 0.81 (Dawson et al., 2004) to 0.92 and 0.92 respectively (Mundy et al., 1986).

Large diagnostic group effect sizes, and indices of diagnostic sensitivity and specificity, can be one important characteristic to consider in identifying behavioral measures of mental constructs that are important to particular psychopathological phenotypes (e.g., Gold et al., 2012). In research on autism evidence of their preschool sensitivity and specificity contributed to the inclusion of social attention items in many evidence-based diagnostic and screening instruments for autism (Gotham et al., 2007; Mosconi, Reznick, et al., 2009; Robins et al., 2014; Stone et al., 2004). For example, the Social Affect scale of Modules 1 and 2 of the revised version of the Autism Diagnostic Observation Schedule (ADOS-2, Lord et al., 2012) includes several social attention items, such as measures of initiating and responding to joint attention, pointing, showing and gestures, in the Social Affect (SA) scale of Modules 1 and 2 of the ADOS-2. Modules 1 and 2 are used in the diagnosis of preschool children. Gotham et al. (2007, 2008) observed evidence that these items converge on a single factor or construct in the SA scale of these modules. The manual for the ADOS-2 also provide substantial evidence for the interrater reliabilities of the social attention behavior items in the ADOS (Lord et al., 2012, pp. 256–257).

Mundy and Bullen (2022) have reviewed additional evidence of this kind measurement construct validity with respect to social attention, such as observations that, (1) experimental measures of social-orienting and joint attention behaviors are correlated (e.g., Franchini et al., 2009) even across auditory and visual social attention paradigms (Dawson et al., 2004), (2) observations of social orienting and joint attention in an experimental paradigm are correlated with independent clinical observations on the SA scale of the ADOS-2 (e.g., Mosconi, Reznick, et al., 2009), and (3) multivariate measures of the latent construct of social attention increase the power of research (Dawson et al., 2004) and are applicable across cultures (Frazier et al., 2021).

Several other studies indicate that social attention items of the ADOS-2, exhibit current and predictive criterion validity. The in that they are associated with cognitive, language, and social adaptive outcomes in autistic children and adolescents in a manner consistent with

social attention theory (Bal et al., 2020; Harrison et al., 2016; Maljaars et al., 2012; Sano et al., 2021; Thurm et al., 2007; Zachor & Ben-Itzhak, 2020). Moreover, several longitudinal studies provide evidence for a significant association between neurotypical infant social-attention development and childhood social-cognitive task performance (Abreu et al., 2014; Brooks & Meltzoff, 2015; Kuhn-Popp et al., 2015; Sodian & Kristen-Antonow, 2015). This is the type of concurrent and predictive criterion validity also provides an important type of evidence of construct validity in psychological science (Cronbach & Meehl, 1955; Strauss & Smith, 2009).

Thus, current research has begun to demonstrate evidence of the construct validity of social attention measures for the study mental processes involved on neurodevelopmental disorders and psychopathology (Frazier et al., 2021; Mundy & Bullen, 2022; Tso, Angstadt, et al., 2021). However, consensus has not yet been reached on the validity the social attention construct (Salley & Columbo, 2016; Falck-Ytter et al., 2022). Nevertheless, additional research that informs the evaluation of its construct validity is rapidly becoming available (Doherty et al., 2019; Ji et al., 2020; McKay et al., 2022; Ristic & Capozzi, 2022; Vallorani et al., 2022).

It is clearly the case, though, that measures of social attention are a significant part of the reliable operational diagnostic definition of the preschool phenotype of autism (Mundy & Bullen, 2022). Moreover, beyond the preschool period, social attention can also be reliably and validly measured in children, adolescents and adults with typical development and autism (e.g., Bayliss et al., 2013; Freeth et al., 2020; Freeth & Bugembe, 2019; Gregory & Kessler, 2022; Grynszpan et al., 2019; Mundy et al., 2016; Nowell et al., 2020; Oberwelland et al., 2016), as well as among individuals who exhibit the broad autism phenotype (Elsabbagh et al., 2009; Morgan et al., 2023; Nayar et al., 2022; Swanson et al., 2013; Swanson & Siller, 2014; Zhao et al., 2017). Recent research also suggests that social attention measures may be sensitive to sex differences in autism (Charwarska et al., 2016; Harrop et al., 2020).

Social attention can be assessed in various ways, such as multivariate measures (Nayar et al., 2022), parent report measures (Birkeneder et al., n.d., in submission), measures of temporal dynamics (Del Bianco et al., 2021) and response to eye contact measures (Akechi et al., 2014; Grynszpan et al., 2017; Mundy et al., 2016). Visual social attention can also be assessed directly in social interactions (Freeth & Bugembe, 2019), or with auditory measures in brain imaging studies in children with autism (Hernandez et al., 2020), and in terms of its impact on memory functions (Doherty et al., 2019).

Latency measures can be used to assess the effort associated with social attention/joint attention (Gredebäck et al., 2010; Oberwelland et al., 2016; Vaughn Van Hecke et al., 2012). This is notable because

research suggests that social-attention may remain less efficient or more effortful in older autistic individuals and those who exhibit the broad autism phenotype (Birmingham et al., 2017; Freeth et al., 2020), as well as in social interactions involving higher perceptual or cognitive load (Haskins et al., 2022; Hernandez et al., 2020). Thus, with development children and adults with autism may be better able to engage in social attention, but this may require greater effort which taxes the adaptive and effective use of social attention in social communication or didactic learning interactions (Mundy & Bullen, 2022).

Recall that the RDoC framework also calls for strong evidence that the behavioral measure (s) of a construct maps onto a specific biological system, such as specific functional brain circuits. In this regard, several reviews have summarized the numerous EEG, fMRI, diffusion tensor imaging and optical imaging studies of infants, children and adults that have begun to elucidate the neural circuits that activate during social attention (e.g., Mundy, 2018; Nummenmaa & Calder, 2009; Stephenson et al., 2021; Tso et al., 2020). The studies reviewed suggest that important nodes of the social attention network substantially overlap with social cognitive networks including nodes in the posterior superior temporal sulcus, medial frontal cortex, cingulate cortex, insula and striatum (see Figure 2 for an illustrative model). There is also a nascent research literature on neurotransmitters and metabolic regulators that may be involved in social attention (see Mundy & Bullen, 2022). Translational research also has begun to outline the utility of social attention measures as biomarkers of response in intervention studies with autistic children (Billeci et al., 2017; Bradshaw et al., 2019; Jones et al., 2017).

Of course, an important issue for autism research is whether social attention reflects distinct, domain specific biobehavioral mechanisms, or is better conceptualized in terms of domain general attention mechanisms. It is likely that the development of social and non-social attention reflects overlapping mechanisms, especially early in life (Braithwaite et al., 2020; Falck-Ytter et al., 2022; Nichols et al., 2005). However, theory stipulates that social attention and non-social attention mechanisms differentiate with development as the unique task demands of social attention and non-social attention lead to neural network functional adaptations and the neurodevelopment of distinct neural circuits (Mundy, 2018; Mundy & Bullen, 2022). Indeed, research suggests that social attention measures tap distinct motivation, social cognitive, and referential communication mechanisms not associated with domain general attention (e.g., Birmingham & Kingstone, 2009; Joseph et al., 2015; Mundy & Bullen, 2022; Nummenmaa & Calder, 2009) and that social and non-social attention measures provide unique and complimentary information about the development in autistic children (Bedford et al., 2014) and human social processes (Ramsey & Ward, 2020). A complete consideration of this issue is beyond the scope of

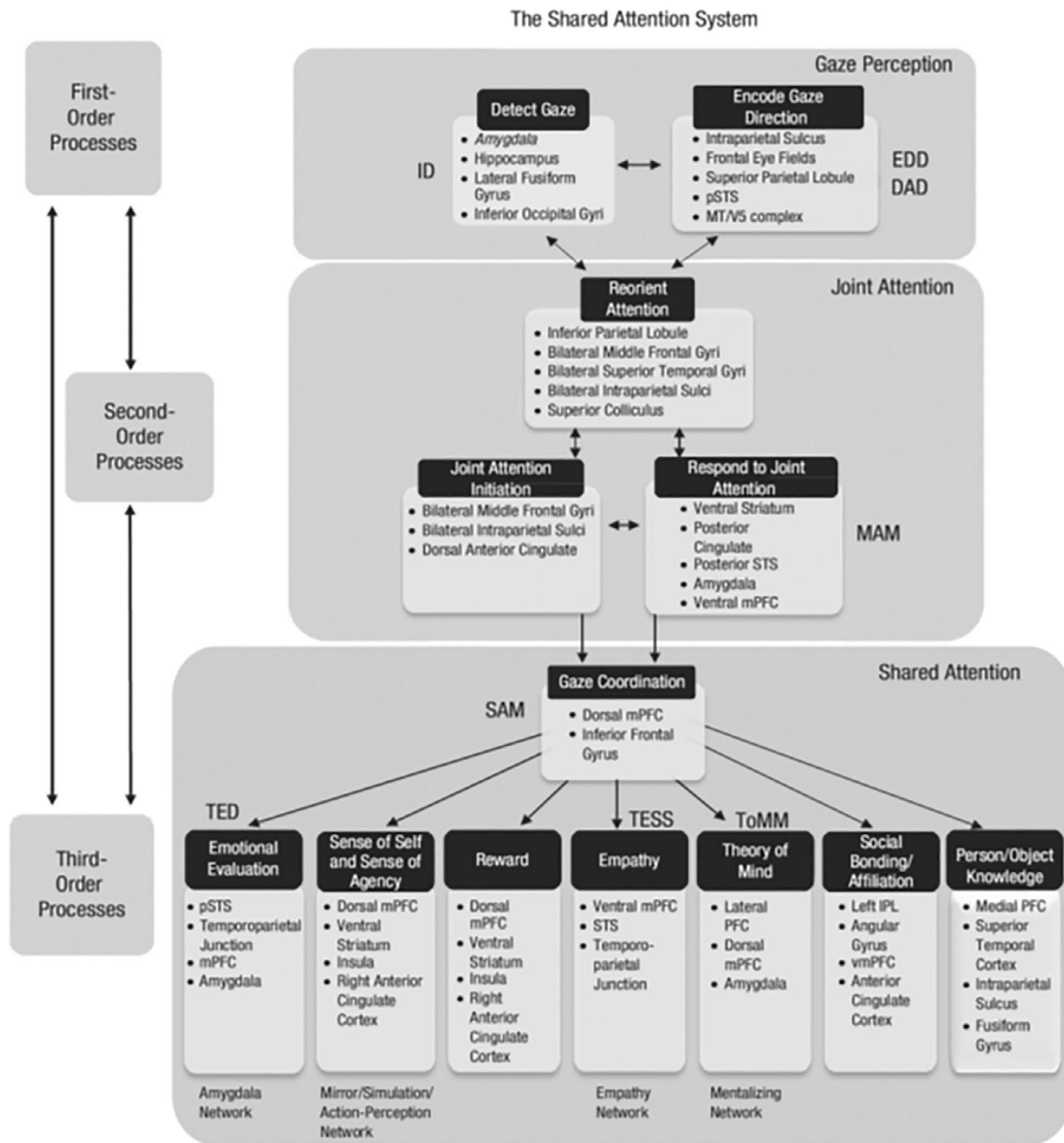
this paper but for additional discussions see Braithwaite et al. (2020), Mundy and Bullen (2022), Ramsey and Ward (2020) and Salley and Colombo (2016).

## SOCIAL ATTENTION AND THE CURRENT RDOC MATRIX

The importance of measures of social attention was recognized in the conceptualization of the RDoC social process dimension, which includes behavioral measures of joint attention, reciprocal eye contact, and eye gaze detection, as well as face scanning and animacy perception measures of social-orienting. However, the conceptualization of a social attention construct was in an early stage during the development of the RDoC. So, it is not surprising that these measures were not conceptualized as reflecting social attention *pe se*. Rather they were included as measures of other sub-constructs such as the Reception of Facial Communication, Production of Facial Communication, Reception of Non-Facial Communication. However, this designation is debatable for several reasons.

First, social attention is not limited to the visual modality. Social attention can be measured in the auditory modality and, therefore, does not always occur in conjunction with looking at faces (Adamson et al., 2021; Bigelow, 2003; Hernandez et al., 2020). Indeed, the first observations of social orienting symptoms in autism came from research on orienting to social sounds, not faces (Dawson et al., 1998; Klin, 1991). It is also the case that studies indicate that the combined complexity of visual and auditory stimuli creates a level of stimulus complexity that may impact selective social attention in autistic children. Shic et al. (2014, 2020) have observed that infants with autistic siblings, as well as toddlers with autism, display face related social attention disturbance more clearly in the presence of a speaking social partner rather than a silent social partner.

Second, social attention also may involve the “eye contact effect” (Becchio et al., 2008; Niedźwiecka, 2020; Senju & Johnson, 2009a). Again, this refers to observations that gaze directed to one’s self has an impact on cognitive arousal, attention engagement, stimulus salience, motivation and affiliative behavior in infants, children and adults (Bayliss et al., 2013; Conty et al., 2016; Hietanen, 2018; Jarick & Bencic, 2019; Rayson et al., 2019; Rogers et al., 2014). Hypothetically, the eye contact effect is a function of a “fast track” neural network that is engaged approximately 150–170 msec after perception of eye-gaze directed either toward or away from an individual (Conty et al., 2010). Eye gaze direction is first processed via the superior colliculus, pulvinar, and amygdala (see Senju & Johnson, 2009a for review) and relayed for cortical processing. Both the time scale and cortical systems involved in this effect are distinct from those deemed specific to face processing



**FIGURE 2** An illustration of one model of social processes associated with shared attention that depicts neurocognitive developmental relations between gaze processing, joint attention and social cognition from Stephenson et al. (2021, p. 563). This model illustrates how socially shared attention develops and contributes to important social cognitive outcomes including sense of self and agency, theory of mind, social bonding/affiliation and person knowledge. This model is based, in part, on Baron-Cohen's (1994, 2005) conceptualizations of the development of neurocognitive mechanisms for intentionality detection (ID), an eye-direction detection (EDD), as well as a shared attention mechanism (SAM), the emotion detector (TED), the emphasizing system (TESS) and the theory of mind mechanism (ToMM). It also incorporates the direction of attention detection (DAD) mechanism, and mutual-attention mechanism (MAM) described by Perrett and Emery (1994), as well as "social brain" networks as delineated by Stanley and Adolphs (2013), specifically the amygdala network, empathy, mentalizing and mirror/simulation/action perception networks. This figure first appeared in *Perspectives on Psychological Science* and was reprinted with permission from Sage Publications (license 5434360763908).

(George et al., 2001; Hoffman & Haxby, 2000, Hooker et al., 2003; Senju & Johnson, 2009a), such that gaze and face processing involve interactive but unique subcortical and cortical systems (Hadders-Algra, 2022; Yang & Freiwald, 2021). Hypothetically, the mechanisms specific

to the eye contact effect play a distinct role in the early development of social orienting, joint attention and the social symptoms of ASD (Akechi et al., 2014; Chevallier et al., 2012; Mundy, 2018; Mundy & Bullen, 2022; Rayson et al., 2019; Senju & Johnson, 2009b).



Third, the communicative functions of face processing and social attention are distinctly different. The former often involves the conveyance or interpretation of information about the identity of individual (e.g. Krebs et al., 2011) or their emotions provided by the expression and perception of facial affect (Mehu & Scherer, 2015). These are clearly important parts of human social process. For example, the perception of facial affect plays a role in the social regulation of behaviors, such as when negative affect of parent directed toward a novel object inhibits approach behaviors in a preschool child (Sigman et al., 1992), as well as other forms of social-emotional reciprocity in ASD (Zampella et al., 2020). Nevertheless, the communicative functions of social attention do not necessarily involve processing facial identity or affect. For example, joint attention involves declarative interpersonal referential communication (Bates et al., 1975; Bruner, 1995; Csibra, 2003). Joint attention requires the capacity of two or more people to coordinate their attention to a common perceptual referent in space (Baldwin, 1995; Butterworth & Jarrett, 1991) or a common mental referent (Mundy, 2018; O'Madagain & Tomasello, 2021), with or without the mediation of facial or vocal affect, in order to share experience or information.

The capacity for social referential attention is fundamental to both the phylogenetic (Gong & Shuai, 2012; Kwisthout et al., 2008) and ontogenetic development of human language (Baldwin, 1995; Mundy et al., 2007; Rudd et al., 2008; Tomasello et al., 2005), as well as individual differences in the development of language in autism (Bottema-Beutel, 2016; Kasari et al., 2008; Kelty-Stephen et al., 2020; Loveland & Landry, 1986). These observations have motivated research on the role of mutual gaze and joint attention in early intervention for autism (Kasari et al., 2008; Murza et al., 2016; Rollins et al., 2021). There is far less evidence that directly links face processing, or facial communication and language development (but see, Bigelow et al., 2022; Glauser et al., 2021; Pascalis et al., 2014). Of course, facial affect may impact joint attention in typical development and autism (Kasari et al., 1990), but joint attention symptoms in autism can be observed in the context of neutral facial affect (Gangi et al., 2014).

It is also the case that eye contact may elicit evidence of emotional responses and be involved in processing of identity (Nomi & Uddin, 2015). However, data on phenomenon associated with directional cuing of gaze (Tye et al., 2022) may more precisely interpreted in relation to the literature on social attention (Frischen, Bayliss, et al., 2007; Frischen, Smilek, et al., 2007; Itier & Batty, 2009; Nummenmaa & Calder, 2009) rather than under the rubric of face processing.

Fourth, individual differences in joint attention development are significantly correlated with intellectual development in autism (Harrison et al., 2016; Mundy et al., 1990; Sano et al., 2021). Didactic instruction

requires that a “learner” coordinate their attention with a “teacher,” and visa-versa, in order to share information about a common point of reference (Mundy, 2018; O'Madagain & Tomasello, 2021; Striano et al., 2006). Hence, the development of social attention/joint attention plays a fundamental role in human learning (Baldwin, 1995). Autism, in turn, is associated with a syndrome specific distribution of intellectual development wherein 35% of children are comorbid for intellectual disability and another 23% are affected by intellectual disturbance or borderline intellectual difficulties (IQ = 71–85), but 42% function in the average or above average range (IQ > 85%, Maenner et al., 2021). An early onset and chronic disturbance of social attention/joint attention may contribute to the syndrome specific distribution of IQ through its link to learning and cognitive development (Dawson, 2008; Klin et al., 2015; Mundy & Crowson, 1997; Vivanti et al., 2013). Such a link between face processing and intelligence is far less clear (Karle et al., 2018).

Notably, the RDoC does classify joint attention as a measure of the Perception and Understanding of Others but under the subconstructs of Animacy Perception and Action Perception, rather than the subconstruct of Understanding of Mental States. Arguably, though, theory and developmental research have long made the case for a direct and formative role of social attention in the development of the human capacity to understand the mental states of others (e.g., Baron-Cohen, 1994; Charman et al., 2000; Frischen, Bayliss, et al., 2007; Frischen, Smilek, et al., 2007; Itier & Batty, 2009; Mundy, 2018; Stephenson et al., 2021; Tomasello et al., 2005). Accordingly, the early development of joint attention allows infants to repeatedly adopt and experience shared perceptual perspectives with other people between 6- and 18-months of age. This provides a necessary but not sufficient source of self-other social information processing that stimulates the development of our human ability to mentally represent and adopt the perspective of another person (Mundy & Newell, 2007; Mundy et al., 2009; Tomasello et al., 2005). In other words, understanding mental states involves the cognitive developmental internalization of joint attention or the action of sharing perceptual states with other people. Support for the connection between joint attention and the development of mentalizing is supported by longitudinal studies, as noted earlier, and brain imaging studies (Mundy, 2018; Stephenson et al., 2021). The current classifications of the social attention construct in the RDoC is not currently well aligned with these observations.

## SOCIAL ATTENTION AND A REVISED RDOC FRAMEWORK

If the construct of social attention is not well classified in the current RDoC framework, what is the alternative? A

compelling argument could be made for the designation of social attention as sub-construct under the construct of Perception and Understanding of Others (e.g., Itier & Batty, 2009; Mundy, 2018; Stephenson et al., 2021; Tomasello et al., 2005). However, a recent research review suggests that the social process sub-constructs of Perception and Understanding of Other, Perception and Understanding of Self, Social Communication and Affiliation may reflect a set of social-cognitive functions that involve activation of a common set of neural circuits (Lobo et al., 2023). Hence, it may not be surprising that certain aspects social attention, such as joint attention, could be considered as a subconstruct under social communication (Charman, 2003; Farrant et al., 2011; Kasari et al., 2008). It is also the case, though, that joint attention and eye eye-contact may play significant roles in perception and development of understanding agency and the self (Metcalf & Terrace, 2013; Mundy et al., 2010; Reddy, 2003) as well as a sense of intersubjectivity, shared experience, relatedness and affiliation with other people (Mundy et al., 1994; Stephenson et al., 2021; Wolf et al., 2016; Wolf & Tomasello, 2020) but not necessarily attachment (Capps et al., 1994; Claussen et al., 2002; Naber et al., 2007).

Thus, social attention is a construct that may be fundamental to many aspects of the human social process systems. The centrality of social attention in this regard has been discussed in a recent paper by Stephenson et al. (2021) on the development of shared social attention and its role in social cognition and is illustrated in Figure 2. However, to entertain a revision of the RDoC framework that would include social attention as a construct, evidence that this construct has applications to psychopathology beyond autism would likely be required.

In this regard, research on social attention/joint attention has contributed to understanding the common and distinct phenotypic feature of autism, specific language delay, fragile X syndrome, Down syndrome, Williams Syndrome and sex chromosome trisomies (Bouw et al., 2022; Brewe et al., 2018; Franchini et al., 2019; Hahn et al., 2018; Thurman & Dimachkie Nunnally, 2022; Vivanti et al., 2017; Wolff et al., 2012). Perhaps even more relevant, Tso et al. (2020) have argued that disruptions of eye gaze perception mechanisms of social attention is a fundamental component of several other mental health conditions.

Schizophrenia is characterized by a tendency to over interpret ambiguous gaze direction information as indicative of self-referenced gaze, or the perception of being the object of attention of another person (Caruana et al., 2019; Chan et al., 2021; Hooker & Park, 2005; Tso et al., 2014; Tso, Angstadt, et al., 2021). This “self-referential bias” in the perception of gaze plays also appears to play a role in bipolar disorder and social anxiety (Berchio et al., 2017; Gamer et al., 2011; Schmitz et al., 2012; Schulze et al., 2013; Yao et al., 2018), and possibly ADHD (Mauriello et al., 2022). Alternatively,

hypo-responsiveness to self-referential gaze or the eye contact effect has been observed in research on ASD (Akechi et al., 2014; Grynspan et al., 2017, Mundy & Bullen, 2022). Interestingly, different patterns of preconscious processing of eye contact have been reported for autism (Akechi et al., 2014) and schizophrenia (Seymour et al., 2016) and differences in response to the perception of gaze direction may distinguish social attention symptoms in autism from those in social anxiety (Hessels et al., 2018). Evidence also indicates that atypical social attention correlates with differences in social-cognition in schizophrenia (Tso et al., 2014) and bipolar disorder (Tso, Burton, et al., 2021; Yao et al., 2018), just as it does in ASD (Oberwlland et al., 2017; von dem Hagen et al., 2014) and in typical development. This literature recently led Tso et al. (2020) to propose that social attention, or at least the altered eye-gaze perception, represents a common pathway to social dysfunction across psychiatric conditions regardless of diagnosis.

As alluded to earlier, in the study of social-attention it is important to employ methods to distinguish whether what appear to be social attention mechanisms can be more parsimoniously explained in terms of general attention mechanisms (Lasagna et al., 2020). Tso et al. (2014); Tso, Angstadt, et al. (2021) have reported data that indicate that self-referential or eye contact effects of gaze may be regulated by different neural networks than non-social attention mechanisms and the former contribute to different symptoms and functions in individuals with psychopathology. Similarly, domain-general visual attention disengagement and domain specific social attention have been observed to provide unique and additive predictive information about the development of ASD in infant siblings (Bedford et al., 2014). Thus, as noted previously, rather than one dimension being primary or explanatory, social and non-social attention measures may provide additive and complimentary information about the development of ASD (Bedford et al., 2014; Capozzi & Ristic, 2020; Ramsey & Ward, 2020) and psychopathology more generally (Tso et al., 2020).

One reason to expect a complimentary rather the mediational relations between social attention and general attention is that the former taps into specific neural systems (e.g., Klein et al., 2009; Yang & Freiwald, 2021) and interpersonal mental processes that are not involved in the latter (Mundy & Bullen, 2022). Social attention can be bi-directional as it often involves both seeing and being seen (Marotta et al., 2018; Myllyneva & Heitonen, 2016; Reddy, 2003). Social neuroscience has begun to document numerous significant effects of the perception of being seen or being the object of attention of other people (Heitonen, 2018; Mundy & Bullen, 2022; Rayson et al., 2019; Redcay & Schilbach, 2019; Reddy, 2003; Senju & Johnson, 2009a; Stephenson et al., 2021). These phenomena and their underlying neural mechanisms are not measured, or even measurable in non-social attention paradigms. Nevertheless, current research raises the



hypothesis that processes associated with self-referenced attention may play important roles in various forms of psychopathology (Mundy & Bullen, 2022; Schmitz et al., 2012; Schulze et al., 2013; Tso et al., 2020).

## SUMMARY AND IMPLICATIONS

We are still in the age of initial discovery about the nature and mechanisms of human development (Miller, 2003; Ochsner & Lieberman, 2001) and psychiatric conditions, especially with respect to social process systems (Pan et al., 2022). Thus, there is a need to systematically update dimensional frameworks, such as the RDoC, that are designed to guide the development of more refined taxonomies of mental disorders. Observations of reliably measured constructs that are associated with identified neural circuits, and are associated with large or consistent diagnostic groups differences, may be especially useful in this regard. Such appears to be the case with respect to the construct of social attention. However, by no stretch of the imagination has this construct been fully elucidated, but the same can be said for many of the constructs relied upon for research on mental processes. Assuming that the significance of social attention becomes more widely recognized, and included in a future iteration of the RDoC framework, here are few examples of how that could support new and valuable programs of study.

Autism and Attention Deficit Hyperactivity Disorder may be related childhood neurodevelopmental disorders of attention, rather than distinct conditions (Antshel & Russo, 2019; Baribeau et al., 2019; Grzadzinski et al., 2011; Stergiakouli et al., 2017). However, since social attention is a relatively new construct, few studies have compared these diagnostic groups on measures of social attention (Braithwaite et al., 2020). Nevertheless, Groom et al. (2017) observed that autistic and ADHD children differ in electrophysiological response to gaze cues (Groom et al., 2017) and autistic children differ for children with ADHD symptoms in the cognitive impact of having their own gaze followed in the context of joint attention (Mundy et al., 2016). It is reasonable to expect more comparative research on social attention in preschool and school-aged children would provide new insights into the common as well as unique attention mechanisms involved in autism and ADHD (Braithwaite et al., 2020).

A significant neuroimaging literature has emerged that provides a foundation for understanding the neurodevelopment of social attention development in autism (Greene et al., 2011; Mundy, 2018; Nummenmaa & Calder, 2009; Senju & Johnson, 2009b; Stephenson et al., 2021). However, surprisingly little research has been conducted to examine the cortical correlates of social attention development in autism (Mundy, 2018) or comparatively across psychiatric conditions (Tso

et al., 2020). Still, there are examples of intriguing if preliminary sets of findings. As one example, Shen et al. (2022) observed altered growth in the amygdala among 6 to 12-month old infants with faster growth related to higher social symptom scores on the SA scale of the ADOS in infants who went on to receive the diagnosis of autism. Connectivity of amygdala with the ventral-medial prefrontal cortex, via the uncinate fasciculus, at 6 months of age has also been observed to predict joint attention in the 9th month of typical development (Elison et al., 2013). However, Mosconi, Cody-Hazlett, et al. (2009) reported that rate of growth of the amygdala by 2 years of age was positively related to joint attention in autistic four-year-olds. This observation is at variance with the general understanding that enlargement of the amygdala is related poorer social development in autism (e.g. Shen et al., 2022). Together, though, the three studies indicate that methods are available to begin a concerted empirical investigation into important questions and hypotheses about the neurodevelopment social attention early in the development of children with autism.

There is a much smaller literature available on the genetics of social attention, but a foundation for future research has emerged (Mundy & Bullen, 2022). Behavioral genetics studies provide evidence of significant heritability of attention to eyes in 18-month-olds (Constantino et al., 2017), as well as gaze direction perception in adolescents (Wang et al., 2018, 2020). Several studies indicate that the dopamine, oxytocin and vasopressin transported genes are related to individual difference and the development of social attention in primates, typical development and autism (Gangi et al., 2016; Hopkins et al., 2023; Nishizato et al., 2017; Sjaarda et al., 2019; Tops et al., 2011; Wade et al., 2014). Moreover, genome wide DNA methylation is associated with attention to face stimuli with direct gaze in infant siblings of children with ASD (Gui et al., 2020) and methylation of the oxytocin receptor gene correlates with individual differences in social attention in typical adults (Puglia et al., 2018). If the construct of social attention is as central to autism, as is suggested here, then an increase in the recognition of the value of the construct for research on the genetics of social attention could advance autism science and developmental psychopathology more generally.

Finally, there is relatively little data on the development of social attention across childhood and adults in autism or other conditions. Paradigms used for preschool social attention research may not be sensitive to significant differences in social attention in older individuals (Mundy & Bullen, 2022). Instead, measures of the effort or efficiency of social attention may be more useful. Moreover, the need to consider the ecological validity in research on social processes argues that we likely need to employ new methods of second person or interpersonal neuroscience in psychiatric research on social attention

(e.g., Canigueral et al., 2022; Hoehl & Markova, 2018; Pan et al., 2022; Redcay & Schilbach, 2019).

In conclusion, over the past two decades science has begun to reveal the fundamental role of social attention in typical and atypical human social development. However, there is much more to be learned about the unique nature and role of social attention in autism and developmental psychopathology in general, and the encouragement of research in that regard is perhaps the most important point to be made in this commentary.

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## DATA AVAILABILITY STATEMENT

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

## ETHICS STATEMENT

The author declares that there were no conflicts of interest or any interest or relationships, financial or otherwise that might be perceived as influencing the objectivity of the content of this paper.

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## REFERENCES

- Abreu, C., Cardoso-Martins, C., & Barbosa, P. (2014). The relations between joint attention and theory of mind: A longitudinal study. *Psicologia: Reflexão e Crítica*, 27, 409–414.
- Adamson, L. B., Suma, K., Bakeman, R., Kellerman, A., & Robins, D. L. (2021). Auditory joint attention skills: Development and diagnostic differences during infancy. *Infant Behavior and Development*, 63, 101560.
- Akechi, H., Stein, T., Senju, A., Kikuchi, Y., Tojo, Y., Osanai, H., & Hasegawa, T. (2014). Absence of preferential unconscious processing of eye contact in adolescents with autism spectrum disorder. *Autism Research*, 7(5), 590–597.
- Antshel, K. M., & Russo, N. (2019). Autism spectrum disorders and ADHD: Overlapping phenomenology, diagnostic issues, and treatment considerations. *Current Psychiatry Reports*, 21(5), 1–11.
- Bal, V. H., Fok, M., Lord, C., Smith, I. M., Mirenda, P., Szatmari, P., Vaillancourt, T., Volden, J., Waddell, C., Zwaigenbaum, L., Bennett, T., Duku, E., Elsabbagh, M., Georgiades, S., Ungar, W. J., & Zaidman-Zait, A. (2020). Predictors of longer-term development of expressive language in two independent longitudinal cohorts of language-delayed preschoolers with autism spectrum disorder. *Journal of Child Psychology and Psychiatry*, 61(7), 826–835.
- Baldwin, D. A. (1995). Understanding the link between joint attention and language. *Joint Attention: Its Origins and Role in Development*, 131, 158.
- Baribeau, D., Dupuis, A., Paton, T., Hammill, C., Scherer, S., Schachar, R., Arnold, P. D., Szatmari, P., Nicolson, R., Georgiades, S., Crosbie, J., Brian, J., Iaboni, A., Kushki, A., Lerch, J. P., & Anagnostou, E. (2019). Structural neuroimaging correlates of social deficits are similar in autism spectrum disorder and attention deficit/hyperactivity disorder: Analysis from the POND network. *Translational Psychiatry*, 9, 1–14.
- Baron-Cohen, S. (1989). Joint-attention deficits in autism: Towards a cognitive analysis. *Development and Psychopathology*, 1(3), 185–189.
- Baron-Cohen, S. (1994). The mindreading system: New directions for research. *Current Psychology of Cognition*, 13, 724–750.
- Baron-Cohen, S. (2005). The empathizing system: A revision of the 1994 model of the mind reading system. In B. Ellis & D. Bjorklund (Eds.), *Origins of the social mind: Evolutionary psychology and child development* (pp. 468–492). Guilford.
- Bates, E., Camaioni, L., & Volterra, V. (1975). The acquisition of performatives prior to speech. *Merrill-Palmer Quarterly of Behavior and Development*, 21(3), 205–226.
- Bayliss, A. P., Murphy, E., Naughtin, C. K., Kritikos, A., Schilbach, L., & Becker, S. I. (2013). “Gaze leading”: Initiating simulated joint attention influences eye movements and choice behavior. *Journal of Experimental Psychology: General*, 142(1), 76–92.
- Becchio, C., Bertone, C., & Castiello, U. (2008). How the gaze of others influences object processing. *Trends in Cognitive Sciences*, 12(7), 254–258.
- Bedford, R., Pickles, A., Gliga, T., Elsabbagh, M., Charman, T., Johnson, M. H., & BASIS Team. (2014). Additive effects of social and non-social attention during infancy relate to later ASD spectrum disorder. *Developmental Science*, 17(4), 612–620.
- Berchio, C., Piguat, C., Michel, C. M., Cordera, P., Rihs, T. A., Dayer, A. G., & Aubry, J. M. (2017). Dysfunctional gaze processing in bipolar disorder. *Neuroimage: Clinical*, 16, 545–556.
- Bigelow, A. E. (2003). The development of joint attention in blind infants. *Development and Psychopathology*, 15(2), 259–275.
- Bigelow, F. J., Clark, G. M., Lum, J. A., & Enticott, P. G. (2022). Facial emotion processing and language during early-to-middle childhood development: An event related potential study. *Developmental Cognitive Neuroscience*, 53, 101052.
- Billeci, L., Narzisi, A., Tonacci, A., Sbriscia-Fioretti, B., Serasini, L., Fulceri, F., Apicella, F., Sicca, F., Calderoni, S., & Muratori, F. (2017). An integrated EEG and eye-tracking approach for the study of responding and initiating joint attention in Autism Spectrum Disorders. *Scientific Reports*, 7(1), 1–13.
- Birkeneder, S., Bullen, J., McIntyre, N., Zajic, M., Lerro, L., Solomon, M., Sparapani, N., & Mundy, P. (n.d., (in submission)). Diagnostic and construct validity of the Childhood Joint Attention Rating Scale (C-JARS). *Journal of Autism and Related Disability*.
- Birmingham, E., Johnson, K., & Iarocci, G. (2017). Spontaneous gaze selection and following during naturalistic social interactions in school-aged children and adolescents with autism spectrum disorder. *Canadian Journal of Experimental Psychology*, 71, 243–257.
- Birmingham, E., & Kingstone, A. (2009). Human social attention: A new look at past, present, and future investigations. *Annals of the New York Academy of Sciences*, 1156(1), 118–140.
- Bottema-Beutel, K. (2016). Associations between joint attention and language in autism spectrum disorder and typical development: A systematic review and meta-regression analysis. *Autism Research*, 9(10), 1021–1035.
- Bouw, N., Swaab, H., Tartaglia, N., & van Rijn, S. (2022). The impact of sex chromosome trisomies (XXX, XXY, XYY) on early social cognition: Social orienting, joint attention, and theory of mind. *Archives of Clinical Neuropsychology*, 37(1), 63–77.
- Bradshaw, J., Shic, F., Holden, A. N., Horowitz, E. J., Barrett, A. C., German, T. C., & Vernon, T. W. (2019). The use of eye tracking as a biomarker of treatment outcome in a pilot randomized clinical trial for young children with autism. *Autism Research*, 12(5), 779–793.
- Braithwaite, E. K., Gui, A., & Jones, E. J. (2020). Social attention: What is it, how can we measure it, and what can it tell us about autism and ADHD? *Progress in Brain Research*, 254, 271–303.

- Brewe, A. M., Reisinger, D. L., Adlof, S. M., & Roberts, J. E. (2018). Initiating joint attention use in infants at high-risk for autism spectrum disorder. *Journal of Intellectual Disability Research, 62*(10), 842–853.
- Brooks, R., & Meltzoff, A. N. (2015). Connecting the dots from infancy to childhood: A longitudinal study connecting gaze following, language, and explicit theory of mind. *Journal of Experimental Child Psychology, 130*, 67–78.
- Bruner, J. (1995). From joint attention to the meeting of minds: An introduction. In *Joint Attention: Its Origins and Role in Development* (p. 1–14). Psychological Press.
- Butterworth, G., & Jarrett, N. (1991). What minds have in common is space: Spatial mechanisms serving joint visual attention in infancy. *British Journal of Developmental Psychology, 9*(1), 55–72.
- Canigueral, R., Krishnan-Barman, S., & Hamilton, A. (2022). Social signaling as a framework for second-person neuroscience. *Psychonomic Bulletin & Review, 29*, 2083–2095.
- Capozzi, F., & Ristic, J. (2020). Attention AND mentalizing? Reframing a debate on social orienting of attention. *Visual Cognition, 28*(2), 97–105.
- Capps, L., Sigman, M., & Mundy, P. (1994). Attachment security in children with autism. *Development and Psychopathology, 6*(2), 249–261.
- Caruana, N., Seymour, K., Brock, J., & Langdon, R. (2019). Responding to joint attention bids in schizophrenia: An interactive eye-tracking study. *Quarterly Journal of Experimental Psychology, 72*(8), 2068–2083.
- Carver, C. S., & Johnson, S. L. (2018). Impulsive reactivity to emotion and vulnerability to psychopathology. *American Psychologist, 73*(9), 1067–1078.
- Chan, S. K. W., Liu, T., Wong, A. O. Y., Wong, G. H. Y., Hsiao, J., Hui, C. L. M., Chang, W. C., Lee, E. H., & Chen, E. Y. H. (2021). Self-referential gaze perception of patients with schizophrenia and its relationship with symptomatology and cognitive functions. *Schizophrenia Research, 228*, 288–294.
- Charman, T. (2003). Why is joint attention a pivotal skill in autism? *Philosophical Transactions of the Royal Society of London Series B: Biological Sciences, 358*(1430), 315–324.
- Charman, T., Baron-Cohen, S., Swettenham, J., Baird, G., Cox, A., & Drew, A. (2000). Testing joint attention, imitation, and play as infancy precursors to language and theory of mind. *Cognitive Development, 15*(4), 481–498.
- Chawarska, K., Macari, S., & Shic, F. (2013). Decreased spontaneous attention to social scenes in 6-month-old infants later diagnosed with autism spectrum disorders. *Biological Psychiatry, 74*(3), 195–203.
- Charwarska, K., Ye, S., Shic, F., & Chen, L. (2016). Multilevel differences in spontaneous social attention in toddlers with autism spectrum disorder. *Child Development, 87*(2), 543–557.
- Chevallier, C., Kohls, G., Troiani, V., Brodtkin, E. S., & Schultz, R. T. (2012). The social motivation theory of autism. *Trends in Cognitive Sciences, 16*(4), 231–239.
- Chevallier, C., Parish-Morris, J., Tonge, N., Le, L., Miller, J., & Schultz, R. T. (2014). Susceptibility to the audience effect explains performance gap between children with and without autism in a theory of mind task. *Journal of Experimental Psychology: General, 143*(3), 972–979.
- Claussen, A. H., Mundy, P. C., Mallik, S. A., & Willoughby, J. C. (2002). Joint attention and disorganized attachment status in infants at risk. *Development and Psychopathology, 14*(2), 279–291.
- Constantino, J., Kennon-McGill, S., Weichselbaum, C., Marrus, N., Haider, A., Glowinski, A., Gillespie, S., Klaiman, C., Klin, A., & Jones, W. (2017). Infant viewing of social scenes is under genetic control and is atypical in ASD. *Nature, 647*(7663), 340–344.
- Conty, L., George, N., & Hietanen, J. K. (2016). Watching Eyes effects: When others meet the self. *Consciousness and Cognition, 45*, 184–197.
- Conty, L., Gimmig, D., Belletier, C., George, N., & Huguet, P. (2010). The cost of being watched: Stroop interference increases under concomitant eye contact. *Cognition, 115*(1), 133–139.
- Cronbach, L. J., & Meehl, P. E. (1955). Construct validity in psychological tests. *Psychological Bulletin, 52*(4), 281–302.
- Csibra, G. (2003). Teleological and referential understanding of action in infancy. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences, 358*(1431), 447–458.
- Cuthbert, B. N. (2022). Research domain criteria (RDoC): Progress and potential. *Current Directions in Psychological Science, 31*(2), 107–114.
- Cuthbert, B. N., & Insel, T. R. (2013). Toward the future of psychiatric diagnosis: The seven pillars of RDoC. *BMC Medicine, 11*(1), 1–8.
- Dawson, G. (2008). Early behavioral intervention, brain plasticity, and the prevention of autism spectrum disorder. *Development and Psychopathology, 20*(3), 775–803.
- Dawson, G., Bernier, R., & Ring, R. H. (2012). Social attention: A possible early indicator of efficacy in ASD clinical trials. *Journal of Neurodevelopmental Disorders, 4*(1), 11.
- Dawson, G., Meltzoff, A. N., Osterling, J., Rinaldi, J., & Brown, E. (1998). Children with ASD fail to orient to naturally occurring social stimuli. *Journal of ASD and Developmental Disorders, 28*(6), 479–485.
- Dawson, G., Toth, K., Abbott, R., Osterling, J., Munson, J., Estes, A., & Liaw, J. (2004). Early social attention impairments in ASD: Social orienting, joint attention, and attention to distress. *Developmental Psychology, 40*(2), 271–283.
- Del Bianco, T., Mason, L., Charman, T., Tillman, J., Loth, E., Hayward, H., Shic, F., Buitelaar, J., Johnson, M. H., Jones, E. J. H., & Ahmad, J. (2021). Temporal profiles of social attention are different across development in autistic and neurotypical people. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging, 6*(8), 813–824.
- Doherty, B. R., Fraser, A., Nobre, A. C., & Scerif, G. (2019). The functional consequences of social attention on memory precision and on memory-guided orienting in development. *Developmental Cognitive Neuroscience, 36*, 100625.
- Elison, J. T., Wolff, J. J., Heimer, D. C., Paterson, S. J., Gu, H., Hazlett, H. C., Styner, M., Gerig, G., Piven, J., & IBIS Network. (2013). Frontolimbic neural circuitry at 6 months predicts individual differences in joint attention at 9 months. *Developmental Science, 16*(2), 186–197.
- Elsabbagh, M., Volein, A., Csibra, G., Holmboe, K., Garwood, H., Tucker, L., Krljes, S., Baron-Cohen, S., Bolton, P., Charman, T., Baird, G., & Johnson, M. H. (2009). Neural correlates of eye gaze processing in the infant broader autism phenotype. *Biological Psychiatry, 65*(1), 31–38.
- Emery, N. J. (2000). The eyes have it: The neuroethology, function and evolution of social gaze. *Neuroscience & Biobehavioral Reviews, 24*(6), 581–604.
- Falck-Ytter, T., Kleberg, J. L., Portugal, A. M., & Thorup, E. (2022). Social attention: Developmental foundations and relevance for autism spectrum disorder. *Biological Psychiatry. <https://doi.org/10.1016/j.biopsych.2022.09.035>*
- Farrant, B. M., Maybery, M. T., & Fletcher, J. (2011). Socio-emotional engagement, joint attention, imitation, and conversation skill: Analysis in typical development and specific language impairment. *First Language, 31*(1), 23–46.
- Feldman, R. (2017). The neurobiology of human attachments. *Trends in Cognitive Science, 21*, 80–99.
- Fonagy, P., Gergely, G., & Target, M. (2007). The parent-infant dyad and the construction of the subjective self. *The Journal of Child Psychology and Psychiatry, 48*, 288–328.
- Franchini, M., Hamodat, T., Armstrong, V. L., Sacrey, L. A., Brian, J., Bryson, S. E., Garon, N., Roberts, W., Zwaigenbaum, L., & Smith, I. M. (2019). Infants at risk for ASD spectrum disorder: Frequency, quality, and variety of joint attention behaviors. *Journal of Abnormal Child Psychology, 47*(5), 907–920.



- Franchini, M., Glaser, B., Wood de Wilde, H., Gentaz, E., Eliez, S., & Schaar, M. (2009). Social orienting and joint attention in pre-schoolers with ASD. *PLoS one*, *12*(6), e0178859.
- Frazier, T. W., Uljarevic, M., Ghazal, I., Klingemier, E. W., Langfus, J., Youngstrom, E. A., Aldosari, M., Al-Shammari, H., El-Hag, S., Tolefat, M., Ali, M., & Al-Shaban, F. A. (2021). Social attention as a cross-cultural transdiagnostic neurodevelopmental risk marker. *Autism Research*, *14*(9), 1873–1885.
- Freeth, M., & Bugembe, P. (2019). Social partner gaze direction and conversational phase; factors affecting social attention during face-to-face conversations in autistic adults? *Autism*, *23*(2), 503–513.
- Freeth, M., & Morgan, E. (2022). I see you, you see me: The impact of social presence on the social interaction processes in autistic and non-autistic people. *Philosophical Transactions of the Royal Society B: Biological Sciences*. <https://doi.org/10.1098/rstb.2021.0479>
- Freeth, M., Morgan, E., Bugembe, P., & Brown, A. (2020). How accurate are autistic adults and those high in autistic traits at making face-to-face line-of-sight judgements? *Autism*, *24*(6), 1482–1493.
- Friesen, C., & Kingstone, A. (1998). The eyes have it! Reflexive orienting is triggered by nonpredictive gaze. *Psychonomic Bulletin & Review*, *5*, 490–495.
- Frischen, A., Bayliss, A. P., & Tipper, S. P. (2007). Gaze cueing of attention: Visual attention, social cognition, and individual differences. *Psychological Bulletin*, *133*(4), 694–724.
- Frischen, A., Smilek, D., Eastwood, J., & Tipper, S. (2007). Inhibition of return in response to gaze cues: The role of time course and fixation cue. *Visual Cognition*, *15*, 881–895.
- Gamer, M., Hecht, H., Seipp, N., & Hiller, W. (2011). Who is looking at me? The cone of gaze widens in social phobia. *Cognition and Emotion*, *25*(4), 756–764.
- Gangi, D. N., Ibañez, L. V., & Messinger, D. S. (2014). Joint attention initiation with and without positive affect: Risk group differences and associations with ASD symptoms. *Journal of Autism and Developmental Disorders*, *44*(6), 1414–1424.
- Gangi, D. N., Messinger, D. S., Martin, E. R., & Cuccaro, M. L. (2016). Dopaminergic variants in siblings at high risk for autism: Associations with initiating joint attention. *Autism Research*, *9*(11), 1142–1150.
- George, N., Driver, J., & Dolan, R. J. (2001). Seen gaze-direction modulates fusiform activity and its coupling with other brain areas during face processing. *NeuroImage*, *13*(6), 1102–1112.
- Georgiades, S., Szatmari, P., & Boyle, M. (2013). Importance of studying heterogeneity in autism. *Neuropsychiatry*, *3*(2), 123–125.
- Glauser, J., Wilkinson, C. L., Gabard-Durnam, L. J., Choi, B., Tager-Flusberg, H., & Nelson, C. A. (2021). Neural correlates of face processing associated with language and social development in 12-month infants with familial risk of autism Spectrum disorder. <https://doi.org/10.21203/rs.3.rs-850435/v1>
- Gold, J. M., Barch, D. M., Carter, C. S., Dakin, S., Luck, S. J., MacDonald, A. W., III, Ragland, J. D., Ranganath, C., Kovacs, I., Silverstein, S. M., & Strauss, M. (2012). Clinical, functional, and intertask correlations of measures developed by the Cognitive Neuroscience Test Reliability and Clinical Applications for Schizophrenia Consortium. *Schizophrenia Bulletin*, *38*(1), 144–152.
- Gong, T., & Shuai, L. (2012). Modelling the coevolution of joint attention and language. *Proceedings of the Royal Society B: Biological Sciences*, *279*(1747), 4643–4651.
- Gotham, K., Risi, S., Dawson, G., Tager-Flusberg, H., Joseph, R., Carter, A., Hepburn, S., McMahon, W., Rodier, P., Hyman, S. L., Sigman, M., Rogers, S., Landa, R., Spence, M. A., Osann, K., Flodman, P., Volkmar, F., Hollander, E., Buxbaum, J., ... Lord, C. (2008). A replication of the Autism Diagnostic Observation Schedule (ADOS) revised algorithms. *Journal of the American Academy of Child and Adolescent Psychiatry*, *47*(6), 642–651.
- Gotham, K., Risi, S., Pickles, A., & Lord, C. (2007). The ASD Diagnostic Observation Schedule: Revised algorithms for improved diagnostic validity. *Journal of ASD and Developmental Disorders*, *37*(4), 613–627.
- Gredebäck, G., Fikke, L., & Melinder, A. (2010). The development of joint visual attention: A longitudinal study of gaze following during interactions with mothers and strangers. *Developmental Science*, *13*(6), 839–848.
- Greene, D. J., Colich, N., Iacoboni, M., Zaidel, E., Bookheimer, S. Y., & Dapretto, M. (2011). Atypical neural networks for social orienting in autism spectrum disorders. *NeuroImage*, *56*(1), 354–362.
- Gregory, S. E., & Kessler, K. (2022). Investigating age differences in the influence of joint attention on working memory. *Psychology and Aging*, *37*, 731–741.
- Groom, M. J., Kochhar, P., Hamilton, A., Liddle, E. B., Simeou, M., & Hollis, C. (2017). Atypical processing of gaze cues and faces explains comorbidity between autism spectrum disorder (ASD) and attention deficit/hyperactivity disorder (ADHD). *Journal of Autism and Developmental Disorders*, *47*(5), 1496–1509.
- Grynspan, O., Bouteiller, J., Grynspan, S., Le Barillier, F., Martin, J. C., & Nadel, J. (2019). Altered sense of gaze leading in ASD. *Research in ASD Spectrum Disorders*, *67*, 101441.
- Grynspan, O., Martin, J., & Fossati, P. (2017). Gaze leading is associated with liking. *Acta Psychologica*, *173*, 66–72.
- Grzadzinski, R., di Martino, A., Brady, E., Mairena, M. A., O’Neale, M., Petkova, E., Lord, C., & Castellanos, F. X. (2011). Examining autistic traits in children with ADHD: Does the autism spectrum extend to ADHD? *Journal of Autism and Developmental Disorders*, *41*(9), 1178–1191.
- Gui, A., Jones, E. J., Wong, C. C., Meaburn, E., Xia, B., Pasco, G., Lloyd-Fox, S., Charman, T., Bolton, P., Johnson, M. H., & BASIS Team. (2020). Leveraging epigenetics to examine differences in developmental trajectories of social attention: A proof-of-principle study of DNA methylation in infants with older siblings with autism. *Infant Behavior and Development*, *60*, 101409.
- Hadders-Algra, M. (2022). Human face and gaze perception is highly context specific and involves bottom-up and top-down neural processing. *Neuroscience & Biobehavioral Reviews*, *132*, 304–323.
- Hahn, L. J., Loveall, S. J., Savoy, M. T., Neumann, A. M., & Ikuta, T. (2018). Joint attention in Down syndrome: A meta-analysis. *Research in Developmental Disabilities*, *78*, 89–102.
- Hamilton, A. F. D. C., & Lind, F. (2016). Audience effects: What can they tell us about social neuroscience, theory of mind and autism? *Culture and Brain*, *4*(2), 159–177.
- Harrison, A. J., Lu, Z. L., McLean, R. L., & Sheinkopf, S. J. (2016). Cognitive and adaptive correlates of an ADOS-derived joint attention composite. *Research in Autism Spectrum Disorders*, *29*, 66–78.
- Harrop, C., Jones, D. R., Sasson, N. J., Zheng, S., Nowell, S. W., & Parish-Morris, J. (2020). Social and object attention is influenced by biological sex and toy gender-congruence in children with and without ASD. *ASD Research*, *13*(5), 763–776.
- Haskins, A., Mentch, J., Botch, T., Garcia, B., Burrows, A., & Roberson, C. (2022). Reduced social attention in autism is magnified by perceptual load in naturalistic environment. *Autism Research*. <https://doi.org/10.1002/aur.2829>
- Hernandez, L. M., Green, S. A., Lawrence, K. E., Inada, M., Liu, J., Bookheimer, S. Y., & Dapretto, M. (2020). Social attention in autism: Neural sensitivity to speech over background noise predicts encoding of social information. *Frontiers in Psychiatry*, *11*, 343.
- Hessels, R. S., Holleman, G. A., Cornelissen, T. H., Hooge, I. T., & Kemner, C. (2018). Eye contact takes two—autistic and social anxiety traits predict gaze behavior in dyadic interaction. *Journal of Experimental Psychopathology*, *9*(2), jep.062917.
- Hietanen, J. K. (2018). Affective eye contact: An integrative review. *Frontiers in Psychology*, *9*, 1587. <https://doi.org/10.3389/fpsyg.2018.01587>

- Hoehl, S., & Markova, G. (2018). Moving developmental social neuroscience toward a second person approach. *PLoS Biology*, *16*(12), e3000055.
- Hoffman, E. A., & Haxby, J. V. (2000). Distinct representations of eye gaze and identity in the distributed human neural system for face perception. *Nature Neuroscience*, *3*, 80–84.
- Hollander, E., Cartwright, C., Wong, C. M., DeCaria, C. M., DelGiudice-Asch, G., Buchsbaum, M. S., & Aronowitz, B. R. (1998). A dimensional approach to the autism spectrum. *CNS Spectrums*, *3*(3), 22–39.
- Hooker, C., Paller, K., Gitelman, D., Parrich, T., Mesulam, M., & Reber, P. (2003). Brain networks for analyzing eye gaze. *Cognitive Brain Research*, *17*(2), 406–418.
- Hooker, C., & Park, S. (2005). You must be looking at me: The nature of gaze perception in schizophrenia patients. *Cognitive Neuropsychiatry*, *10*(5), 327–345.
- Hopkins, W. D., Staes, N., Guevara, E. E., Mulholland, M. M., Sherwood, C. C., & Bradley, B. J. (2023). Vasopressin, and not oxytocin, receptor gene methylation is associated with individual differences in receptive joint attention in chimpanzees (*Pan troglodytes*). *Autism Research*, *16*, 713–722. <https://doi.org/10.1002/aur.2895>
- Hyman, S. E. (2019). New evidence for shared risk architecture of mental disorders. *JAMA Psychiatry*, *76*(3), 235–236.
- Hyman, S. E. (2021). Psychiatric disorders: Grounded in human biology but not natural kinds. *Perspectives in Biology and Medicine*, *64*(1), 6–28.
- Insel, T., Cuthbert, B., Garvey, M., Heinssen, R., Pine, D. S., Quinn, K., Sanislow, C., & Wang, P. (2010). Research domain criteria (RDoC): Toward a new classification framework for research on mental disorders. *American Journal of Psychiatry*, *167*(7), 748–751.
- Itier, R. J., & Batty, M. (2009). Neural bases of eye and gaze processing: The core of social cognition. *Neuroscience & Biobehavioral Reviews*, *33*(6), 843–863.
- Jarick, M., & Bencic, R. (2019). Eye contact is a two-way street: Arousal is elicited by the sending and receiving of eye gaze information. *Frontiers in Psychology*, *10*, 1262.
- Ji, H., Wang, L., & Jiang, Y. (2020). Cross-category adaptation of reflexive social attention. *Journal of Experimental Psychology: General*, *149*(11), 2145–2153.
- Jones, E. J., Dawson, G., Kelly, J., Estes, A., & Webb, S. J. (2017). Parent-delivered early intervention in infants at risk for ASD: Effects on electrophysiological and habituation measures of social attention. *Autism Research*, *10*(5), 961–972.
- Jones, W., & Klin, A. (2013). Attention to eyes is present but in decline in 2–6-month-old infants later diagnosed with ASD. *Nature*, *504*(7480), 427–431.
- Joseph, R. M., Fricker, Z., & Keehn, B. (2015). Activation of frontoparietal attention networks by non-predictive gaze and arrow cues. *Social Cognitive and Affective Neuroscience*, *10*(2), 294–301.
- Karle, K. N., Ethofer, T., Jacob, H., Brück, C., Erb, M., Lotze, M., Nizielski, S., Schütz, A., Wildgruber, D., & Kreifelts, B. (2018). Neurobiological correlates of emotional intelligence in voice and face perception networks. *Social Cognitive and Affective Neuroscience*, *13*(2), 233–244.
- Kasari, C., Paparella, T., Freeman, S., & Jahromi, L. B. (2008). Language outcome in autism: Randomized comparison of joint attention and play interventions. *Journal of Consulting and Clinical Psychology*, *76*(1), 125–137.
- Kasari, C., Sigman, M., Mundy, P., & Yirmiya, N. (1990). Affective sharing in the context of joint attention interactions of normal, autistic, and mentally retarded children. *Journal of Autism and Developmental Disorders*, *20*(1), 87–100.
- Kelty-Stephen, E., Fein, D. A., & Naigles, L. R. (2020). Children with ASD use joint attention and linguistic skill in pronoun development. *Language Acquisition*, *27*(4), 410–433.
- Kim, H., Keifer, C., Rodriguez-Seijas, C., Eaton, N., Lerner, M., & Gadow, K. (2019). Quantifying the optimal structure of the autism phenotype: A comprehensive comparison of dimensional, categorical, and hybrid models. *Journal of the American Academy of Child & Adolescent Psychiatry*, *58*(9), 876–886.
- Klein, J. T., Shepherd, S. V., & Platt, M. L. (2009). Social attention and the brain. *Current Biology*, *19*(20), R958–R962.
- Kliemann, D., & Adolphs, R. (2018). The social neuroscience of mentalizing: Challenges and recommendations. *Current Opinion in Psychology*, *24*, 1–6.
- Klin, A. (1991). Young autistic children's listening preferences in regard to speech: A possible characterization of the symptom of social withdrawal. *Journal of ASD and Developmental Disorders*, *21*(1), 29–42.
- Klin, A., Jones, W., Schultz, R., Volkmar, F., & Cohen, D. (2002). Defining and quantifying the social phenotype in autism. *American Journal of Psychiatry*, *159*(6), 895–908.
- Klin, A., Shultz, S., & Jones, W. (2015). Social visual engagement in infants and toddlers with ASD: Early developmental transitions and a model of pathogenesis. *Neuroscience & Biobehavioral Reviews*, *50*, 189–203.
- Krebs, J., Biswas, A., Pascalis, O., Kamp-Becker, I., Remschmidt, H., & Schwarzer, G. (2011). Face processing in children with autism spectrum disorder: Independent or interactive processing of facial identity and facial expression? *Journal of Autism and Developmental Disorders*, *41*, 796–804.
- Kuhn-Popp, N., Kristen, S., Paulus, M., Meinhardt, J., & Sodian, B. (2015). Left hemisphere EEG coherence in infancy predicts infant declarative pointing and preschool epistemic language. *Social Neuroscience*, *11*, 49–59.
- Kwisthout, J., Vogt, P., Haselager, P., & Dijkstra, T. (2008). Joint attention and language evolution. *Connection Science*, *20*(2–3), 155–171.
- Lasagna, C. A., McLaughlin, M. M., Deng, W. Y., Whiting, E. L., & Tso, I. F. (2020). Deconstructing eye contact perception: Measuring perceptual precision and self-referential tendency using an online psychophysical eye contact detection task. *PLoS One*, *15*(3), e0230258.
- Lobo, R., Bottenhorn, K., Riedel, M., Toma, A., Hare, M., Smith, D., Moor, A., Cowan, I. K., Valdes, J. A., Bartley, J. E., Salo, T., Boeving, E. R., Pankey, B., Sutherland, M. T., Musser, E. D., & Laird, A. (2023). Neural systems underlying RDoC social constructs: An activation likelihood estimation meta-analysis. *Neuroscience & Biobehavioral Reviews*, *144*, 104971. <https://doi.org/10.1016/j.neubiorev.2022.104971>
- Lord, C., & Jones, R. M. (2012). Annual Research Review: Re-thinking the classification of autism spectrum disorders. *Journal of Child Psychology and Psychiatry*, *53*(5), 490–509.
- Lord, C., Rutter, M., DiLavore, P., Risi, S., Gotham, K., & Bishop, S. (2012). *Autism and diagnostic observation schedule, second edition (ADOS-2)*. [Manual Modules 1-4]. Western Psychological Services.
- Loveland, K. A., & Landry, S. H. (1986). Joint attention and language in autism and developmental language delay. *Journal of Autism and Developmental Disorders*, *16*(3), 335–349.
- MacCorquodale, K., & Meehl, P. E. (1948). On a distinction between hypothetical constructs and intervening variables. *Psychological Review*, *55*(2), 95–107.
- Maenner, M. J., Shaw, K. A., Bakian, A. V., Bilder, D. A., Durkin, M. S., Esler, A., Furnier, S. M., Hallas, L., Hall-Lande, J., Hudson, A., Hughes, M. M., Patrick, M., Pierce, K., Poynter, J. N., Salinas, A., Shenouda, J., Vehorn, A., Warren, Z., Constantino, J. N., ... Cogswell, M. E. (2021). Prevalence and characteristics of autism spectrum disorder among children aged 8 years—Autism and developmental disabilities monitoring network, 11 sites, United States, 2018. *MMWR Surveillance Summaries*, *70*(11), 1–16.
- Maljaars, J., Noens, I., Scholte, E., & van Berckelaer-Onnes, I. (2012). Language in low-functioning children with autistic disorder: Differences between receptive and expressive skills and concurrent

- predictors of language. *Journal of Autism and Developmental Disorders*, 42(10), 2181–2191.
- Marotta, A., Román-Caballero, R., & Lupiáñez, J. (2018). Arrows don't look at you: Qualitatively different attentional mechanisms triggered by gaze and arrows. *Psychonomic Bulletin & Review*, 25(6), 2254–2259.
- Mauriello, C., Pham, E., Kumar, S., Pigué, C., Deiber, M. P., Aubry, J. M., Dayer, A., Michel, C. M., Perroud, N., & Berchio, C. (2022). Dysfunctional temporal stages of eye-gaze perception in adults with ADHD: A high-density EEG study. *Biological Psychology*, 108351, 108351.
- McKay, K. T., Talipski, L. A., Grainger, S. A., Alister, M., & Henry, J. D. (2022). How does aging affect social attention? A test of competing theories using multilevel meta-analysis. *The Journals of Gerontology: Series B*, 77(8), 1454–1463.
- Mehu, M., & Scherer, K. R. (2015). Emotion categories and dimensions in the facial communication of affect: An integrated approach. *Emotion*, 15(6), 798–811.
- Metcalf, J., & Terrace, H. S. (Eds.). (2013). *Agency and joint attention*. Oxford University Press.
- Miller, G. A. (2003). The cognitive revolution: A historical perspective. *Trends in Cognitive Sciences*, 7(3), 141–144.
- Morgan, E. J., Smith, D. T., & Freeth, M. (2023). Gaze cueing, mental states, and the effect of autistic traits. *Attention, Perception, & Psychophysics*, 85, 485–493.
- Mosconi, M. W., Cody-Hazlett, H., Poe, M. D., Gerig, G., Gimpel-Smith, R., & Piven, J. (2009). Longitudinal study of amygdala volume and joint attention in 2-to 4-year-old children with autism. *Archives of General Psychiatry*, 66(5), 509–516.
- Mosconi, M. W., Reznick, J. S., Mesibov, G., & Piven, J. (2009). The Social Orienting Continuum and Response Scale (SOC-RS): A dimensional measure for preschool-aged children. *Journal of ASD and Developmental Disorders*, 39(2), 242–250.
- Mundy, P. (2018). A review of joint attention and social-cognitive brain systems in typical development and ASD spectrum disorder. *European Journal of Neuroscience*, 47(6), 497–514.
- Mundy, P. (2021). Autism and the social mind. *Scientific American*, 324(5), 87–88. <https://www.scientificamerican.com/article/autism-and-the-social-mind/?print=true>
- Mundy, P., Block, J., Delgado, C., Pomares, Y., Van Hecke, A. V., & Parlade, M. V. (2007). Individual differences and the development of joint attention in infancy. *Child Development*, 78(3), 938–954.
- Mundy, P., & Bullen, J. (2022). The bidirectional social-cognitive mechanisms of the social-attention symptoms of autism. *Frontiers in Psychiatry*, 12, 752274. <https://doi.org/10.3389/fpsy.2021.752274>
- Mundy, P., & Crowson, M. (1997). Joint attention and early social communication: Implications for research on intervention with autism. *Journal of Autism and Developmental Disorders*, 27(6), 653–676.
- Mundy, P., Gwaltney, M., & Henderson, H. (2010). Self-referenced processing, neurodevelopment and joint attention in autism. *Autism*, 14(5), 408–429.
- Mundy, P., Kim, K., McIntyre, N., Lerro, L., & Jarrold, W. (2016). Brief report: Joint attention and information processing in children with higher functioning ASD spectrum disorders. *Journal of ASD and Developmental Disorders*, 46(7), 2555–2560.
- Mundy, P., & Newell, L. (2007). Attention, joint attention, and social cognition. *Current Directions in Psychological Science*, 16(5), 269–274.
- Mundy, P., & Sigman, M. (1989). The theoretical implications of joint-attention deficits in autism. *Development and Psychopathology*, 1(3), 173–183.
- Mundy, P., Sigman, M., & Kasari, C. (1990). A longitudinal study of joint attention and language development in autistic children. *Journal of Autism and Developmental Disorders*, 20(1), 115–128.
- Mundy, P., Sigman, M., & Kasari, C. (1994). Joint attention, developmental level, and symptom presentation in autism. *Development and Psychopathology*, 6(3), 389–401.
- Mundy, P., Sigman, M., Ungerer, J., & Sherman, T. (1986). Defining the social deficits of ASD: The contribution of non-verbal communication measures. *Journal of Child Psychology and Psychiatry*, 27(5), 657–669.
- Mundy, P., Sullivan, L., & Mastergeorge, A. (2009). A parallel and distributed-processing model of joint attention, social cognition and autism. *Autism Research*, 2(1), 2–21.
- Murza, K. A., Schwartz, J. B., Hahs-Vaughn, D. L., & Nye, C. (2016). Joint attention interventions for children with autism spectrum disorder: A systematic review and meta-analysis. *International Journal of Language & Communication Disorders*, 51(3), 236–251.
- Myllyneva, A., & Hietanen, J. (2016). The dual nature of eye contact: To see and to be seen. *Social Cognitive and Affective Neuroscience*, 11(7), 1089–1095.
- Naber, F., Swinkels, S., Buitelaar, J., Dietz, C., Van Daalen, E., Bakermans-Kranenburg, M., Van IJzendoorn, M. H., & Van Engeland, H. (2007). Joint attention and attachment in toddlers with autism. *Journal of Abnormal Child Psychology*, 35, 899–911.
- Nayar, K., Shic, F., Winston, M., & Losh, M. (2022). A constellation of eye-tracking measures reveals social attention differences in ASD and the broad autism phenotype. *Molecular Autism*, 13(1), 1–23.
- Nichols, K. E., Fox, N., & Mundy, P. (2005). Joint attention, self-recognition, and neurocognitive function in toddlers. *Infancy*, 7(1), 35–51.
- Niedźwiecka, A. (2020). Look me in the eyes: Mechanisms underlying the eye contact effect. *Child Development Perspectives*, 14(2), 78–82.
- Nishizato, M., Fujisawa, T., Kosaka, H., & Tomada, A. (2017). Developmental changes in social attention and oxytocin levels in infants and children. *Scientific Reports*, 7, 2540. <https://doi.org/10.1038/s41598-017-02368-x>
- Nomi, J. S., & Uddin, L. Q. (2015). Face processing in autism spectrum disorders: From brain regions to brain networks. *Neuropsychologia*, 71, 201–216.
- Nowell, S. W., Watson, L. R., Crais, E. R., Baranek, G. T., Faldowski, R. A., & Turner-Brown, L. (2020). Joint attention and sensory-regulatory features at 13 and 22 months as predictors of preschool language and social-communication outcomes. *Journal of Speech, Language, and Hearing Research*, 63, 1–17.
- Nummenmaa, L., & Calder, A. J. (2009). Neural mechanisms of social attention. *Trends in Cognitive Sciences*, 13(3), 135–143.
- Oberwilling, E., Schilbach, L., Barisic, I., Krall, S. C., Vogeley, K., Fink, G. R., Herpertz-Dahlmann, B., Konrad, K., & Schulte-Rüther, M. (2016). Look into my eyes: Investigating joint attention using interactive eye-tracking and fMRI in a developmental sample. *NeuroImage*, 130, 248–260.
- Oberwilling, E., Schilbach, L., Barisic, I., Krall, S. C., Vogeley, K., Fink, G. R., Herpertz-Dahlmann, B., Konrad, K., & Schulte-Rüther, M. (2017). Young adolescents with autism show abnormal joint attention network: A gaze contingent fMRI study. *NeuroImage: Clinical*, 14, 112–121.
- Ochsner, K. N., & Lieberman, M. D. (2001). The emergence of social cognitive neuroscience. *American Psychologist*, 56(9), 717–734.
- O'Madagain, C., & Tomasello, M. (2021). Joint attention to mental content and the social origin of reasoning. *Synthese*, 198(5), 4057–4078.
- Pan, Y., Novembre, G., & Olsson, A. (2022). The interpersonal neuroscience of social learning. *Perspectives on Psychological Science*, 17(3), 680–695.
- Pascalis, O., Loevenbruck, H., Quinn, P. C., Kandel, S., Tanaka, J. W., & Lee, K. (2014). On the links among face processing, language processing, and narrowing during development. *Child Development Perspectives*, 8(2), 65–70.
- Perrett, D., & Emery, N. (1994). Understanding the intentions of others from visual signals: Neurophysiological evidence. *Cashiers de Psychologies Cognitives/Current Psychology of Cognition*, 13, 683–694.



- Puglia, M. H., Connelly, J. J., & Morris, J. P. (2018). Epigenetic regulation of the oxytocin receptor is associated with neural response during selective social attention. *Translational Psychiatry, 8*(1), 1–10.
- Purcell, D. G., & Stewart, A. L. (1988). The face-detection effect: Configuration enhances detection. *Perception & Psychophysics, 43*(4), 355–366.
- Ramsey, R., & Ward, R. (2020). Putting the nonsocial into social neuroscience: A role for domain-general priority maps during social interactions. *Perspectives on Psychological Science, 15*(4), 1076–1094.
- Rayson, H., Bonaiuto, J. J., Ferrari, P. F., Chakrabarti, B., & Murray, L. (2019). Building blocks of joint attention: Early sensitivity to having one's own gaze followed. *Developmental Cognitive Neuroscience, 37*, 100631.
- Redcay, E., & Schilbach, L. (2019). Using second-person neuroscience to elucidate the mechanisms of social interaction. *Nature Reviews Neuroscience, 20*(8), 495–505.
- Reddy, V. (2003). On being the object of attention: Implications for self–other consciousness. *Trends in Cognitive Sciences, 7*(9), 397–402.
- Ristic, J., & Capozzi, F. (2022). Mechanisms for individual, group-based and crowd-based attention to social information. *Nature Reviews Psychology, 1*(12), 721–732.
- Ristic, J., Wright, A., & Kingstone, A. (2007). Attentional control and reflexive orienting to gaze and arrow cues. *Psychonomic Bulletin & Review, 14*, 964–969.
- Robins, D. L., Casagrande, K., Barton, M., Chen, C. M. A., Dumont-Mathieu, T., & Fein, D. (2014). Validation of the modified checklist for ASD in toddlers, revised with follow-up (M-CHAT-R/F). *Pediatrics, 133*(1), 37–45.
- Rogers, R. D., Bayliss, A. P., Szepietowska, A., Dale, L., Reeder, L., Pizzamiglio, G., Czarna, K., Wakeley, J., Cowen, P. J., & Tipper, S. P. (2014). I want to help you, but I am not sure why: Gaze-cuing induces altruistic giving. *Journal of Experimental Psychology: General, 143*(2), 763–777.
- Rollins, P. R., De Froy, A., Campbell, M., & Hoffman, R. T. (2021). Mutual gaze: An active ingredient for social development in toddlers with ASD: A randomized control trial. *Journal of Autism and Developmental Disorders, 51*(6), 1921–1938.
- Rudd, L. C., Cain, D. W., & Saxon, T. F. (2008). Does improving joint attention in low-quality child-care enhance language development? *Early Child Development and Care, 178*(3), 315–338.
- Salley, B., & Colombo, J. (2016). Conceptualizing social attention in developmental research. *Social Development, 25*(4), 687–703.
- Sanislow, C. A., Morris, S. E., Cuthbert, B. N., & Pacheco, J. (2022). Development and environment in the National Institute of Mental Health (NIMH) Research Domain Criteria. *Journal of Psychopathology and Clinical Science, 131*(6), 653–659.
- Sanislow, C. A., Pine, D. S., Quinn, K. J., Kozak, M. J., Garvey, M. A., Heinssen, R. K., Wang, P. S. E., & Cuthbert, B. N. (2010). Developing constructs for psychopathology research: Research domain criteria. *Journal of Abnormal Psychology, 119*(4), 631–639.
- Sano, M., Yoshimura, Y., Hirotsawa, T., Hasegawa, C., An, K. M., Tanaka, S., Naitou, N., & Kikuchi, M. (2021). Joint attention and intelligence in children with autism spectrum disorder without severe intellectual disability. *Autism Research, 14*(12), 2603–2612.
- Schmitz, J., Scheel, C. N., Rigon, A., Gross, J. J., & Blechert, J. (2012). You don't like me, do you? Enhanced ERP responses to averted eye gaze in social anxiety. *Biological Psychology, 91*(2), 263–269.
- Schulze, L., Renneberg, B., & Lobmaier, J. S. (2013). Gaze perception in social anxiety and social anxiety disorder. *Frontiers in Human Neuroscience, 7*, 872.
- Senju, A., & Johnson, M. H. (2009a). The eye contact effect: Mechanisms and development. *Trends in Cognitive Sciences, 13*(3), 127–134.
- Senju, A., & Johnson, M. H. (2009b). Atypical eye contact in autism: Models, mechanisms and development. *Neuroscience & Biobehavioral Reviews, 33*(8), 1204–1214.
- Seymour, K., Rhodes, G., Stein, T., & Langdon, R. (2016). Intact unconscious processing of eye contact in schizophrenia. *Schizophrenia Research: Cognition, 3*, 15–19.
- Shen, M. D., Swanson, M. R., Wolff, J. J., Elison, J. T., Girault, J. B., Kim, S. H., Smith, R. G., Graves, M. M., Weisenfeld, L. A. H., Flake, L., MacIntyre, L., Gross, J. L., Burrows, C. A., Fonov, V. S., Collins, D. L., Evans, A. C., Gerig, G., McKinstry, R. C., Pandey, J., ... for the IBIS Network. (2022). Subcortical brain development in autism and fragile X syndrome: Evidence for dynamic, age- and disorder-specific trajectories in infancy. *The American Journal of Psychiatry, 179*, 562–572.
- Shic, F., Macari, S., & Chawarska, K. (2014). Speech disturbs face scanning in 6-month-old infants who develop autism spectrum disorder. *Biological Psychiatry, 75*(3), 231–237.
- Shic, F., Wang, Q., Macari, S. L., & Chawarska, K. (2020). The role of limited salience of speech in selective attention to faces in toddlers with autism spectrum disorders. *Journal of Child Psychology and Psychiatry, 61*(4), 459–469.
- Sigman, M., & Mundy, P. (1989). Social attachments in autistic children. *Journal of the American Academy of Child & Adolescent Psychiatry, 28*(1), 74–81.
- Sigman, M. D., Kasari, C., Kwon, J. H., & Yirmiya, N. (1992). Responses to the negative emotions of others by autistic, mentally retarded, and normal children. *Child Development, 63*(4), 796–807.
- Sjaarda, C. P., Sabbagh, M., Wood, S., Ward-King, J., McNaughton, A. J., Hudson, M. L., Tao, M., Ayub, M., & Liu, X. (2019). Homozygosity for the 10-repeat dopamine transporter (DAT1) allele is associated with reduced EEG response in males with ASD. *Research in Autism Spectrum Disorders, 60*, 25–35.
- Sodian, B., & Kristen-Antonow, S. (2015). Declarative joint attention as a foundation of theory of mind. *Developmental Psychology, 51*, 1190–1200.
- Stallworthy, I. C., Lasch, C., Berry, D., Wolff, J. J., Pruett, J. R., Jr., Marrus, N., Swanson, M. R., Botteron, K. N., Dager, S. R., Estes, A. M., Hazlett, H. C., Schultz, R. T., Zwaigenbaum, L., Piven, J., Elison, J. T., & IBIS Network. (2022). Variability in responding to joint attention cues in the first year is associated with autism outcome. *Journal of the American Academy of Child & Adolescent Psychiatry, 61*(3), 413–422.
- Stanley, D., & Adolphs, R. (2013). Toward a neural basis for social behavior. *Neuron, 80*, 816–826.
- Stephenson, L. J., Edwards, S. G., & Bayliss, A. P. (2021). From gaze perception to social cognition: The shared-attention system. *Perspectives on Psychological Science, 16*(3), 553–576.
- Stergiakouli, E., Davey Smith, G., Martin, J., Skuse, D. H., Viechtbauer, W., Ring, S. M., Ronald, A., Evans, D. E., Fisher, S. E., Thapar, A., & St Pourcain, B. (2017). Shared genetic influences between dimensional ASD and ADHD symptoms during child and adolescent development. *Molecular Autism, 8*(1), 1–13.
- Stone, W. L., Coonrod, E. E., Turner, L. M., & Pozdol, S. L. (2004). Psychometric properties of the STAT for early ASD screening. *Journal of ASD and Developmental Disorders, 34*(6), 691–701.
- Strauss, M. E., & Smith, G. T. (2009). Construct validity: Advances in theory and methodology. *Annual Review of Clinical Psychology, 5*, 1–25.
- Striano, T., Chen, X., Cleveland, A., & Bradshaw, S. (2006). Joint attention social cues influence infant learning. *European Journal of Developmental Psychology, 3*(3), 289–299.
- Swanson, M. R., Serlin, G. C., & Siller, M. (2013). Broad autism phenotype in typically developing children predicts performance on an eye-tracking measure of joint attention. *Journal of Autism and Developmental Disorders, 43*(3), 707–718.

- Swanson, M. R., & Siller, M. (2014). Brief report: Broad autism phenotype in adults is associated with performance on an eye-tracking measure of joint attention. *Journal of Autism and Developmental Disorders*, *44*(3), 694–702.
- Thurm, A., Lord, C., Lee, L. C., & Newschaffer, C. (2007). Predictors of language acquisition in preschool children with autism spectrum disorders. *Journal of Autism and Developmental Disorders*, *37*(9), 1721–1734.
- Thurman, A. J., & Dimachkie Nunnally, A. (2022). Joint attention performance in preschool-aged boys with autism or fragile X syndrome. *Frontiers in Psychology*, *13*. <https://doi.org/10.3389/fpsyg.2022.918181>
- Tomasello, M., Carpenter, M., Call, J., Behne, T., & Moll, H. (2005). Understanding and sharing intentions: The origins of cultural cognition. *Behavioral and Brain Sciences*, *28*(5), 675–691.
- Tops, M., Van Ijzendoorn, M. H., Riem, M. M., Boksem, M. A., & Bakermans-Kranenburg, M. J. (2011). Oxytocin receptor gene associated with the efficiency of social auditory processing. *Frontiers in Psychiatry*, *2*, 60.
- Tso, I. F., Angstadt, M., Rutherford, S., Peltier, S., Diwadkar, V. A., & Taylor, S. F. (2021). Dynamic causal modeling of eye gaze processing in schizophrenia. *Schizophrenia Research*, *229*, 112–121.
- Tso, I. F., Burton, C. Z., Lasagna, C. A., Rutherford, S., Yao, B., Peltier, S. J., Johnson, T. D., McInnis, M. G., & Taylor, S. F. (2021). Aberrant activation of the mentalizing brain system during eye gaze discrimination in bipolar disorder. *Psychiatry Research: Neuroimaging*, *315*, 111340.
- Tso, I. F., Carp, J., Taylor, S. F., & Deldin, P. J. (2014). Role of visual integration in gaze perception and emotional intelligence in schizophrenia. *Schizophrenia Bulletin*, *40*(3), 617–625.
- Tso, I. F., Lasagna, C. A., Fitzgerald, K. D., Colombi, C., Sripada, C., Peltier, S. J., Johnson, T. D., & Thakkar, K. N. (2020). Disrupted eye gaze perception as a biobehavioral marker of social dysfunction: An RDoC investigation. *Journal of Psychiatry and Brain Science*, *5*, 1–22.
- Tye, C., Bussu, G., Gliga, T., Elsabbagh, M., Pasco, G., Johnsen, K., Charman, T., Jones, E. J. H., Buitelaar, J., Johnson, M. H., & BASIS team. (2022). Understanding the nature of face processing in early autism: A prospective study. *Journal of Psychopathology and Clinical Science*, *131*(6), 542–555.
- Vallorani, A., Brown, K. M., Fu, X., Gunther, K. E., MacNeill, L. A., Ermanni, B., Hallquist, M. N., & Pérez-Edgar, K. (2022). Relations between social attention, expressed positive affect and behavioral inhibition during play. *Developmental Psychology*, *58*, 2036–2048.
- Vaughn Van Hecke, A. V., Mundy, P., Block, J. J., Delgado, C. E., Parlade, M. V., Pomares, Y. B., & Hobson, J. A. (2012). Infant responding to joint attention, executive processes, and self-regulation in preschool children. *Infant Behavior and Development*, *35*(2), 303–311.
- Vivanti, G., Barbaro, J., Hudry, K., Dissanayake, C., & Prior, M. (2013). Intellectual development in autism spectrum disorders: New insights from longitudinal studies. *Frontiers in Human Neuroscience*, *7*, 354.
- Vivanti, G., Fanning, P. A., Hocking, D. R., Sievers, S., & Dissanayake, C. (2017). Social attention, joint attention and sustained attention in autism spectrum disorder and Williams syndrome: Convergences and divergences. *Journal of Autism and Developmental Disorders*, *47*(6), 1866–1877.
- Vivanti, G., & Messinger, D. S. (2021). Theories of autism and autism treatment from the DSM III through the present and beyond: Impact on research and practice. *Journal of Autism and Developmental Disorders*, *51*(12), 4309–4320.
- von dem Hagen, E. A., Stoyanova, R. S., Rowe, J. B., Baron-Cohen, S., & Calder, A. J. (2014). Direct gaze elicits atypical activation of the theory-of-mind network in autism spectrum conditions. *Cerebral Cortex*, *24*(6), 1485–1492.
- Wade, M., Hoffmann, T. J., Wigg, K., & Jenkins, J. M. (2014). Association between the oxytocin receptor (OXTR) gene and children's social cognition at 18 months. *Genes, Brain and Behavior*, *13*(7), 603–610.
- Wang, L., Wang, Y., Xu, Q., Liu, D., Ji, H., Yu, Y., Hu, Z., Yuan, P., & Jiang, Y. (2020). Heritability of reflexive social attention triggered eye gaze and walking direction: common and unique genetic underpinnings. *Psychological Medicine*, *50*(3), 475–483.
- Wang, Y., Wang, L., Xu, Q., Liu, D., Chen, L., Troje, N., He, S., & Jiang, Y. (2018). Heritable aspects of biological motion perception and its covariation with autistic traits. *Proceedings of the National Academy of Sciences*, *115*(8), 1937–1942.
- Warrier, V., Zhang, X., Reed, P., Havdahl, A., Moore, T. M., Cliquet, F., Leblond, C. S., Rolland, T., Rosengren, A., EU-AIMS LEAP, Caceres, A. S. J., Hayward, H., Crawley, D., Faulkner, J., Sabet, J., Ellis, C., Oakley, B., Loth, E., Charman, T., ... Baron-Cohen, S. (2022). Genetic correlates of phenotypic heterogeneity in autism. *Nature Genetics*, *54*, 1293–1304. <https://doi.org/10.1038/s41588-022-01072-5>
- Wetherby, A., & Prutting, C. (1984). Profiles of communicative and cognitive-social abilities in autistic children. *Journal of Speech, Language and Hearing Research*, *27*(3), 364–377.
- Wolf, W., Launay, J., & Dunbar, R. I. (2016). Joint attention, shared goals, and social bonding. *British Journal of Psychology*, *107*(2), 322–337.
- Wolf, W., & Tomasello, M. (2020). Watching a video together creates social closeness between children and adults. *Journal of Experimental Child Psychology*, *189*, 104712.
- Wolff, J. J., Bodfish, J. W., Hazlett, H. C., Lightbody, A. A., Reiss, A. L., & Piven, J. (2012). Evidence of a distinct behavioral phenotype in young boys with fragile X syndrome and autism. *Journal of the American Academy of Child & Adolescent Psychiatry*, *51*(12), 1324–1332.
- Yang, Z., & Freiwald, W. A. (2021). Joint encoding of facial identity, orientation, gaze, and expression in the middle dorsal face area. *Proceedings of the National Academy of Sciences*, *118*(33), e2108283118.
- Yao, B., Mueller, S. A., Grove, T. B., McLaughlin, M., Thakkar, K., Ellingrod, V., McInnis, M. G., Taylor, S. F., Deldin, P. J., & Tso, I. F. (2018). Eye gaze perception in bipolar disorder: Self-referential bias but intact perceptual sensitivity. *Bipolar Disorders*, *20*(1), 60–69.
- Zachor, D. A., & Ben-Itzhak, E. (2020). From toddlerhood to adolescence, trajectories and predictors of outcome: Long-term follow-up study in autism Spectrum disorder. *Autism Research*, *13*(7), 1130–1143.
- Zampella, C. J., Bennetto, L., & Herrington, J. D. (2020). Computer vision analysis of reduced interpersonal affect coordination in youth with autism spectrum disorder. *Autism Research*, *13*(12), 2133–2142.
- Zhao, S., Uono, S., Yoshimura, S., Kubota, Y., & Toichi, M. (2017). Atypical gaze cueing pattern in a complex environment in individuals with ASD. *Journal of Autism and Developmental Disorders*, *47*(7), 1978–1986.

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