Published in final edited form as:

J Autism Dev Disord. 2012 June ; 42(6): . doi:10.1007/s10803-012-1514-z.

The Implications of Social Neuroscience for Social Disability

James C. McPartland and Kevin A. Pelphrey

Yale Child Study Center at Yale University

Abstract

Social disability represents a unifying feature in the diverse group of individuals with autism spectrum disorder (ASD). Social neuroscience is the study of brain mechanisms supporting interpersonal interaction. In this paper, we review brain imaging studies of the social brain and highlight practical applications of these scientific insights. Understanding of social brain mechanisms holds promise as a tool for defining meaningful subgroups of children with ASD to facilitate genetic analyses and inform treatment selection. Because social brain systems emerge in infancy, social neuroscience may help to detect atypical development before symptoms manifest. This conceptualization of ASD is a hopeful one, as social brain systems remain malleable well into development and thus amenable to targeted intervention.

Keywords

Autism Spectrum Disorder; social neuroscience; translational neuroscience

A social disorder and a social brain

Autism is a disorder of brain development that emerges in the first three years of life. The current edition of the classification system used for psychiatric diagnoses in the United States, the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition (American Psychiatric Association, 2000), lists autism in the category of Pervasive Developmental Disorders. In this class, Autistic Disorder, Asperger's Disorder, and Pervasive Developmental Disorder – Not Otherwise Specified, together, are conceptually grouped as autism spectrum disorder (ASD). ASD is characterized by difficulties in (a) social interaction and (b) communication, along with (c) repetitive or restricted interests and behaviors. Diagnostic evaluation is based on clinical observation and parent-report of problems in these areas; children with significant difficulties spanning the social domain and either or both of the other domains may qualify for a diagnosis of ASD. There are 12 individual diagnostic criteria, and a child may meet diagnostic threshold while exhibiting as few as 2 or 3 of these symptoms. Thus, there is wide variability in the specific symptoms that any child may display. This *phenotypic heterogeneity* mirrors variability in the genetic causes of ASD (Geschwind & Levitt, 2007; Gupta & State, 2007). Research has identified many genetic anomalies associated with individual cases of ASD, but each accounts for only a small portion of cases (Weiss et al., 2008). The large number of potential genetic mechanisms suggests that no single explanation will apply to the majority of cases (Abrahams & Geschwind, 2008). There is currently no biological test for ASD.

Correspondence concerning this article should be addressed to James McPartland, Yale Child Study Center, 230 South Frontage Road, New Haven, Connecticut 06520, Phone: 203-785-7179, james.mcpartland@yale.edu.

The authors report no conflicts of interest.

Despite the wide variation in presentation of children with ASD, important commonalities have been observed since Leo Kanner (1943) first described the disorder and emphasized its particular impact on social functioning. In the years of research that have followed, despite wide variation in factors such as intellectual ability, executive function, and attentional characteristics, social impairment stands as a universal feature of the disorder. Though diagnostic criteria have evolved during the past 70 years and continue to evolve, social dysfunction remains a required symptom to qualify for a diagnosis of ASD. Differences in social functioning are present for simple (e.g., eye contact) and complex behaviors (e.g., navigating group conversations), bearing remarkable similarity in manifestation between very high- or low-functioning individuals. Likewise, difficulties with social perception occur across both visual (Pelphrey et al., 2002) and auditory (Dawson, Meltzoff, Osterling, Rinaldi, & Brown, 1998) sensory modalities. While repetitive behaviors or language deficits are seen in other disorders (e.g., obsessive-compulsive disorder and specific language impairment, respectively), basic social deficits of this nature are unique to ASD. Furthermore, in the course of autistic development, onset of the social deficits appears to precede difficulties in other domains (Osterling, Dawson, & Munson, 2002; Osterling & Dawson, 1994; Zwaigenbaum et al., 2005) and may emerge by 6 months of age (Maestro et al., 2002).

These behaviorally observed and quantified differences in social behavior provide a target for understanding the brain bases of ASD. During the last few decades, research has elucidated specific brain circuits that support perception of other living beings, in humans and in other species. This *social perception* refers to “the initial stages in the processing of information that culminates in the accurate analysis of the dispositions and intentions of other individuals” (Allison, Puce, & McCarthy, 2000). Both in terms of the evolution of a species and brain development within a person’s lifetime, basic social perception represents a necessary precursor to more sophisticated social behaviors, such as thinking about the motives and emotions of others. Leslie Brothers (1990) first put forward the notion of a *social brain*, a network of brain regions dedicated to processing social information and enabling us to recognize other individuals and to evaluate their mental states (e.g., intentions, dispositions, desires, and beliefs). The social brain is hypothesized to consist of the superior temporal sulcus (STS), the amygdala, the orbital frontal cortex (OFC), and the fusiform gyrus (FG), among other structures. Though all work in coordination to support social processing, each appears to serve a distinct role. In humans, the STS region, particularly the posterior STS in the right hemisphere, analyzes biological motion cues, including eye, hand, and other body movements, to interpret and predict the actions and intentions of others (e.g., Bonda, Petrides, Ostry, & Evans, 1996; Pelphrey, Morris, Michelich, Allison, & McCarthy, 2005). The FG, located in the ventral occipitotemporal cortex, has been implicated in face detection (identifying a face as a face) and face recognition (identifying one’s friend versus a stranger; e.g., Kanwisher, McDermott, & Chun, 1997; Puce, Allison, Asgari, Gore, & McCarthy, 1996). The OFC supports social reinforcement and reward processes more broadly (e.g., Rolls, 2000). Finally, the amygdala helps us recognize the emotional states of others through analysis of facial expressions (e.g., Morris et al., 1996) and also to experience and regulate emotion (e.g., Davis & Whalen, 2001; Kluver & Bucy, 1939; LeDoux, 1992).

Current understanding of social perception in ASD

Because the functions of the social brain correspond closely to social difficulties in ASD, this network has become a focus of study. Multiple brain imaging technologies have been employed, but here we focus on the two most commonly used methods, functional magnetic resonance imaging (fMRI) and event-related potentials (ERP). fMRI and ERP are complementary imaging methods; though both are appropriate for the study of brain

function in ASD from infancy through adulthood, each measures a distinct facet of brain activity and contributes unique strengths to scientific inquiry. fMRI entails the use of powerful magnets to measure the levels of oxygen within the brain that vary with changes in neural activity. That is, as the neurons in specific brain regions “work harder” when performing a specific task, they require more oxygen. By having people listen to or view social percepts in an MRI scanner, fMRI specifies the brain regions that evidence a relative increase in blood flow. In this way, fMRI provides excellent spatial information, pinpointing with millimeter accuracy, the brain regions most critical for different social processes. ERP, in contrast, directly measures the firing of groups of neurons in the cortex. As a person views or listens to specific types of information, neuronal activity creates small electrical currents that can be recorded from non-invasive sensors placed on the scalp. ERP provides excellent information about the timing of processing, clarifying brain activity at the millisecond pace at which it unfolds. The excellent *spatial resolution* of fMRI and *temporal resolution* of ERP offer complementary information, and both have been critical in understanding the nature of social perception in ASD. From fMRI, we learn what brain regions are involved and whether different regions are activated in people with ASD and typically developing people. From ERP, we learn the specific stages of processing that might be affected (the same brain regions can perform distinct functions at different points in a perceptual process) as well as differences in the timing of social perceptual processes. Both imaging methods have revealed much about the functions of the social brain in both typical and typical development. To date, the most thoroughly investigated nodes of the social brain in ASD are the STS, underlying perception and interpretation of biological motion, and the FG, supporting face perception.

Heightened sensitivity to biological motion serves an essential role in the development of humans and other social species, orienting vulnerable young to critical sources of sustenance, support, and learning. The ability to detect biological motion emerges in the first days of life and develops independent of visual experience. Babies as young as two-days-old recognize and preferentially attend to biological motion (Simion, Regolin, & Bulf, 2008), and people can infer complex attributes about identity, activity, and emotional state from even dramatically simplified displays of human form (Dittrich, Troscianko, Lea, & Morgan, 1996; Troje, 2002). Distinction of biological motion occurs rapidly; by 200 milliseconds, the brain distinguishes biological motion from other forms of movement (Hirai, Fukushima, & Hiraki, 2003; Hirai & Hiraki, 2005; Hirai, Watanabe, Honda, & Kakigi, 2009; Jokisch, Daum, Suchan, & Troje, 2005; Reid, Hoehl, Landt, & Striano, 2008; Reid, Hoehl, & Striano, 2006). This remarkable sensitivity to biological motion serves as an inborn “life detector” that provides a foundation for subsequent development of more complex social behaviors (Johnson, 2006). Behavioral studies have shown that from very early in life, children with ASD display reduced sensitivity to biological motion (Klin, Lin, Gorrindo, Ramsay, & Jones, 2009). Neuroimaging studies show that individuals with ASD show in portions of the STS reduced activity during biological motion perception while individuals at genetic risk for ASD who do not develop symptoms of the disorder show increased compensatory activity in these regions (e.g., Kaiser et al., 2010).

Face perception is also an important function of the social brain that has been well studied in ASD (Schultz, 2005). In typical development, preferential attention to faces and the ability to recognize individual faces emerge in the first days of life (Bushnell, Sai, & Mullin, 1989; Goren, Sarty, & Wu, 1975; Johnson, Dziurawiec, Ellis, & Morton, 1991). Brain specialization for face perception is evident by three months of age (de Haan, Johnson, & Halit, 2003; Leppanen & Nelson, 2009) and throughout the lifespan (Haxby et al., 1994; Kanwisher, McDermott, & Chun, 1997; Puce, Allison, Gore, & McCarthy, 1995; Bentin, Allison, Puce, Perez, & et al., 1996). In ASD, decreased attention to human faces has been documented by 6 to 12 months (Maestro, et al., 2002; Osterling & Dawson, 1994), and

behavioral difficulties and attentional differences in face perception and recognition are evident in children and adults (Hobson, 1986; Hobson, Ouston, & Lee, 1988; Joseph & Tanaka, 2003; Klin et al., 1999; Langdell, 1978; Schultz, 2005; Klin, Jones, Schultz, Volkmar, & Cohen, 2002; Spezio, Adolphs, Hurley, & Piven, 2006). Children with autism show reduced activity in the FG during free viewing of faces (Hubl et al., 2003; Pierce, Mueller, Ambrose, Allen, & Courchesne, 2001; Schultz, 2005; Schultz et al., 2000) that may reflect underlying differences in visual attention (Dalton, Nacewicz, Alexander, & Davidson, 2007; Dalton et al., 2005). People with ASD also show slowed processing of faces (McPartland, Dawson, Webb, Panagiotides, & Carver, 2004; McPartland et al., 2011; O'Connor, Hamm, & Kirk, 2005, 2007; Webb, Dawson, Bernier, & Panagiotides, 2006), a finding that has also been observed in parents of children with ASD (Dawson et al., 2005) and infants at-risk for ASD by virtue of having an older sibling with the disorder (McCleery, Akshoomoff, Dobkins, & Carver, 2009).

Research has yet to clarify to what extent these atypicalities in the social brain reflect causes of autism versus experience-dependent reflections of developing with autism. For example, social deficits might result from inborn difficulties with perceiving faces; in contrast, difficulties with face perception might simply reflect a consequence of failing to attend to faces during important periods of development. Most likely, some combination of these factors is at play. Autistic dysfunction originates in social brain systems but exerts secondary impact on the same systems through developmental effects, such as lost learning; an initial problem with social function worsens over time. This premise underlies the social motivation hypothesis, an account theorizing that reduced social drive in ASD leads to inattention to people and consequent failure of developmental specialization in experience-driven brain systems, such as the face perception system (Dawson, Webb, & McPartland, 2005).

Practical implications and future directions

Harnessing heterogeneity

Scientific findings from social neuroscience evidence heterogeneity similar to that described by preceding behavioral and clinical studies. These differences among samples of children with ASD possess great potential for defining meaningful subgroups of ASD, or *parsing the heterogeneity* of ASD. Because of the limited specificity of the behavioral methods used to diagnose ASD and the current diagnostic rubric, which permits similar diagnoses despite distinct symptom profiles (McPartland, Webb, Keehn, & Dawson, 2011), it is likely that the group of children currently referred to as having ASD may actually represent different syndromes with distinct causes. Studies of the social brain promise to reveal meaningful subgroups of children with ASD. Measurements of brain activity in specific regions and the timing of this activity provide reliable sources of detailed information to more accurately profile children with ASD. For example, even well replicated findings, such as atypical brain activation during face perception, are not evident in all samples of individuals with ASD (Hadjikhani et al., 2004; Jemel, Mottron, & Dawson, 2006; Kemner, Schuller, & van Engeland, 2006; Kleinhans et al., 2008; Lahaie et al., 2006; Pierce, Haist, Sedaghat, & Courchesne, 2004; Senju, Tojo, Yaguchi, & Hasegawa, 2005; Webb et al., 2009). One of the goals of social neuroscience research is to harness this informative variance to effectively define subgroups. We see the integration of imaging methods as critical for this endeavor. Using face perception as an example, the combination of fMRI and ERP could specify the subgroup of individuals showing anomalies in the fusiform gyrus and further determine the stage of processing at which such atypicalities occur. Because different processing stages reflect varied cognitive processes, this level of understanding could inform treatment. For example, differences observed in the early processing stages might reflect problems with low-level visual perception, while later differences would indicate problems with higher-

order processes, such as emotion decoding. These same principles can be applied to the broader network of social brain regions and combined with measures of behavioral functioning to offer a comprehensive profile of brain-behavior performance for a given individual.

One straightforward objective of this subgroup approach is to improve the ability to tailor treatments to the individual. For example, a common target for social skills intervention in ASD is face perception (e.g., recognition of identity or emotion). Based on social neuroscience findings of atypical FFA activity in ASD, specific computer programs have been designed to target the specific processing mechanisms typically applied to faces (e.g., processing them in a holistic rather than piecemeal way; Wolf et al., 2008). However, detection of normative activity in some children with ASD suggests that such interventions might not be appropriate for all children. With the insight provided by multimodal assays of the social brain, treatment providers would be equipped with specific knowledge to address the unique profiles of strengths and vulnerabilities evident in their patients. Over time, as practitioners and scientists work together to learn which profiles respond best to particular interventions (i.e., specific content or mode of intervention), these descriptive profiles could enable providers to predict likely response to treatment, a critical goal in establishing a hierarchy of intervention objectives and in long-term planning for children on the autism spectrum. We are working towards this objective in our research group at present. By identifying individuals demonstrating atypical brain responses in an emotion regulation task, we can refer them to cognitive-behavioral therapy specifically addressing this skill. Furthermore, by recording ERP and fMRI before and after treatment, we are able to directly tie brain change to behavior change (Sukhodolsky et al., 2011). In some cases, such prognostications might be made very early in life; in children who develop learning disabilities, neonatal ERP responses predict functioning up to 8 years later (deRegnier, Nelson, Thomas, Wewerka, & Georgieff, 2000; Molfese, 2000). In addition to specifying areas of vulnerability as treatment targets, brain research might also highlight areas of proficiency upon which to capitalize. Recent work from our group demonstrates that unaffected siblings of children with ASD share some anomalies in social brain function but demonstrate apparent compensatory activity in other regions of the social brain (Kaiser et al., 2010). This finding suggests that interventions designed to bolster functioning of this brain region or its behavioral correlates might effectively improve social function of individuals with ASD.

A second objective of dissecting heterogeneity is to improve the power of other scientific tools. Most studies of individuals with ASD are designed to compare groups of individuals. This commonly entails contrasting individuals on the autism spectrum with typically developing peers; however, studies have also attempted to compare children on the spectrum grouped by differential diagnosis (e.g., Asperger's Disorder versus Autistic Disorder) or by other characteristics (e.g., cognitively able versus intellectually disabled). The power of a scientific study to detect differences is only as strong as the accuracy of the factor used to define groups. With the more complex, descriptive approaches detailed above, subtler and more accurate distinctions will become possible. This is especially critical for investigations into the genetic bases of ASD. Distinct findings from neuroimaging, or *biomarkers*, can guide genetic research. *Endophenotypes*, or characteristics that reflect a genetic liability for disease reflect the most basic components of a complex clinical presentation and are less developmentally malleable than overt behavior (Gottesman & Shields, 1973). By describing specific characteristics in these objective ways, neuroimaging research will facilitate identification of genetic contributions to ASD.

Detecting atypical development in the absence of atypical behavior

At present, clinical detection of autistic symptoms and ultimate diagnosis of the disorder is entirely reliant on observation of behavior. Across development, but especially during infancy, behavior is widely variable and often unreliable. Moreover, many of the social features of autism do not emerge in typical development until after 12 months of age, and one cannot be certain whether they will manifest during the limited periods of observation involved in clinical evaluations or in pediatrician's offices. In published research to-date, even highly sophisticated behavioral methods, such as eye tracking, do not reveal differences in children with ASD until 12 months (Ozonoff et al., 2010). The imaging methods we have described offer promise for earlier detection of the derailment of social development. Measuring brain activity associated with social perception can detect differences that are not evident in behavior until much later. ERP studies of typical social development reveal that three-month old infants make social-perceptual distinctions unobservable with behavioral methods until six months later (Gliga & Dehaene-Lambertz, 2005). A recent study demonstrated that ERP measures of brain response to eye gaze in infants as young as six months who showed normal patterns of visual fixation predicted subsequent development of autism, suggesting the great promise of brain imaging for early recognition of ASD (Elsabbagh et al., 2012). With earlier detection, treatments could move from treating extant symptoms to preventing their emergence by altering the course of abnormal brain development, steering it toward normality.

Hope for improved outcomes

We see the neuroimaging research described above, as well as social brain theories of autism, more broadly, as harbingers of hope for the future of ASD treatment. Many of the functions of the social brain reflect significant *plasticity*, meaning that, despite clear roles in development, their functioning can be affected by experience over time. For example, the same brain regions involved in face perception are co-opted for other cognitive functions when people learn intensively about them. When aficionados of birds or cars immerse themselves in the area of interest, to efficiently process the depth of information required for rapid identification, they begin to employ face-processing regions, developmentally experienced in making these types of rapid distinctions (Tanaka & Curran, 2001). Because these experts were not "reared" on these objects, it makes clear that nodes of the social brain can be re-activated even when the typical window of developmental exposure has lapsed. In contrast to theories that the brains of people with autism have difficulty processing complex information or communicating across large expanses of cortex (Minshew & Williams, 2007), we see this characteristic of the social brain as a positive prognosticator for the development of treatment; the brains of people with ASD are not *broken*, but rather they are not wired to process social information optimally in a world in which these calculations are taken for granted. The plasticity of the social brain suggests that, rather than representing an insurmountable obstacle, remediation of these difficulties may be possible with appropriate and timely intervention.

Acknowledgments

This work was supported by NIMH K23MH086785 (JM), NIMH R21MH091309 (JM), NARSAD Atherton Young Investigator Award (JM), and NIMH K01MH071284 (KP).

References

- Abrahams BS, Geschwind DH. Advances in autism genetics: on the threshold of a new neurobiology. *Nature reviews Genetics*. 2008; 9(5):341–355.
- Allison T, Puce A, McCarthy G. Social perception from visual cues: role of the STS region. *Trends in Cognitive Science*. 2000; 4(7):267–278.

- American Psychiatric Association. Diagnostic and statistical manual of mental disorders: DSM-IV-TR. 4. Washington, DC: American Psychiatric Association; 2000.
- Bentin S, Allison T, Puce A, Perez E, et al. Electrophysiological studies of face perception in humans. *Journal of Cognitive Neuroscience*. 1996; 8(6):551–565. [PubMed: 20740065]
- Bonda E, Petrides M, Ostry D, Evans A. Specific involvement of human parietal systems and the amygdala in the perception of biological motion. *Journal of Neuroscience*. 1996; 16(11):3737–3744. [PubMed: 8642416]
- Bushnell I, Sai F, Mullin J. Neonatal recognition of the mother's face. *British Journal of Developmental Psychology*. 1989; 7:3–15.
- Brothers L. The social brain: a project for integrating primate behavior and neurophysiology in a new domain. *Concepts in Neuroscience*. 1990; 1:27–51.
- Dalton KM, Nacewicz BM, Alexander AL, Davidson RJ. Gaze-fixation, brain activation, and amygdala volume in unaffected siblings of individuals with autism. *Biol Psychiatry*. 2007; 61(4):512–520. [PubMed: 17069771]
- Dalton KM, Nacewicz BM, Johnstone T, Schaefer HS, Gernsbacher MA, Goldsmith HH, et al. Gaze fixation and the neural circuitry of face processing in autism. *Nat Neurosci*. 2005; 8(4):519–526. [PubMed: 15750588]
- Davis M, Whalen PJ. The amygdala: vigilance and emotion. *Molecular Psychiatry*. 2001; 6(1):13–34. [PubMed: 11244481]
- Dawson G, Meltzoff AN, Osterling J, Rinaldi J, Brown E. Children with autism fail to orient to naturally occurring social stimuli. *Journal of Autism & Developmental Disorders*. 1998; 28(6):479–485. [PubMed: 9932234]
- Dawson G, Webb SJ, McPartland J. Understanding the nature of face processing impairment in autism: insights from behavioral and electrophysiological studies. *Dev Neuropsychol*. 2005; 27(3):403–424. [PubMed: 15843104]
- Dawson G, Webb SJ, Wijsman E, Schellenberg G, Estes A, Munson J, et al. Neurocognitive and electrophysiological evidence of altered face processing in parents of children with autism: implications for a model of abnormal development of social brain circuitry in autism. *Dev Psychopathol*. 2005; 17(3):679–697. [PubMed: 16262987]
- de Haan M, Johnson MH, Halit H. Development of face-sensitive event-related potentials during infancy: a review. *Int J Psychophysiol*. 2003; 51(1):45–58. [PubMed: 14629922]
- deRegnier RA, Nelson CA, Thomas KM, Wewerka S, Georgieff MK. Neurophysiologic evaluation of auditory recognition memory in healthy newborn infants and infants of diabetic mothers. *J Pediatr*. 2000; 137(6):777–784. [PubMed: 11113833]
- Dittrich WH, Troscianko T, Lea SE, Morgan D. Perception of emotion from dynamic point-light displays represented in dance. *Perception*. 1996; 25(6):727–738. [PubMed: 8888304]
- Elsabbagh M, Mercure E, Hudry K, Chandler S, Pasco G, Charman T, et al. Infant neural sensitivity to dynamic eye gaze is associated with later emerging autism. *Curr Biol*. 2012; 22(4):338–342. [PubMed: 22285033]
- Geschwind DH, Levitt P. Autism spectrum disorders: developmental disconnection syndromes. *Current Opinion in Neurobiology*. 2007; 17(1):103–111. [PubMed: 17275283]
- Gliga T, Dehaene-Lambertz G. Structural encoding of body and face in human infants and adults. *J Cogn Neurosci*. 2005; 17(8):1328–1340. [PubMed: 16197687]
- Goren CC, Sarty M, Wu PY. Visual following and pattern discrimination of face-like stimuli by newborn infants. *Pediatrics*. 1975; 56(4):544–549. [PubMed: 1165958]
- Gottesman II, Shields J. Genetic theorizing and schizophrenia. *Br J Psychiatry*. 1973; 122:15–30. [PubMed: 4683020]
- Gupta AR, State MW. Recent advances in the genetics of autism. *Biol Psychiatry*. 2007; 61(4):429–437. [PubMed: 16996486]
- Hadjikhani N, Joseph RM, Snyder J, Chabris CF, Clark J, Steele S, et al. Activation of the fusiform gyrus when individuals with autism spectrum disorder view faces. *Neuroimage*. 2004; 22(3):1141–1150. [PubMed: 15219586]

- Haxby JV, Grady CL, Horwitz B, Ungerleider JM, Maisog M, Pietrini P. The functional organization of human extrastriate cortex: A PET/CT study of selective attention to faces and locations. *The Journal of Neuroscience*. 1994; 14:6336–6353. [PubMed: 7965040]
- Hirai M, Fukushima H, Hiraki K. An event-related potentials study of biological motion perception in humans. *Neuroscience Letters*. 2003; 344(1):41–44. [PubMed: 12781917]
- Hirai M, Hiraki K. An event-related potentials study of biological motion perception in human infants. *Brain Res Cogn Brain Res*. 2005; 22(2):301–304. [PubMed: 15653301]
- Hirai M, Watanabe S, Honda Y, Kakigi R. Developmental changes in point-light walker processing during childhood and adolescence: An event-related potential study. *Neuroscience*. 2009; 161(1):311–325. [PubMed: 19303916]
- Hobson R. The autistic child's appraisal of expressions of emotion. *Journal of Child Psychology and Psychiatry*. 1986; 27(3):321–342. [PubMed: 3733915]
- Hobson R, Ouston J, Lee A. What's in a face? The case of autism. *British Journal of Psychology*. 1988; 79:441–453. [PubMed: 3208000]
- Hubl D, Bolte S, Feineis-Matthews S, Lanfermann H, Federspiel A, Strik W, et al. Functional imbalance of visual pathways indicates alternative face processing strategies in autism. *Neurology*. 2003; 61(9):1232–1237. [PubMed: 14610126]
- Jemel B, Mottron L, Dawson M. Impaired face processing in autism: fact or artifact? *J Autism Dev Disord*. 2006; 36(1):91–106. [PubMed: 16477517]
- Johnson MH. Biological motion: a perceptual life detector? *Curr Biol*. 2006; 16(10):R376–377. [PubMed: 16713949]
- Johnson MH, Dziurawiec S, Ellis H, Morton J. Newborns' preferential tracking of face-like stimuli and its subsequent decline. *Cognition*. 1991; 40(1-2):1–19. [PubMed: 1786670]
- Jokisch D, Daum I, Suchan B, Troje NF. Structural encoding and recognition of biological motion: evidence from event-related potentials and source analysis. *Behav Brain Res*. 2005; 157(2):195–204. [PubMed: 15639170]
- Joseph R, Tanaka J. Holistic and part-based face recognition in children with autism. *Journal of Child Psychology and Psychiatry*. 2003; 44(4):529–542. [PubMed: 12751845]
- Kaiser MD, Hudac CM, Shultz S, Lee SM, Cheung C, Berken AM, et al. Neural signatures of autism. *Proceedings of the National Academy of Sciences of the United States of America*. 2010; 107(49):21223–21228. [PubMed: 21078973]
- Kanner L. Autistic disturbances of affective contact. *Nervous Child*. 1943; 2:217–250.
- Kanwisher N, McDermott J, Chun MM. The fusiform face area: a module in human extrastriate cortex specialized for face perception. *Journal of Neuroscience*. 1997; 17(11):4302–4311. [PubMed: 9151747]
- Kemner C, Schuller AM, van Engeland H. Electrocortical reflections of face and gaze processing in children with pervasive developmental disorder. *J Child Psychol Psychiatry*. 2006; 47(10):1063–1072. [PubMed: 17073985]
- Kleinmans NM, Richards T, Sterling L, Stegbauer KC, Mahurin R, Johnson LC, et al. Abnormal functional connectivity in autism spectrum disorders during face processing. *Brain*. 2008; 131(Pt 4):1000–1012. [PubMed: 18234695]
- Klin A, Jones W, Schultz R, Volkmar F, Cohen D. Visual fixation patterns during viewing of naturalistic social situations as predictors of social competence in individuals with autism. *Archives of General Psychiatry*. 2002; 59(9):809–816. [PubMed: 12215080]
- Klin A, Lin DJ, Gorrindo P, Ramsay G, Jones W. Two-year-olds with autism orient to non-social contingencies rather than biological motion. *Nature*. 2009; 459(7244):257–261. [PubMed: 19329996]
- Klin A, Sparrow S, De Bildt A, Cicchetti D, Cohen D, Volkmar F. A normed study of face recognition in autism and related disorders. *Journal of Autism & Developmental Disorders*. 1999; 29(6):499–508. [PubMed: 10638462]
- Kluver H, Bucy PC. Preliminary analysis of functions of the temporal lobes in monkeys. *Archives of Neurology and Psychiatry*. 1939; 42(6):979–1000.

- Lahaie A, Mottron L, Arguin M, Berthiaume C, Jemel B, Saumier D. Face perception in high-functioning autistic adults: evidence for superior processing of face parts, not for a configural face-processing deficit. *Neuropsychology*. 2006; 20(1):30–41. [PubMed: 16460220]
- Langdell T. Recognition of faces: an approach to the study of autism. *J Child Psychol Psychiatry*. 1978; 19(3):255–268. [PubMed: 681468]
- Leppanen JM, Nelson CA. Tuning the developing brain to social signals of emotions. *Nat Rev Neurosci*. 2009; 10(1):37–47. [PubMed: 19050711]
- LeDoux JE. Brain mechanisms of emotion and emotional learning. *Current Opinion in Neurobiology*. 1992; 2(2):191–197. [PubMed: 1638153]
- Maestro S, Muratori F, Cavallaro MC, Pei F, Stern D, Golse B, et al. Attentional skills during the first 6 months of age in autism spectrum disorder. *J Am Acad Child Adolesc Psychiatry*. 2002; 41(10):1239–1245. [PubMed: 12364846]
- McCleery JP, Akshoomoff N, Dobkins KR, Carver LJ. Atypical face versus object processing and hemispheric asymmetries in 10-month-old infants at risk for autism. *Biol Psychiatry*. 2009; 66(10):950–957. [PubMed: 19765688]
- McPartland JC, Dawson G, Webb SJ, Panagiotides H, Carver LJ. Event-related brain potentials reveal anomalies in temporal processing of faces in autism spectrum disorder. *J Child Psychol Psychiatry*. 2004; 45(7):1235–1245. [PubMed: 15335344]
- McPartland JC, Webb SJ, Keehn B, Dawson G. Patterns of visual attention to faces and objects in autism spectrum disorder. *J Autism Dev Disord*. 2011; 41(2):148–157. [PubMed: 20499148]
- McPartland JC, Wu J, Bailey CA, Mayes LC, Schultz RT, Klin A. Atypical neural specialization for social percepts in autism spectrum disorder. *Soc Neurosci*. 2011; 6(5-6):436–451. [PubMed: 21777159]
- Minshew NJ, Williams DL. The new neurobiology of autism: cortex, connectivity, and neuronal organization. *Arch Neurol*. 2007; 64(7):945–950. [PubMed: 17620483]
- Molfese DL. Predicting dyslexia at 8 years of age using neonatal brain responses. *Brain Lang*. 2000; 72(3):238–245. [PubMed: 10764519]
- Morris JS, Frith CD, Perrett DI, Rowland D, Young AW, Calder AJ, et al. A differential neural response in the human amygdala to fearful and happy facial expressions. *Nature*. 1996; 383(6603):812–815. [PubMed: 8893004]
- O'Connor K, Hamm JP, Kirk IJ. The neurophysiological correlates of face processing in adults and children with Asperger's syndrome. *Brain Cogn*. 2005; 59(1):82–95. [PubMed: 16009478]
- O'Connor K, Hamm JP, Kirk IJ. Neurophysiological responses to face, facial regions and objects in adults with Asperger's syndrome: An ERP investigation. *Int J Psychophysiol*. 2007; 63(3):283–293. [PubMed: 17267061]
- Osterling JA, Dawson G, Munson JA. Early recognition of 1-year-old infants with autism spectrum disorder versus mental retardation. *Development & Psychopathology*. 2002; 14(2):239–251. [PubMed: 12030690]
- Osterling JA, Dawson G. Early recognition of children with autism: A study of first birthday home videotapes. *Journal of Autism & Developmental Disorders*. 1994; 24(3):247–257. [PubMed: 8050980]
- Ozonoff S, Iosif AM, Baguio F, Cook IC, Hill MM, Hutman T, et al. A prospective study of the emergence of early behavioral signs of autism. *Journal of the American Academy of Child and Adolescent Psychiatry*. 2010; 49(3):256–266 e. 251–252. [PubMed: 20410715]
- Pelphrey KA, Sasson NJ, Reznick JS, Paul G, Goldman BD, Piven J. Visual scanning of faces in autism. *J Autism Dev Disord*. 2002; 32(4):249–261. [PubMed: 12199131]
- Pelphrey KA, Morris JP, Michelich CR, Allison T, McCarthy G. Functional anatomy of biological motion perception in posterior temporal cortex: an FMRI study of eye, mouth and hand movements. *Cerebral Cortex*. 2005; 15(12):1866–1876. [PubMed: 15746001]
- Pierce K, Haist F, Sedaghat F, Courchesne E. The brain response to personally familiar faces in autism: findings of fusiform activity and beyond. *Brain*. 2004; 127(Pt 12):2703–2716. [PubMed: 15319275]

- Pierce K, Mueller RA, Ambrose J, Allen G, Courchesne E. Face processing occurs outside the fusiform 'face area' in autism: Evidence from functional MRI. *Brain*. 2001; 124(10):2059–2073. [PubMed: 11571222]
- Puce A, Allison T, Asgari M, Gore JC, McCarthy G. Differential sensitivity of human visual cortex to faces, letterstrings, and textures: A functional magnetic resonance imaging study. *Journal of Neuroscience*. 1996; 16(16):5205–5215. [PubMed: 8756449]
- Puce A, Allison T, Gore J, McCarthy G. Face-sensitive regions in human extrastriate cortex studied by functional MRI. *Journal of Neurophysiology*. 1995
- Reid VM, Hoehl S, Landt J, Striano T. Human infants dissociate structural and dynamic information in biological motion: evidence from neural systems. *Soc Cogn Affect Neurosci*. 2008; 3(2):161–167. [PubMed: 19015106]
- Reid VM, Hoehl S, Striano T. The perception of biological motion by infants: an event-related potential study. *Neuroscience Letters*. 2006; 395(3):211–214. [PubMed: 16298485]
- Rolls ET. The orbitofrontal cortex and reward. *Cerebral Cortex*. 2000; 10(3):284–294. [PubMed: 10731223]
- Schultz RT. Developmental deficits in social perception in autism: the role of the amygdala and fusiform face area. *Int J Dev Neurosci*. 2005; 23(2-3):125–141. [PubMed: 15749240]
- Schultz RT, Gauthier I, Klin A, Fulbright RK, Anderson AW, Volkmar F, et al. Abnormal ventral temporal cortical activity during face discrimination among individuals with autism and Asperger syndrome. *Archives of General Psychiatry*. 2000; 57(4):331–340. [PubMed: 10768694]
- Senju A, Tojo Y, Yaguchi K, Hasegawa T. Deviant gaze processing in children with autism: an ERP study. *Neuropsychologia*. 2005; 43(9):1297–1306. [PubMed: 15949514]
- Simion F, Regolin L, Bulf H. A predisposition for biological motion in the newborn baby. *Proc Natl Acad Sci U S A*. 2008; 105(2):809–813. [PubMed: 18174333]
- Spezio ML, Adolphs R, Hurley RS, Piven J. Abnormal Use of Facial Information in High-Functioning Autism. *J Autism Dev Disord*. 2006
- Sukhodolsky, DG.; Bolling, DZ.; Wu, J.; Crowley, M.; McPartland, J.; Scahill, L., et al. Cognitive behavior therapy for irritability in high-functioning ASD: Pilot study of neurobiological mechanisms; Paper presented at the International Meeting for Autism Research; 2011.
- Tanaka JW, Curran T. A neural basis for expert object recognition. *Psychol Sci*. 2001; 12(1):43–47. [PubMed: 11294227]
- Troje NF. Decomposing biological motion: a framework for analysis and synthesis of human gait patterns. *J Vis*. 2002; 2(5):371–387. [PubMed: 12678652]
- Webb SJ, Dawson G, Bernier R, Panagiotides H. ERP evidence of atypical face processing in young children with autism. *J Autism Dev Disord*. 2006; 36(7):881–890. [PubMed: 16897400]
- Webb SJ, Merkle K, Murias M, Richards T, Aylward E, Dawson G. ERP responses differentiate inverted but not upright face processing in adults with ASD. *Soc Cogn Affect Neurosci*. 2009
- Weiss LA, Shen Y, Korn JM, Arking DE, Miller DT, Fossdal R, et al. Association between microdeletion and microduplication at 16p11.2 and autism. *The New England Journal of Medicine*. 2008; 358(7):667–675. [PubMed: 18184952]
- Wolf JM, Tanaka JW, Klaiman C, Cockburn J, Herlihy L, Brown C, et al. Specific impairment of face-processing abilities in children with autism spectrum disorder using the Let's Face It! skills battery. *Autism research : official journal of the International Society for Autism Research*. 2008; 1(6):329–340. [PubMed: 19360688]
- Zwaigenbaum L, Bryson S, Rogers T, Roberts W, Brian J, Szatmari P. Behavioral manifestations of autism in the first year of life. *Int J Dev Neurosci*. 2005; 23(2-3):143–152. [PubMed: 15749241]