Review

Speech and Language Impairments in Autism: Insights from Behavior and Neuroimaging

Maria Mody, PhD;* John W. Belliveau, PhD

MGH/HST Athinoula A. Martinos Center for Biomedical Imaging, Harvard Medical School, Department of Radiology, Charlestown, MA

A failure to develop language is one of the earliest signs of autism. The ability to identify the neural signature of this deficit in very young children has become increasingly important, given that the presence of speech before five years of age is the strongest predictor for better outcomes in autism. This review consolidates what is known about verbal and preverbal precursors of language development as a framework for examining behavioral and brain anomalies related to speech and language in autism spectrum disorders. Relating the disruptions in the speech network to the social deficits observed will provide promising targets for behavioral and pharmacological interventions in ASD.
[N A J Med Sci. 2012;5(3):157-161.]

Key Words: *autism, speech, language, neuroimaging, children*

INTRODUCTION

When it was first observed independently by Leo Kanner[1] and Hans Asperger,[2] autism was viewed as a psychiatric condition with mental retardation as a characteristic feature of the disorder, often accompanied by social awkwardness. The last couple of decades have witnessed an explosion of research in this area, leading to detailed characterization of the behavioral features, and paving the way for the identification of phenotypes of the disorder.[3,4] Included under autism spectrum disorders (ASD) in the Diagnostic and Statistical Manual of Mental Disorders (fourth edition, text revision; DSM-IV TR) are autistic disorder, Asperger's syndrome and pervasive developmental disorder, not otherwise specified (PDD-NOS). Whereas under the new DSM-V, Asperger's syndrome will no longer constitute a separate diagnostic category, the research reported here will respect the use of this label in citing study findings that incorporate it. However, we will focus on the core symptoms across the spectrum and their neurological basis, acknowledging that while there still is a controversy regarding the boundaries between diagnostic categories, there is consensus that the different types of autism spectrum disorders fall along a continuum, but vary in overall severity of the core symptoms as well as in IQ and linguistic skill.[5,6]

Autism spectrum disorders encompass a range of presentations which may be traced to a triad of symptoms: a. impaired reciprocal social interaction, b. disordered verbal and nonverbal communication, c. restricted, repetitive behavior or circumscribed interests. An increasingly common neurodevelopmental disorder, prevalence rates place it at 1:88 individuals, affecting boys more than girls (4:1) (Centers for Disease Control, 2009). Autism is also known to have a high heritability of 0.07, with an expected concordance of 70-90% in monozygotic twins vs. 10-25% in dizygotic twins. Recent cytogenetic work has shown that certain copy number variations (CNVs) on chromosome 16p, 15q, 22q, 2q, 5p, or 17p may account for 6-7% of the cases. More than 20 genes related to nervous system development have already been identified and hold great promise for constructing a genetic model that will account for phenotype heterogeneity and offers interventional opportunities.[7] However, the broad range of symptoms that constitute the autism spectrum has resulted in characteristics varying dramatically across the different diagnoses and within a single diagnostic category. Thus, while a failure to meet language development milestones is one of the earliest red flags for autism, speech and language impairments in individuals with autism are far from consistent, making intervention and prognosis a challenge. Recent neuroimaging studies using exciting new approaches are beginning to reveal important differences in the functional wiring of the young autistic brain compared to typically developing controls using language tasks. Our goal is to provide an overview of some of these findings and resulting new insights into the disorder. First, however, a review of behavioral studies of speech and language in autism relative to typically developing children appears warranted.

LANGUAGE CHARACTERISTICS OF AUTISM SPECTRUM DISORDERS

As mentioned earlier, impairments in language and social communication are included in the primary diagnostic criteria for ASD. Variable characteristics like sensory processing and attention issues that go beyond the core symptoms, however,

Received 7/14/2012; Revised 7/23/2012; Accepted 7/25/2012
***Corresponding Author:** MGH/HST Athinoula A. Martinos Center for Biomedical Imaging, Harvard Medical School, Dept. of Radiology, 149 13th Street, Charlestown, MA 02129. Tel: 617-726-6913.
(Email:maria@nmr.mgh.harvard.edu)

frequently interact with the core symptoms, adding to the heterogeneity of the disorder and the manifestations of the symptoms. As such, language abilities may range from being nonverbal to highly idiosyncratic language with echolalia and unusual prosody (tone or inflection). At least half of all children who have autism have intellectual disabilities; those who are in normal IQ range are considered high functioning even though they may have significant language and communication deficits. Asperger's syndrome, which until recently was considered a distinct clinical disorder from autism, appears to have the characteristic difficulty with social communication, though without any early language delay and with intellectual abilities in the average and even superior range. Some language skills including articulation, vocabulary, and grammar appear to be relatively preserved. In contrast, the difficulties in prosody and abstract use of language are clearly evident.

For the most part, children with ASD have receptive and expressive language impairments. However, the profile of language impairment varies with age and developmental level. For example, deficits in joint attention and receptive language and reduced vocal output are evident as early as in the first two years of life. Thus, very young children with ASD must be evaluated for language and social communication. This is because infants as young as 12 months understand single words and gestures in the context of play, and are already producing their first words. Between 1.5 to 2 years of age, children exhibit a rapid spurt in vocabulary and knowledge of the rules of conversational exchange. In fact, the two-year-old toddler has hundreds of words which he or she uses in diverse contexts and puts together in simple "sentences" or "phrases". For the child with ASD, these developmental processes appear to be hijacked taking the form of impaired or delayed language abilities at a very early age.[8,9]

The typically developing child uses language for social reasons to initiate conversational interactions.[10] In contrast, the child with ASD typically uses words to regulate his or her environment (e.g., to demand, protest). Some children who have ASD may have apraxia or oral-motor impairment impacting their ability to communicate. However, it is the "absence of communicative intent" due to social deficits that often disguises itself as an expressive language impairment.[11] It is easy to conceive that a reduced social drive to talk may manifest as delayed or impaired language development. Thus, social deficits and communication difficulties often go hand-in-hand and may be mutually reinforcing in autism. It is important to note that when social withdrawal is found to accompany language regression in children with ASD, typically between 12-18 months of age, it should be considered a significant red flag in prognostic terms and warrants immediate attention.

In autism, receptive language is often seen to lag behind expressive language. However, this, too, may be related to a lack of social reciprocity[12] as parents of a child on the spectrum often remark how their children appear to tune out of conversational exchanges. In fact, children with ASD tend to ignore voices around them though they do respond to other non-vocal stimuli, reflecting their disengagement from the social world.[13] That children on the spectrum frequently have attention issues as well, also makes it difficult to elicit reliable responses on auditory language tasks. It thus makes sense that children who have superior spoken language comprehension tend to be the ones who display more advanced play and are better at conversational turn-taking.[14] Children on the autism spectrum also present with echolalia early in language acquisition, though this diminishes with time. It takes the form of repetition of a sentence or final word of the speaker and may be immediate or delayed and for the most part is vocal stereotypy; occasionally, it may be used to make requests or gain time in order to process the repeated utterance for meaning.[15] Qualitative differences in communication between ASD and typically developing children are evident even in the preverbal stage. Specifically, children with ASD do not use symbolic gestures like showing or pointing out objects of interest (included in DSM criteria for autism) to compensate for lack of or delayed speech, rather they use physical cues such as pushing or directing another's hand to an object of interest. Consequently, impairment in joint-attention may result in a cascade of missed learning opportunities as part of the normal development process for building vocabulary through object-word associations.

In summary, individuals with ASD tend to have very limited language, with progress depending on IQ, comprehension and attention skills.[16] In general verbal children on the spectrum do not have difficulty with speech sound articulation [17], though their speech can be quite perseverative [18], with an unusual vocal quality (e.g., monotonic, nasal, atypical stress). The core difficulty, however, is one of language pragmatics: children who have ASD show limited use of language in social context (e.g., rarely to comment or request information), once again pointing to a strong link between language and social skills in autism. Of late, there has been a growing interest in examining potential correspondences between genetic and biological findings and endophenotypes along the spectrum[19] given that the most striking differences between individuals on the autism spectrum are related to IQ (low- vs. high-functioning) and speech and language. In one such study, Alarcon and colleagues[20] examined a potential association between language development (age at first word) in autism and the Contactin Associated Protein-like 2 (CNTNAP 2) gene. An interesting finding in several of the studies is the significantly elevated rate of documented histories of language delay and language-based deficits among family members of children with autism.[21,22] The strong outcome predictor value of the presence of speech before 5 years of age in autism[23] provides an impetus for developing early speech and language intervention programs for children on the spectrum. However, given the heterogeneity of the condition, we turn to neuroimaging studies for a better understanding of the nature of the speech disruption in autism.

NEUROIMAGING STUDIES OF LANGUAGE IN AUTISM

The number of neuroimaging studies of young children with autism or of those that are low functioning is relatively limited. This is primarily due to difficulties with subject compliance during scanning; specifically, the ability to stay still, which is crucial for quality data acquisition, is a challenge for this population. However, recent improvements in hardware (multi-channel array coils in order to speed up acquisition) and software (e.g., data acquisition protocols incorporating online motion correction) developments, combined with creative data acquisition paradigms (e.g., recording brain responses to speech while subject is sleeping), have dramatically increased our capabilities to scan children and different clinical populations, including individuals with ASD.

Before reviewing the neuroimaging literature it is important to note that there are many conflicting findings that have yet to be reconciled. Differences in subject characteristics including age, gender, handedness, IQ, language level, attentional factors and other comorbid conditions have contributed to the differences across studies. Behavioral compliance issues also make it challenging to elicit reliable and consistent responses, leading to fewer functional than structural neuroimaging studies with this population.

Brain Structure Findings

The presence of enlarged overall brain volume in individuals with autism is one of the most replicated anatomical findings in the disorder. A meta-analysis of cross-sectional studies of different aged cohorts with autism suggests a rapid increase in brain volume over the first two years of life, though this appears not to be maintained in later years.[24] Interestingly, the observed increase in overall brain volume is attributed to greater white-matter volume.[25-27] The structural differences in the brain between individuals with autism and age- and gender-matched control subjects appear not to be generalized but rather in specific regions, including language areas. Using voxel-based morphometry, Abell and colleagues[28] found decreased gray-matter volume in the left inferior frontal gyrus (IFG) in adults with ASD compared to controls. Reversed asymmetry of this region (viz., Broca's area) has been reported in boys with ASD.[26,29] Interestingly, though, only boys with language impairment but not those without language impairment in this sample revealed a rightward asymmetry of the pars opercularis and pars triangularis,[29] thereby linking structural difference to language function in ASD. Thus, absolute differences in morphometry between autistic and typically developing subjects, although informative, do not provide a full neurobiological explanation for the cognitive differences in autism. An increase in the number of functional neuroimaging studies with ASD has made it possible to relate performance measures and/or brain activation patterns during specific tasks of interest to brain structure in order to infer structure-function relationships. Using the superior temporal gyrus (STG) as a window into language function, Bigler et al.[30] found a positive correlation between STG volume and receptive language scores (assessed with CELF-3) in control subjects, but not in ASD. In fact, morphometric measures in Asperger's syndrome and autism seem to be related to performance and verbal IQ differences that define their respective clinical diagnoses.[31,32]

That individuals with autism typically present with uneven IQ profiles is evident in the peaks and valleys that characterize their performance on a visuospatial task like the Block Design test compared with that on the comprehension test of the WISC.[11] Anatomically, local patterns of brain overconnectivity together with disrupted long-range frontotemporal connections (which affect integration of information) may account for these uneven cognitive profiles.[33] The view of autism as a disorder of connectivity has focused interest on white matter changes in autism.[34,35] Recent studies have attempted to use new diffusion tensor imaging techniques (DTI) to investigate the intactness of white matter connections in autism.[36,37] They have found that compared with IQ-matched controls, children with autism presented with lower fractional anisotropy (FA), a measure of white matter integrity in the brain, in several areas including anterior cingulate and the temporoparietal junction; however, the functional significance of these findings in ASD is not clear.

Relating Structure and Function in the Autistic Brain: The Language Puzzle

Recently, in a series of studies, Sahyoun and colleagues[38-40] used functional magnetic resonance imaging (fMRI) and DTI in conjunction with a novel behavioral paradigm to look for neurobiological evidence of an apparent discrepancy between visual and language processing abilities that has long been observed in individuals with autism. Specifically, the authors used a picture-based problem solving task that equated cognitive complexity across three conditions while manipulating the availability of linguistic vs. visuospatial information for solving the problems. The three pictorial conditions were: semantics (S) requiring access to concepts illustrated by the pictures and drawing relationships between them, visuospatial (V) requiring visuospatial manipulation of meaningless geometric forms, and visuospatial + semantic (V+S), a hybrid condition requiring visuospatial manipulation of easily recognizable items (i.e., with common verbal labels) while allowing for verbal mediation. The authors examined within and between group (high-functioning autism and age- and IQ-matched controls) differences in cortical activation as a function of task condition, white matter integrity of pathways between functionally-implicated nodes of activation and correlation between tract integrity and processing efficiency (i.e., reaction times) in each condition. This comprehensive approach allowed the emergence of the structure-function relationship underlying the hypothesized visuospatial-verbal distinction in autistic cognition.

The results were quite striking. Children with high-functioning autism who were selected on the basis of a history of language delay were slowest on the semantic (S) condition and fastest on the two visually-mediated conditions (V and V+S). They also showed a correlation between

accuracy on the V+S condition and their performance IQ, suggestive of their use of a non-verbal problem solving approach.[38] The finding suggests an increased reliance by these children on visuospatial strategies and reduced engagement of language mediation.[41] This view is consistent with intact posterior occipitoparietal circuits and reduced activation in frontal language areas in high functioning autism compared to controls.[42-44] Additionally, the lower white matter integrity between ventral temporal and inferior frontal regions found in the tractography analyses may be related to the decreased frontal activation that was observed and thus suggests an underlying role for ventral temporal area in the superior visual processing abilities in autism.[39] Support for this interpretation comes from the correlation between processing speed on the V and V+S conditions and fractional anisotropy values in the ventral temporoparietal areas in the group with autism. In contrast, the control group showed increased correlation between processing speed on the S-condition and FA in the superior longitudinal fasciculus connecting frontal and temporal regions indicative of their strength in the verbal domain and consequent reliance on frontotemporal language areas.[40]

Sahyoun and colleagues are among the first to show neurobiological evidence of a visuospatial processing bias in autism.[45] It is important to note, though, that the results do not shed light on the directionality of these effects between connectivity patterns, language, and visuospatial bias. As such, the brain-behavior events leading to this pattern remain to be elucidated. Further complicating the situation is the fact that neurodevelopmental disorders such as autism often result in systemic reorganization of the brain. Hence, rather than focusing on localized abnormalities, an examination of network alterations and modifications of functions seems called for.[46]

Pushing the Boundary: Neuroimaging language in very young children with autism

More recently, creative paradigms and methodological advances in neuroimaging have demonstrated that it is possible to obtain functional MRI data in response to language stimuli in very young children during natural sleep, thus eliminating the requirement for the child participant to stay still;[47] this will pave the way for the identification of a neural marker of the core language deficit in the very early stages of autism. An additional advantage of this method is that it can be used with subjects at all functioning levels, including the large number of children with autism who remain minimally verbal despite years of intervention.[48]

Using sleep fMRI, Eyler and colleagues presented three types of stimuli in 20-ms blocks to toddlers ranging in age from 12-48 months: complex forward speech consisting of a children's story written at a comprehension level over 48 months; simple forward speech, where the toddlers heard stories written at a comprehension level between 12 and 36 months; backward speech, where the simple story was played backwards. The authors found significantly less activation in response to speech in the left STS (Brodmann's area 22) in the group with autism than with the typical group. The toddlers with autism also exhibited reduced or reversed laterality patterns. Importantly, they displayed stronger activation on the right than on the left in the anterior STG, an area know to be responsive to speech sounds in normal controls.[49] The abnormal lateralization is consistent with studies of older autistic children and adults.[50-52] Eyler and colleagues hypothesized that this left hemisphere failure for language specialization in autism and the corresponding rightward functional asymmetry may also impair the development of social language behaviors like prosody by crowding it out from its rightful place in the right hemisphere.[49] The findings and interpretation further reinforce the strong link between language and social development, and the consequent deficits in both these domains in autism.

In summary, there is considerable neuroimaging evidence for an impaired language system in autism. Studies have reported bilateral hypoperfusion of the temporal lobe in autism, possibly related to language deficits or avoidance of verbal mediation observed behaviorally.[53] In addition, the IFG appears to show reduced activation difference between semantic and perceptual (letter-case judgment) processing in autism compared with controls.[54] Participants with autism also showed decreased IFG activity in a sentence comprehension task.[44] Taken together, the structural and functional neuroimaging studies of autism point to decreased use of frontal areas and increased reliance on right hemisphere language homologues, as well as posterior ventral temporal regions of the brain during language processing.

CONCLUSION

The difficulty in identifying a behavioral or cognitive etiology of autism stems from the neurodevelopmental aspect of the disorder. Current mechanistic models describing abnormal distribution of connectivity patterns provide a reasonable, though yet to be ascertained account of autistic symptomatology, and may be consistent with evidence of glial inflammation or minicolumnopathy[55] as altered minicolumns would affect the geometry of gyral windows, thereby favoring shorter connections. In the face of the tremendous heterogeneity in ASD, focusing on the development of well-defined neurophenotypes will be critical for understanding autism and helping those with the disorder by providing targets for behavioral and pharmacological interventions.

CONFLICT OF INTEREST

None.

ACKNOWLEDGMENTS

Grants: National Institutes of Health (NS037462, HD040712); National Center for Research Resources (P41RR14075). The authors would like to thank Cherif Sahyoun and Seppo Ahlfors for their help with various aspects of this manuscript.

REFERENCES

1. Kanner L. Early infantile autism. J Pediatrics. 1944;25(3):211.
2. Asperger H. The "autistic psychopathy" in childhood. Arch Psychiatr Nervenkr. 1944;117(1):76-136.
3. Tager-Flusberg H, Joseph RM. Identifying neurocognitive phenotypes in autism. Philos Trans R Soc Lond B Biol Sci. 2003;358(1430):303-314.

4. Tager-Flusberg H, Lindgren K, Mody M. Structural and functional imaging research on language disorders: Specific language impairment and autism spectrum disorders. In: Wolf L, Schreiber H, J. W, eds. Adult learning disorders: Contemporary issues New York: Psychology Press; 2008:127-157.
5. Constantino JN, Gruber CP, Davis S, Hayes S, Passanante N, Przybeck T. The factor structure of autistic traits. J Child Psychol Psychiatry. 2004;45(4):719-726.
6. Wing L. The spectrum of autistic disorders. Hospital Medicine. 2004;65:542-545.
7. Abrahams BS, Geschwind DH. Advances in autism genetics: on the threshold of a new neurobiology. Nat Rev Genet. 2008;9(5):341-355.
8. Luyster RJ, Kadlec MB, Carter A, Tager-Flusberg H. Language assessment and development in toddlers with autism spectrum disorders. J Autism Dev Disord. 2008;38(8):1426-1438.
9. Mitchell S, Brian J, Zwaigenbaum L, et al. Early language and communication development of infants later diagnosed with autism spectrum disorder. J Dev Behav Pediatr. 2006;27(2 Suppl):S69-78.
10. Wetherby AM. Ontogeny of communicative functions in autism. J Autism Dev Disord. 1986;16(3):295-316.
11. Happe F, Frith U. The neuropsychology of autism. Brain. 1996;119(Pt 4):1377-1400.
12. Rutter M, Mawhood L, Howlin P. Language delay and social development. In: Fletcher P, Hall D, eds. Specific speech and language disorders in children: correlates, characteristics and outcomes. London: Whurr Publishers; 1992:63–78.
13. Klin A. Young autistic children's listening preferences in regard to speech: a possible characterization of the symptom of social withdrawal. J Autism Dev Disord. 1991;21(1):29-42.
14. Lord C. Autism and the comprehension of language. In: Schopler E, Mesibov G, eds. Communication problems in autism. New York: Plenum; 1985:257–281.
15. Prizant BM. Echolalia in autism: Assessment and intervention. Seminars in Speech and Language. 1983;4:63-77.
16. Sigman M, Ruskin E, Arbeile S, et al. Continuity and change in the social competence of children with autism, Down syndrome, and developmental delays. Monogr Soc Res Child Dev. 1999;64(1):1-114.
17. Kjelgaard MM, Tager-Flusberg H. An Investigation of Language Impairment in Autism: Implications for Genetic Subgroups. Lang Cogn Process. 2001;16(2-3):287-308.
18. Volden J, Lord C. Neologisms and idiosyncratic language in autistic speakers. J Autism Dev Disord. 1991;21(2):109-130.
19. Belmonte MK, Cook EH, Jr., Anderson GM, et al. Autism as a disorder of neural information processing: directions for research and targets for therapy. Mol Psychiatry. 2004;9(7):646-663.
20. Alarcon M, Abrahams BS, Stone JL, et al. Linkage, association, and gene-expression analyses identify CNTNAP2 as an autism-susceptibility gene. Am J Hum Genet. 2008;82(1):150-159.
21. Fombonne E, Bolton P, Prior J, Jordan H, Rutter M. A family study of autism: cognitive patterns and levels in parents and siblings. J Child Psychol Psychiatry. 1997;38(6):667-683.
22. Piven J, Palmer P, Jacobi D, Childress D, Arndt S. Broader autism phenotype: evidence from a family history study of multiple-incidence autism families. Am J Psychiatry. 1997;154(2):185-190.
23. Rutter M. Autistic children: infancy to adulthood. Semin Psychiatry. 1970;2(4):435-450.
24. Redcay E, Courchesne E. When is the brain enlarged in autism? A meta-analysis of all brain size reports. Biol Psychiatry. 2005;58(1):1-9.
25. Carper RA, Moses P, Tigue ZD, Courchesne E. Cerebral lobes in autism: early hyperplasia and abnormal age effects. Neuroimage. 2002;16(4):1038-1051.
26. Herbert MR, Harris GJ, Adrien KT, et al. Abnormal asymmetry in language association cortex in autism. Ann Neurol. 2002;52(5):588-596.
27. Herbert MR, Ziegler DA, Makris N, et al. Localization of white matter volume increase in autism and developmental language disorder. Ann Neurol. 2004;55(4):530-540.
28. Abell F, Krams M, Ashburner J, et al. The neuroanatomy of autism: a voxel-based whole brain analysis of structural scans. Neuroreport. 1999;10(8):1647-1651.
29. De Fosse L, Hodge SM, Makris N, et al. Language-association cortex asymmetry in autism and specific language impairment. Ann Neurol. 2004;56(6):757-766.
30. Bigler ED, Mortensen S, Neeley ES, et al. Superior temporal gyrus, language function, and autism. Dev Neuropsychol. 2007;31(2):217-238.
31. Kwon H, Ow AW, Pedatella KE, Lotspeich LJ, Reiss AL. Voxel-based morphometry elucidates structural neuroanatomy of high-functioning autism and Asperger syndrome. Dev Med Child Neurol. 2004;46(11):760-764.
32. Lotspeich LJ, Kwon H, Schumann CM, et al. Investigation of neuroanatomical differences between autism and Asperger syndrome. Arch Gen Psychiatry. 2004;61(3):291-298.
33. Koshino H, Carpenter PA, Minshew NJ, Cherkassky VL, Keller TA, Just MA. Functional connectivity in an fMRI working memory task in high-functioning autism. Neuroimage. 2005;24(3):810-821.
34. Hendry J, DeVito T, Gelman N, et al. White matter abnormalities in autism detected through transverse relaxation time imaging. Neuroimage. 2006;29(4):1049-1057.
35. Waiter GD, Williams JH, Murray AD, Gilchrist A, Perrett DI, Whiten A. Structural white matter deficits in high-functioning individuals with autistic spectrum disorder: a voxel-based investigation. Neuroimage J. 2005;24(2):455-461.
36. Alexander AL, Lee JE, Lazar M, et al. Diffusion tensor imaging of the corpus callosum in Autism. Neuroimage. 2007;34(1):61-73.
37. Barnea-Goraly N, Kwon H, Menon V, Eliez S, Lotspeich L, Reiss AL. White matter structure in autism: preliminary evidence from diffusion tensor imaging. Biol Psychiatry. 2004;55(3):323-326.
38. Sahyoun CP, Soulieres I, Belliveau JW, Mottron L, Mody M. Cognitive differences in pictorial reasoning between high-functioning autism and Asperger's syndrome. J Autism Dev Disord. 2009;39(7):1014-1023.
39. Sahyoun CP, Belliveau JW, Soulieres I, Schwartz S, Mody M. Neuroimaging of the functional and structural networks underlying visuospatial vs. linguistic reasoning in high-functioning autism. Neuropsychologia. 2010;48(1):86-95.
40. Sahyoun CP, Belliveau JW, Mody M. White matter integrity and pictorial reasoning in high-functioning children with autism. Brain Cogn. 2010;73(3):180-188.
41. Dakin S, Frith U. Vagaries of visual perception in autism. Neuron. 2005;48(3):497-507.
42. Manjaly ZM, Bruning N, Neufang S, et al. Neurophysiological correlates of relatively enhanced local visual search in autistic adolescents. Neuroimage. 2007;35(1):283-291.
43. Kana RK, Keller TA, Cherkassky VL, Minshew NJ, Just MA. Sentence comprehension in autism: thinking in pictures with decreased functional connectivity. Brain. 2006;129(Pt 9):2484-2493.
44. Just MA, Cherkassky VL, Keller TA, Minshew NJ. Cortical activation and synchronization during sentence comprehension in high-functioning autism: evidence of underconnectivity. Brain. 2004;127(Pt 8):1811-1821.
45. Minshew NJ, Keller TA. The nature of brain dysfunction in autism: functional brain imaging studies. Curr Opin Neurol. 2010;23(2):124-130.
46. Muller RA. The study of autism as a distributed disorder. Ment Retard Dev Disabil Res Rev. 2007;13(1):85-95.
47. Pierce K. Early functional brain development in autism and the promise of sleep fMRI. Brain Res. 2011;1380:162-174.
48. Tager-Flusberg H, Paul R, Lord CE. Language and communication in autism. In: Volkman F, Paul R, Klin A, eds. Handbook of Autism and Pervasive Developmental Disorders. Vol 1. 3rd ed. New York: Wiley; 2005:335-364.
49. Eyler LT, Pierce K, Courchesne E. A failure of left temporal cortex to specialize for language is an early emerging and fundamental property of autism. Brain. 2012;135(Pt 3):949-960.
50. Dawson G, Finley C, Phillips S, Lewy A. A comparison of hemispheric asymmetries in speech-related brain potentials of autistic and dysphasic children. Brain Lang. 1989;37(1):26-41.
51. Kleinhans NM, Muller RA, Cohen DN, Courchesne E. Atypical functional lateralization of language in autism spectrum disorders. Brain Res. 2008;1221:115-125.
52. Anderson JS, Lange N, Froehlich A, et al. Decreased left posterior insular activity during auditory language in autism. AJNR Am J Neuroradiol. 2010;31(1):131-139.
53. Boddaert N, Zilbovicius M. Functional neuroimaging and childhood autism. Pediatr Radiol. 2002;32(1):1-7.
54. Harris GJ, Chabris CF, Clark J, et al. Brain activation during semantic processing in autism spectrum disorders via functional magnetic resonance imaging. Brain Cogn. 2006;61(1):54-68.
55. Casanova MF, El-Baz A, Mott M, et al. Reduced gyral window and corpus callosum size in autism: possible macroscopic correlates of a minicolumnopathy. J Autism Dev Disord. 2009;39(5):751-764.