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Behavioral, perceptual, and neural alterations in sensory and multisensory function in autism spectrum disorder

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ABSTRACT

Although sensory processing challenges have been noted since the first clinical descriptions of autism, it has taken until the release of the fifth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) in 2013 for sensory problems to be included as part of the core symptoms of autism spectrum disorder (ASD) in the diagnostic profile. Because sensory information forms the building blocks for higher-order social and cognitive functions, we argue that sensory processing is not only an additional piece of the puzzle, but rather a critical cornerstone for characterizing and understanding ASD. In this review we discuss what is currently known about sensory processing in ASD, how sensory function fits within contemporary models of ASD, and what is understood about the differences in the underlying neural processing of sensory and social communication observed between individuals with and without ASD. In addition to highlighting the sensory features associated with ASD, we also emphasize the importance of multisensory processing in building perceptual and cognitive representations, and how deficits in multisensory integration may also be a core characteristic of ASD.

Contents

Abbreviations: ASD, autism spectrum disorder; DSM-5, diagnostic and statistical manual of mental disorders; EFT, Embedded Figures Test; TD, typically developing; SIFI, sound induced flash illusion; ToM, theory of mind; WCC, weak central coherence; STS, superior temporal sulcus; TPJ, temporal parietal junction; fMRI, functional magnetic resonance imaging; AIS, active information storage; GABA, γ-aminobutyric acid; MRS, magnetic resonance spectroscopy; FFA, fusiform face area; STG, superior temporal gyrus; IFG, inferior frontal gyrus; DMN, default mode network; DTI, diffusion tensor imaging; EEG, electroencephalography; AEP, auditory evoked potentials; SIT, sensory integration therapy; SERT, serotonin transporter.

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1. Introduction

Q4 Autism spectrum disorder (ASD) is a complex neurodevelopmental disorder of strikingly high incidence that represents a major public health challenge. Recent evidence suggests that the incidence of ASD in the general population is now 1 child in every 68, with that number being as high as 1 in 42 for boys (ADDM, 2014). This high incidence, coupled with the often-debilitating symptoms of ASD, result in substantial hardships at the individual, family, and societal levels.

The traditional core diagnostic and clinical features of ASD are weaknesses in social communicative abilities and the presence of restricted interests and repetitive behaviors. In addition, and as recently more formally recognized in the DSM-5, children with ASD also frequently suffer from disturbances in sensory function. Although these sensory deficits have only recently appeared in the diagnostic profile of ASD, they have been reported in the descriptions of autism dating back to the original writings of Kanner (1943). In fact, sensory abnormalities are one of the most prevalent symptoms of ASD, reported in up to 87% of individuals (Le Couteur et al., 1989; Lord, 1995).

The historical absence of sensory features in the diagnostic definition of ASD, despite widespread acknowledgement of their presence, is likely a result of several factors, including difficulties in characterizing sensory function in a strongly empirical manner and a greater focus on the more readily apparent social and cognitive symptoms. Anecdotal and caregiver reports, however, are rife with descriptions of sensory problems in children with ASD, and structured questionnaires invariably identify the presence of processing challenges in a number of sensory domains (Baranek et al., 2006; Rogers et al., 2003; Watling et al., 2001). Thus, the acknowledged high prevalence of sensory features in ASD, coupled with the emerging view that these "lower-level" sensory aspects may play an integral role in the better-characterized, "higher-order" differences (see below for more detail on this argument), demands a more empirical view into sensory contributions in ASD.

Although this examination of sensory processing in ASD must start with exploring differences in the processing of information *within* the different senses, it must also be extended to include the processing of information *across* the different senses. Indeed, it can be argued that such *multisensory* function is likely to be more strongly altered in ASD, given that many of the multisensory deficits observed in ASD go beyond what would be predicted by the individual unisensory performance. For example, deficits in multisensory integration are noted between children with ASD and their typically developing (TD) peers even when unisensory performance is unimpaired (Foxe et al., 2013; Stevenson et al., 2014c–e). Furthermore, evidence for differences in connectivity between distant brain regions in children with ASD (Abrams et al., 2013; Assaf et al., 2010; Maximo et al., 2014; Plitt et al., 2015) would also suggest a propensity towards multisensory deficits. Such communication across regions of the cerebral cortex provides the substrate for multisensory processing and integration, given that it demands the coordination of information processing across different sensory domains (*i.e.*, regions of visual, auditory and somatosensory cortex need to communicate and exchange information in order to accomplish multisensory integration).

The integration of information across the different senses is an essential process in the construction of healthy perceptual representations, and can be argued to represent one of the basic building blocks for the construction of cognitive representations and abilities (see Fig. 1). Given that we live in a world in which we are continually confronted with information conveyed *via* our different senses, an essential function of the nervous system is to combine and synthesize this information into a coherent perceptual whole. Whereas some of this information is reflective of a common source or event and needs to be integrated, much of it

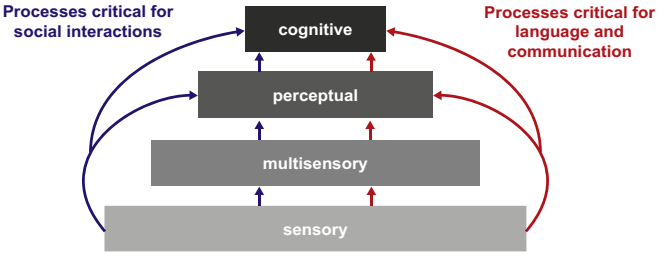

Fig. 1. Conceptual view of the relationship between sensory processing and 'higher-order' perceptual and cognitive processes. Sensory representations form the building blocks for multisensory representations, which in turn are built upon for perceptual and cognitive representations. Social communication and language, both of which are impacted in ASD, rely on the convergence of these representations. Thus, examining sensory and multisensory representations in addition to cognitive representations will be necessary to fully tease apart the mechanisms behind social and language deficits in ASD.

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