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Enhanced pure-tone pitch discrimination among persons with autism but not Asperger syndrome

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ABSTRACT

Persons with Autism spectrum disorders (ASD) display atypical perceptual processing in visual and auditory tasks. In vision, Bertone, Mottron, Jelenic, and Faubert (2005) found that enhanced and diminished visual processing is linked to the level of neural complexity required to process stimuli, as proposed in the neural complexity hypothesis. Based on these findings, Samson, Mottron, Jemel, Belin, and Ciocca (2006) proposed to extend the neural complexity hypothesis to the auditory modality. They hypothesized that persons with ASD should display enhanced performance for simple tones that are processed in primary auditory cortical regions, but diminished performance for complex tones that require additional processing in associative auditory regions, in comparison to typically developing individuals. To assess this hypothesis, we designed four auditory discrimination experiments targeting pitch, non-vocal and vocal timbre, and loudness. Stimuli consisted of spectro-temporally simple and complex tones. The participants were adolescents and young adults with autism, Asperger syndrome, and typical developmental histories, all with IQs in the normal range. Consistent with the neural complexity hypothesis and enhanced perceptual functioning model of ASD (Mottron, Dawson, Soulières, Hubert, & Burack, 2006), the participants with autism, but not with Asperger syndrome, displayed enhanced pitch discrimination for simple tones. However, no discrimination-thresholds differences were found between the participants with ASD and the typically developing persons across spectrally and temporally complex conditions. These findings indicate that enhanced pure-tone pitch discrimination may be a cognitive correlate of speech-delay among persons with ASD. However, auditory discrimination among this group does not appear to be directly contingent on the spectro-temporal complexity of the stimuli.

Autism spectrum disorders (ASD) include a range of neurodevelopmental variants, including autism and Asperger syndrome, that are characterized by mild to severe atypicalities in communication and social interactions, as well as by restricted behaviors and interests (DSM-IV, American Psychiatric Association, 1994). In addition, idiosyncratic reactions to the auditory environment are often noted with examples of both auditory hypersensitivity and hyposensitivity. The former is evidenced in cases where persons with ASD cover their ears in response to certain sounds that do not bother most others, and the latter in the lack of spontaneous orientation to one's own mother's voice (Grandin, 1997; Leekam, Nieto, Libby, Wing & Gould, 2007). Consistent with these anecdotal observations, persons with ASD display enhanced and diminished patterns of perceptual processing across a variety of auditory tasks (for a review, see Kellerman, Fan, & Gorman, 2005; Nieto Del Rincòn, 2008; Samson, Mottron, Jemel, Belin, & Ciocca, 2006).

The various examples of enhanced auditory processing among persons with ASD include the ability to discriminate between and categorize pure tones on the basis of their pitch or height value (Bonnel et al., 2003; Heaton, Hermelin, & Pring, 1998; O'Riordan & Passetti, 2006), and an increased prevalence of absolute pitch, the rare ability to identify or produce the pitch of a tone without reference to an external standard. Whereas five out of 100 individuals with ASD display absolute pitch (Miller, 1999; Rimland & Fein, 1988), this skill is found in only 1/10,000 individuals in the general population (Takeuchi & Hulse, 1993). In contrast, persons with ASD appear to display a relative difficulty in more complex auditory verbal tasks involving figure/ground discrimination (Alcantara, Weisblatt, Moore, & Bolton, 2004; Groen et al., 2008).

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Together with specific peaks in visuo-spatial and other perceptually related aspects of cognitive and behavioral functioning, these auditory strengths are the hallmarks of the Enhanced Perceptual Functioning Model (EPF: Mottron & Burack, 2001; Mottron, Dawson, Soulières, Hubert, & Burack, 2006). This model identifies a short list of "principles" characterizing autistic perception, its overall enhanced performance, and its enhanced role in typically non-perceptual cognitive operations as well as in guiding behaviors in natural settings. As these auditory strengths and difficulties among persons with ASD are identified within the descriptive EPF framework, the next step is to highlight the relevant psychophysical variables and neural mechanisms that are associated with them.

1. Perceptual complexity in autism: from vision to audition

Conceptualizations of atypical visual processing among persons with ASD (for reviews, see Behrmann, Thomas, & Humphreys, 2006; Dakin & Frith, 2005) may provide frameworks for the more nascent work on auditory processing in this population. The study of the neural basis for atypical visual processing among persons with ASD suggests that patterns of enhanced and diminished visual processing may be contingent upon the neural complexity, or extensiveness of the neural network, that is required to process stimuli. For example, Bertone et al. (2005) found that participants with autism outperformed an age and IQ matched group of typically developing persons in discriminating between simple, luminance-defined visual gratings that are processed primarily at the level of *primary* cortical visual area V1, but displayed a diminished ability to discriminate between complex, texture-defined visual gratings that require additional processing in *associative* cortical areas V2 and V3. Accordingly, Bertone et al. suggested a neural complexity hypothesis in which the atypical visual processing among persons with autism might be contingent upon the *simple* versus *complex* physical attributes of the perceptual stimuli that are processed.

Although there is no direct mapping from vision to audition, the neural complexity hypothesis based on visual processing might be considered to be generalizable to audition on the basis of the following parallels between the two modalities. One, simple and complex perceptual stimuli are processed in a posterior–anterior hierarchical fashion in both the visual (e.g., Milner & Goodale, 1995; Mishkin, Ungerleider, & Macko, 1983) and auditory (Hall et al., 2002; Griffiths, 2003; Wessinger et al., 2001) cortices. More specifically, in the auditory modality, stimuli that are spectrally and temporally simple, such as static pure tones, which do not vary in time and consist of a single frequency component, are processed primarily at the level of the primary or "core" auditory cortical area A1 (e.g., Wessinger et al., 2001). In contrast, spectro-temporally complex stimuli, such as band-passed noise bursts (e.g., Wessinger et al., 2001) and speech sounds (Scott & Johnsrude, 2003), require more extensive neuro-integrative processing in primary and associative auditory cortical areas (i.e., belt and lateral parabelt regions). Two, both visual (e.g., Campbell & Robson, 1968; Graham, 1989) and auditory (e.g., Linden & Schreiner, 2003) information are processed according to frequency selective mechanisms in primary perceptual cortices. In vision, neurons that respond preferentially to certain spatial frequencies are grouped together in a columnar fashion (Hubel & Wiesel, 1968; Maffei, 1978). Likewise, in audition, neurons are grouped closely together as a function of their characteristic frequency (i.e., the frequency to which they respond the best) both at the level of the auditory nerve and in the auditory cortex (Moore, 2004).

Drawing from the above structural similarities and from a comprehensive review of the literature on atypical auditory processing among persons with ASD, Samson et al. (2006) proposed that enhanced and diminished patterns of auditory processing among persons with ASD may be linked to the neural complexity required to process acoustic stimuli. They suggested an inverse relationship between gradients of stimulus complexity and patterns of performance on auditory tasks. Accordingly, they predicted that individuals with ASD should display an enhanced ability to discriminate between pure tones in comparison to typically developing persons, because pure tones require minimal neuro-integrative processing at the level of primary area A1. Conversely, they hypothesized that persons with ASD should display diminished auditory discrimination abilities for spectrally or temporally complex tones that require more extensive neural circuitry (i.e., primary and associative auditory cortices). The focus of the present study is to assess this hypothesis at the psychophysical level, to determine if the relevant variables dissociating auditory assets and deficits in autism are related to psychophysical complexity and associated amount of neuro-integrative processing.

2. Preliminary evidence for the neural complexity hypothesis in audition

Samson et al.'s (2006) adaptation of the neural complexity hypothesis is based on consistent evidence that persons with ASD generally outperform age-matched, typically developing participants on auditory tasks that involve pure tones. For example, enhanced processing of simple auditory material is seen in the heightened abilities to: discriminate between and categorize simples tones on the basis of their pitch (Bonnel et al., 2003; Heaton et al., 1998; O'Riordan & Passetti, 2006); identify the individual pitches that make up a chord (Heaton, 2003; Miller, 1989); identify local pitch changes within melodies (Foxton et al., 2003; Heaton et al., 1998; Mottron, Peretz, & Ménard, 2000); label pitch information via absolute pitch (Miller, 1989; Mottron, Peretz, Belleville, & Rouleau, 1999); and memorize pitch information (Heaton et al., 1998; Heaton, 2003). The behavioral findings for enhanced processing of simple auditory material are supported by electrophysiological, auditory event-related potential (ERP) evidence of enlarged Mismatch Negativity (i.e., MNN index of preconscious change detection) responses to pitch changes for simple auditory material among children and adolescents with ASD (e.g., Bruneau & Gomot, 2005; Ferri, Agarwal, Lanuzza, Musumeci, & Pennisi, 2003; Gomot, Giard, Adrien, Barthelemy & Bruneau, 2002; Lepistö et al., 2005).

In contrast to evidence of heightened performance with pure tones, converging behavioral, auditory ERP and brain imaging lines of evidence suggest that persons with ASD generally display diminished auditory processing in tasks involving spectrally or temporally complex stimuli. For instance, a diminished ability to identify speech stimuli presented in noisy backgrounds containing temporal dips (i.e., an intermittent as opposed to constant type of noise) was found among groups of adolescents with autism and Asperger syndrome (Alcantara et al., 2004; Groen et al., 2008). Diminished patterns of auditory processing were also reported in several ERP and brain imaging studies of auditory processing involving spectro-temporally complex speech stimuli. These findings include (1) a diminished ability to discriminate between the prosody of sequences of utterances, as reflected in diminished MMN amplitudes and prolonged latencies for this group (Kujala, Lepistö, Nieminen-von Wendt, Näätänan, & Näätänan, 2005); (2) a lack of orienting response to vowels among children with autism, as suggested by diminished response amplitudes at the level of the P3a index of involuntary attention (Ceponiene et al., 2003); (3) preliminary reports of a failure in a subgroup of adults with autism to activate brain regions that are typically activated in response to vocal stimuli among typically developing individuals (Gervais et al., 2004); and (4) atypical right as opposed to left patterns of cortical activations in the processing of the *temporal* aspects of spectro-temporally complex speech-like stimuli in groups of chil-