Unisensory and Multisensory Disruptions in Autism Spectrum Disorders

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Autism Spectrum Disorders (ASD) are a group of neurodevelopmental disorders which are diagnosed using the following triad of symptoms: impairments in social interaction, impairments in language, and restricted, repetitive, and stereotyped behavior, interests, and activities. A great deal of heterogeneity in the severity of the three symptom classes exists amongst individuals affected by this disorder giving rise to distinct diagnoses such as autism, Asperger's, and Pervasive Developmental Disorder-Not Otherwise Specified (PDD-NOS)[1]. When incorporating all disorders on the autism spectrum, the current prevalence estimate indicates that one in every 150 children is affected by ASD[2]. In addition to the diagnostic triad of symptoms, sensory and perceptual disruptions are frequently associated with ASD. In fact, the original depiction of autism published by Kanner in 1943 included descriptions of sensory abnormalities such as fascination with particular stimuli as well as aversions to innocuous stimuli[3]. Many studies have since been published which seek to characterize these sensory disturbances in ASD. Many researchers have also developed sensory integration therapies which they claim are effective in lessening the severity of symptoms in ASD[4,5,6]. However, many argue that there is no empirical evidence to support the efficacy of these treatments[7,8,9]. This review will highlight studies which examined unisensory and multisensory processing in ASD. Evidence will be described briefly as to why one particular aspect of multisensory integration (i.e. temporal multisensory processing) is likely to be disrupted in ASD. A brief introduction to multisensory processing will follow, and the review will conclude with how the hypothesis of disrupted temporal multisensory processing in autism may be tested.

SENSORY OBSERVATIONS IN AUTISM

One insight into the sensory disturbances in autism comes from autobiographical reports. For example Temple Grandin, a well known high-functioning professor with autism, describes her hearing experiences as "like having a sound amplifier set on maximum loudness[10]." Other reports indicate difficulty for individuals with ASD to process stimuli from multiple senses concurrently which often results in "sensory overload[11]." Retrospective analysis of home videos of infants who would later be diagnosed as autistic have found symptoms of abnormal reactions to sensory stimuli indicating that sensory disruptions are present even before a diagnosis is made[12].

One strategy for quantifying sensory disturbances in ASD which has been used extensively since 1977 is the sensory questionnaire. These questionnaires are administered to parents or caregivers and usually include items on all modalities and varying reactions to stimulation in each modality (i.e. aversions and fascinations). These studies have shown that abnormal reactions to sensory stimulation as reported by parents are nearly universal in ASD with estimates up to 90%[14,15] of individuals with ASD showing sensory symptoms. These studies have also shown that sensory disruptions are present in multiple modalities and include both hypo- and hyperresponsiveness to stimulation[13-20]. Collectively, this literature represent the entire range of both age and ability in autism indicating that sensory disturbances are an integral component in autism. Although this literature is vital in describing and quantifying abnormal reactions to sensory stimulation, it does not provide any information as to the underlying mechanisms of sensory disruption in ASD.

UNISENSORY PSYCHOPHYSICS IN AUTISM

One method which can be used to examine sensory processing in ASD is psychophysical tasks. Many researchers have tested the ability of both children and adults with ASD to detect and discriminate stimuli from varying modalities. One such study found that high-functioning adults with autism showed enhanced discrimination for highly

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similar visual objects[21]. The same group later showed that both children[22] and adults[23] with autism had faster reaction times for detecting visual targets during a visual search task. Similar enhanced perceptual abilities have also been found in the auditory modality. Bonnel *et al* showed that high-functioning individuals with autism were superior in discriminating pitch as well as categorizing “high” vs. “low” tones when compared to controls[24]. O’Riordan *et al* later replicated the finding of enhanced pitch discrimination in autism; however, in the same study they did not find enhanced abilities in the tactile modality for texture discrimination or light touch detection[25]. Recently, Cascio *et al* have found enhanced detection abilities in the tactile modality for some but not all measures. For example, no differences between groups were found for warm/cool detection or ratings of pleasantness for texture. The ASD group did have lower thresholds for thermal pain as well as lower thresholds for vibration detection on the forearm but not the palm[26].

Taken together, the above studies suggest that individuals with autism have superior perceptual abilities; however, other studies indicate that the superior perceptual performance in autism may only be in response to simple stimuli. Bertone *et al* tested this hypothesis by altering the complexity of the stimulus to be discriminated. In this task, participants were asked to discriminate the orientation of a grating which could be luminance-defined (lower order) or texture defined (higher order). Individuals with ASD were superior at identifying orientation for luminance-defined gratings but inferior at identifying orientation for texture-defined gratings indicating that visual stimulus complexity has an inverse relationship with perceptual performance in autism[27]. The relationship between stimulus complexity and perceptual performance in autism was also examined recently by Minshew and Hobson in the tactile domain. In this study the authors differentiated simple vs. complex tactile processing by comparing scores on both simple and complex composite scales between individuals with ASD and without ASD. The simple sensory composite included the following items: localization of cutaneous sensation, sharp vs. dull pressure, and muscle and joint sensation; whereas, the complex sensory composite included the following items: finger-tip writing, tactile finger recognition, wrist shape drawing, and tactile form recognition. Performance was determined by the number of errors made in each composite. Similar to vision, a dichotomy in performance between simple vs. complex processing in ASD was observed. Error rates for the simple sensory composite were similar between groups; whereas, error rates were much higher in individuals with ASD for the complex sensory composite[28]. This study suggests that the inverse relationship between stimulus complexity and perceptual abilities in ASD may be an amodal phenomenon, effecting all modalities. Studies of auditory processing in autism also lend support to this claim. As noted previously, studies examining pitch discrimination in autism tend to show enhanced auditory perception; however, studies utilizing social or verbal auditory stimuli tend to show perceptual impairments[29]. No studies as of yet have directly compared performance on tasks using simple vs. complex auditory stimuli; although, the relationship between stimulus complexity and performance seen in the visual and tactile realms are likely to extend into the auditory realm.

One major theory in autism which explains the dichotomy seen in performance on psychophysical tasks is the theory of weak central coherence which was originally put forth by Frith. This theory proposes that autism is characterized by a processing bias for featural or low-level information at the expense of global processing[30]. One study which tested whether individuals with autism show diminished holistic processing was conducted by Nakahachi *et al*. Participants were asked to detect changes in scenes which could either be related to the theme of the scene or unrelated to the theme of the scene. ASD participants showed lower accuracy for changes related to the theme of the scene but not for changes unrelated to the theme when compared to controls. In the same experiment, participants discriminated between Thatcherized faces and normal faces presented upright or inverted. Typical adults can discriminate Thatcherized faces from normal faces much faster when they are presented upright than when they are presented inverted. This is theorized to occur because people tend to process faces holistically when upright but not when inverted. Participants with ASD showed longer reaction times than controls for upright faces but not for inverted faces. These two experiments together indicate that individuals with autism may have disruptions in processing complex stimuli holistically[31]. Another study found an inverse relationship between disrupted higher order processing (Global Dot Motion Task) and a measure of central coherence (Children’s Embedded Figures Test) in ASD also lending support to the weak central coherence model[32].

UNISENSORY EVENT-RELATED POTENTIALS IN AUTISM

Psychophysical measures have proven vital in our understanding of the mechanisms of sensory disruptions in autism; however, much more can be learned about the neural underpinnings of these disruptions by incorporating measures of neural activity such as event-related potentials into studies of sensory processing in ASD. For example, one study found that the auditory N1c component which is thought to be generated by associative auditory cortex had smaller amplitude and longer latency as well as an unusual lateralization to the right hemisphere. This study indicates that the functioning of the associative auditory cortex may play a role in disrupted auditory processing in autism[33]. Another study examined disruptions in brainstem evoked potentials (EPs) as well as both early and late components of cortical EPs. One participant with autism showed abnormal brainstem EPs; whereas, significant group differences were observed in late components but not early components of the cortical EPs. Because later components are typically more associated with higher order processing than early components, this study indicates that relatively higher order auditory processing in autism may be disrupted[34]. This study may begin to provide a neurological explanation for the dichotomy in perceptual performance discussed earlier in this paper. Samson *et al* addressed this question by reviewing the behavioral and ERP literature on auditory processing in autism. They found that simple stimuli (e.g. pure tones) and simple tasks (e.g. detection) tended to result in superior performance and decreased ERP latencies; whereas, complex stimuli and tasks resulted in inferior performance and ERP activity[35]. Lepisto *et al* also examined whether the different stages of auditory processing may be disrupted differentially. They found evidence of impaired sound encoding as shown by decreased amplitude in response to sound repetition in autism. They also found enhanced discrimination of pitch but disrupted discrimination of duration as evidenced by the mismatch negativity (MMN). They also found disruptions in involuntary orienting to stimuli as shown by the P3a with speech stimuli showing greater disruptions. This study shows that disruptions in auditory processing in autism may occur at multiple levels including involuntary orienting and that they may be more severe for speech stimuli than non-speech stimuli[36]. Other studies also show disruptions in orienting to oddball stimuli in individuals with autism as evidenced by altered MMN or mismatch field (MMF) for auditory[37], visual[38], and somatosensory[38] stimuli.

MULTISENSORY INTEGRATION IN AUTISM

The literature on unisensory processing in autism has given us many clues as to the sensory disruptions in autism. However, much less is known about multisensory integration in autism. The presence of deficient processing in all modalities is suggestive of a larger multisensory defect. A few studies have examined multisensory integration in autism, one of which was published recently by Van der Smagt *et al*. In this study high-functioning adults with autism and controls completed a task which incorporated a well known multisensory illusion known as the flash-beep illusion. This illusion occurs when one flash is presented with two or more beeps, shifting the perception of one flash to two flashes. The authors found no differences between groups on the strength of this illusion, suggesting that multisensory integration of low-level stimuli is intact in high-functioning autism[39]. However, other groups have found evidence of disrupted integration of multisensory verbal stimuli. Williams *et al* presented visual, auditory, and audiovisual syllables such as “ba,” “da,” and “tha” to children with ASD. The authors found that the children with ASD were less accurate at identifying the unimodal syllables. The children with ASD also did not benefit from the congruent multisensory presentation of “ba” as compared to the incongruent presentation of visual “da” with auditory “ba;” whereas, the controls did benefit from congruent multisensory presentations of “ba.” This suggests that the children with ASD were not able to utilize the visual information to improve their performance. However, the deficit in multisensory integration seen in the ASD group could be due to their decreased ability to interpret the visual stimuli. When visual only performance was statistically controlled for, group differences disappeared. Also when a group of children with ASD were trained to lip-read, they did show a benefit from the congruent presentation of “ba” which contrasted with their performance before training[40]. Smith *et al* did find deficits in multisensory integration of speech stimuli in addition to the unisensory deficits. In this task adolescents with autism were presented with auditory speech stimuli in noise and asked to repeat the three key words which they heard. These stimuli were presented in an adaptive staircase procedure in which correct responses resulted in a decrease in speech volume relative to noise whereas incorrect responses resulted in an increase in speech volume relative to noise. This staircase was run twice: once with auditory only stimuli and once with congruent audiovisual stimuli. Both the ASD and TD group showed similar performance on the auditory only task and improvements with the addition of the congruent visual stimuli; however, the TD adolescents showed significantly more improvement from the visual stimuli than the ASD group. Similar to the Williams *et al* study, lipreading was found to be deficient in ASD and significantly affected the ability of the visual stimuli to improve performance. Unlike the Williams *et al* study, this study found that when visual and auditory performance was statistically accounted for, a significant effect of group still remained suggesting disrupted multisensory integration of speech stimuli in autism[41]. The multisensory studies reviewed thus far suggest the same dichotomy between simple vs. complex/social or verbal stimuli seen in individuals with autism for unisensory stimuli. Mongillo *et al* recently tested this hypothesis by running children with ASD on a battery of multisensory psychophysical tasks which included both tasks incorporating human faces and tasks incorporating inanimate objects. Differences were observed between ASD and TD performance of tasks involving human faces (i.e. male/female face classification, Mcgurk, and AV vowel match/mismatch); however, no differences were observed for tasks involving objects (ball composition and size match/mismatch)[42].

One other aspect of multisensory integration which appears to be disrupted is the distribution of attention within a multisensory object. Lovaas *et al* trained children with autism, mental retardation, and typical development (TD) to respond to a multisensory cue (visual, auditory, and tactile) then tested which of the cues elicited a response. They found that children with TD, and to some extent children with mental retardation, did respond to each stimulus when presented separately. However, children with autism tended to respond to one component of the multisensory stimulus (i.e. visual, auditory, *or* tactile). The authors conclude that this finding may have resulted from an overselectivity of attention within a multisensory object[43]. Studies of event-related potentials during audiovisual selective and divided attention tasks show disrupted attentional modulations of brain responses in autism supporting the claims made by Lovaas *et al*[44,45].

One aspect of multisensory processing which has not yet been studied is the temporal characteristics of multisensory integration. However, there is theoretical evidence that general temporal processing may be disrupted in autism. Brock *et al* theorize that the dissociation between performance on simple vs. complex perceptual tasks might be due to a deficit in temporal synchronization between local networks rather than a general "cognitive style" as proposed by the weak central coherence model[46]. This disruption in temporal binding between cortical and subcortical regions could also manifest as a disruption in multisensory integration as well as a distortion in the temporal characteristics of multisensory binding. One study which examined the perception of temporal synchrony in audiovisual events lends evidence to the assertion that multisensory temporal processing may be disrupted in autism. In this study, children with autism participated in a preferential looking paradigm in which linguistic or non-linguistic stimuli were presented synchronously on one screen and at a delay of 3 seconds on a second screen. Children with TD and children with other developmental disabilities showed preferential looking for both linguistic and non-linguistic asynchronous stimuli; however, children with autism only showed preferential looking for asynchronous non-linguistic stimuli. This study confirms that temporal multisensory processing may be disrupted in autism and that it may also follow the pattern of increased disruptions for complex/social or verbal stimuli than for simple/non-social or non-verbal stimuli[47].

TEMPORAL MULTISENSORY INTEGRATION AND IMPLICATIONS FOR AUTISM

The remainder of this review will be devoted to highlighting the literature on temporal multisensory processing in typical adults and will conclude with future directions for studying whether temporal multisensory processing may be disrupted in autism. The first indications of the temporal properties of multisensory integration arose from studies of multisensory neurons in the superior colliculus. Many of these neurons show superadditive enhancements in response to multisensory stimuli. However, the unisensory components of the multisensory stimulus must be presented in close temporal proximity with one another to produce such enhancements. Interestingly, the unisensory components need not be absolutely synchronous. Instead, a relationship between temporal proximity and enhancements observed exists such that stimuli presented close in time lead to larger enhancements than stimuli present farther apart in time[48]. This same relationship has been observed in numerous psychophysical[49-65] and imaging studies[66-68]. Several studies have also defined a "temporal window" of multisensory integration within which multisensory stimuli are likely to be perceptually "bound"[50-52,69]. One such study, which was published by Shams *et al*, defined a temporal window for the flash-beep illusion introduced previously. In this study, one flash was paired with two beeps with stimulus onset asynchronies ranging from 25 to 250 ms. The second beep could either be presented before or after the flash. The authors were able to use this task to define a temporal window of approximately 100 ms. Future studies could use this task as well as others including the Mcgurk which is also constrained by a temporal window[50] to examine whether autism is characterized by disruptions in temporal multisensory integration. Given the evidence of dichotomies in perceptual performance for simple vs. complex/social or verbal stimuli in autism, it is likely that verbal tasks such as the Mcgurk may exhibit greater disruptions in temporal multisensory processing. However, only further research in this area can confirm this hypothesis.

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FURTHER INFORMATION

Mark Wallace's Lab: http://kc.vanderbilt.edu/multisensory/index.html