CLARITY CHAIR™
Technology to Reboot Your Brain

The Research

Below are several published research reports that document the efficacy of a singular program such as auditory therapy or visual therapy alone as well as the use of multi-sensory programs using one or more sensory programs together. This is only a sample of the volumes of research that has been done.

In the real world, outside the therapy center, people use all their senses at one time to perceive and interact in their environment, not just one sense at a time. For example, it would not be very effective to try to learn to ride a bicycle blindfolded. A person uses their sense of sight, sound, touch and balance to learn and use this skill. The more of our senses we use and the more they function together is what enhances the learning process. That is why training multi-senses at the same time can not only help to develop each sense but also train them to work together more optimally. A better integration of the senses can help lay down a fundamental foundation from which awareness, perception, reasoning, judgment and knowledge can develop and grow.

The SAVE Program not only combines and targets five important senses at one time, auditory (sound), visual (sight), tactile (touch), vestibular (movement and balance sense) and proprioception (perception of movement and spatial orientation), but it does it using an automated system that results in faster, more effective and consistent training that is passive, requiring no effort on the part of the client. In the new technical age of computers and digital programs, we have taken sensory integration to this new level of training which is still firmly based on decades of solid published research and results as well as five years of clinical results on The SAVE Program itself.

Multisensory integration of cross-modal stimulus combinations yielded responses that were significantly greater than those evoked by the best component stimulus. *J Neurophysiol* 97: 3193–3205, 2007. doi:10.1152/jn.00018.2007. Multisensory Versus Unisensory Integration: Contrasting Modes in the Superior Colliculus, Juan Carlos Alvarado, J. William Vaughan, Terrence R. Stanford, and Barry E. Stein *Department of Neurobiology and Anatomy, Wake Forest University School of Medicine, Winston-Salem, North Carolina*

When sound and touch were activated simultaneously, the activation of the auditory cortex was strongest. Auditory information in conjunction with tactile input assists with making tactile decisions. Tactile and auditory stimulation simultaneously and individually may positively impact neuroplastic changes in individuals with neurological deficits or impairments. Used singularly, sound produced greater brain activation than touch. When both tactile and auditory stimuli were conveyed simultaneously, the response was more intense. Differences between sound and touch verses a combination of the two stimuli were significant. Again, the combined stimuli were most significant. Kayser C, Petkov CI, Augath M, Logothetis NK. Integration of touch and sound in the auditory cortex. *Neuron.* 2005;48:373-384.3
Kayser C, Petkov C, Augath M, Logothetis N. Integration of touch and sound in the auditory cortex. *Neuron.* 2005;48:373-384.

The sensory integration approach is effective in reducing self-stimulating behaviors, which interfere with the ability to participate in more functional activities. Smith, S. A., Press, B., Koenig, K. P., & Kinnealey, M. (2005). Effects of sensory integration intervention on self-stimulating and self-injurious behaviors. American Journal of Occupational Therapy, 59, 418–425.

Compared to the normal control group, the children with ADHD showed abnormal functional activity in several regions of the brain involved in the processing of visual attention information. The researchers also found that communication among the brain regions within this visual attention-processing pathway was disrupted in the children with ADHD. Functional brain pathways disrupted in children with ADHD November 30, 2011, Radiological Society of North America

Dyslexic children seem to have some highly specific visual deficits in processing moving stimuli.
Clinical Neurophysiology 115 (2004) 90–96 Visual information processing in dyslexic children, P. Scheuerpfluga,*, E. Plumea, V. Vettera, G. Schulte-Koerneb, W. Deimelb, J. Bartlingb, H. Remschmidtb, A. Warnkea Department of Child and Adolescent Psychiatry, University of Wuerzburg, Fuechsleinstrasse 15, 97080 Wuerzburg, Germany bDepartment of Child and Adolescent Psychiatry, University of Marburg, Hans-Sachs-Strasse 6, 35039 Marburg, Germany Accepted 28 July 2003

Neural Plasticity Following Auditory Training in Children with Learning Problem, Hayes, E.A., Warrier, C.M., Nicol, T.G., Zecker, S.G., & Kraus, N. (2003). Neural plasticity following auditory training in children with learning problems. Clinical Neurophysiology, 114, 673-684. Children with learning problems exhibited plasticity of neural encoding following participation in a remediation auditory processing program. The plasticity was accompanied by changes in behavioral performance.

This study suggests that children exhibit differential processing of multisensory compared to unisensory stimuli, as has previously been reported in adults. Multisensory integration in children: A preliminary ERP study Barbara A. Brett-Greena,b,□, Lucy J. Millera,b,c,d, William J. Gavine, Patricia L. Daviese, dDoctoral Program in Pediatrics, Rocky Mountain University of Health Professionals, Provo, Utah, USA eDepartment of Occupational Therapy, Colorado State University, Fort Collins, CO, USA

J Neurophysiol 97: 3193–3205, 2007. doi:10.1152/jn.00018.2007. Multisensory Versus Unisensory Integration: Contrasting Modes in the Superior Colliculus Juan Carlos Alvarado, J. William Vaughan, Terrence R. Stanford, and Barry E. Stein Department of Neurobiology and Anatomy, Wake Forest University School of Medicine, Winston-Salem, North Carolina Multisensory versus unisensory integration: contrasting modes in the superior colliculus. The present study suggests that the neural computations used to integrate information from different senses are distinct from those used to integrate information from within the same sense. It was found that multisensory integration of cross-modal stimulus combinations yielded responses that were significantly greater than those evoked by the best component stimulus. In contrast, unisensory integration of within-modal stimulus pairs yielded re- sponses that were similar to or less than those evoked by the best component stimulus. This difference is exemplified by the disproportionate representations of superadditive responses during multisensory integration and the predominance of subadditive responses during unisensory integration. These observations suggest that different rules have evolved for integrating sensory information, one (unisensory) reflecting the inherent characteristics of the individual sense and, the other (multisensory), unique supramodal characteristics designed to enhance the salience of the initiating event.

Children ages 6–12 with autism spectrum disorders (ASD) were randomly assigned to a fine motor or SI treatment group. Pretests and posttests measured social responsiveness, sensory processing, functional motor skills, and social–emotional factors. Results identified significant more significant positive changes

in Goal Attainment Scaling scores and a significant decrease in autistic mannerisms occurred in the SI group.
Pfeiffer, B. A., Koenig, K., Kinnealey, M., Sheppard, M., & Henderson, L. (2011). Research Scholars Initiative— Effectiveness of sensory integration interventions in children with autism spectrum disorders: A pilot study. American Journal of Occupational Therapy, 65, 76–85. doi: 10.5014/ajot.2011.09205

The results indicate that self-stimulating behaviors were significantly reduced by 11% one hour after SI intervention. Daily ratings of self- stimulating behavior frequency by classroom teachers using a 5-point scale correlated significantly with the frequency counts taken by the investigators (r = 0.32, p < 0.001). These results suggest that the sensory integration approach is effective in reducing self-stimulating behaviors, which interfere with the ability to participate in more functional activities. Smith, S. A., Press, B., Koenig, K. P., & Kinnealey, M. (2005). Effects of sensory integration intervention on self-stimulating and self-injurious behaviors. American Journal of Occupational Therapy, 59, 418–425.

The finding that the audio tactile portion of the brain is activated as the hands interact with the environment is of clinical significance. Vibrotactile and tactile pressure stimuli co-activate the posterior auditory belt of the left side of the brain. Each type of tactile input, vibrotactile-auditory and pressure tactile-auditory, activate the posterior auditory belt. Audio tactile events occur in the brain with vibration and pressure tactile stimuli. The finding that the audio tactile portion of the brain is activated as the hands interact with the environment is of clinical significance. Schurmann M, Caetano G, Hlushchuk Y, Jousmaki V, Hari R. Touch activates human auditory cortex. *NeuroImage.* 2006; 30:1325-1331.1

Foxe J, Wylie G, Martinez A, et al. Auditory-somatosensory multisensory processing in auditory cortex: an fMRI study. *J Neurophysiol.* 2002;88:540-543.6
Foxe and associates' article introduces and provides support for the premise that multisensory integration within cortical centers occurs early. Furthermore, early integration is not initiated through unisensory centers. This study, using fMRI, investigated the overlap of auditory and somatosensory information in the auditory cortex of humans. Study participants were exposed to three stimuli, auditory, tactile, and auditory and tactile combined. Auditory stimulation activated the bilateral superior temporal gyri, which includes the primary auditory cortex, belt, and parabelt areas. The somatosensory stimulation activated the left pre- and post-central gyrus, bilateral insulae. These areas represent the primary and secondary somatosensory cortex. Overlap between the auditory and tactile stimulation was demonstrated in the right and left regions of the auditory cortex. When auditory and tactile stimulation were simultaneously applied, the activation was greater in the region of overlap in the auditory cortex. Resultant from this

study, the authors hypothesize that auditory and tactile integration provides a feedforward process within the auditory cortex of human beings.

Murray M, Molholm S, Michael C, et al. Three principles pertaining to animal sensory-perceptual courses. The first is the “spatial rule”. This rule states “multisensory interactions are dependent on the spatial alignment and/or overlap of receptive fields responsive to the stimuli.” The second rule, “temporal rule”, maintains “that multisensory interactions are also dependent on the coincidence of the neural responses to different stimuli.” The “inverse effectiveness rule” reports “that the strongest stimuli, when presented in isolation, are minimally effective in eliciting a neural response.” Grabbing your ears: rapid auditory-somatosensory multisensory interactions in low-level sensory cortices are not constrained by stimulus alignment. Cereb Cor. 2005;15:963-974.8 Each subject was exposed to the following stimulations: 1) somatosensory alone, 2) auditory alone, 3) auditory and somatosensory presented simultaneously to same location such as left hand and ear (spatial aligned), 4) auditory and somatosensory offered to different locations, such as left hand and right ear (spatially misaligned). Responses to the combination auditory and somatosensory stimuli were observed in the auditory regions of the superior temporal plane in the hemisphere contralateral to the hand stimulated. Multisensory responses were compared to the summed unisensory responses. The multisensory stimuli responses, both for aligned and misaligned, were larger in amplitude than for the summed unisensory responses. Multisensory stimulation reaction was greater than unisensory reaction, for both spatial aligned and misaligned arrangements. Spatially aligned and misaligned stimulation follow similar early sensory courses. Findings suggest early auditory somatosensory inter-relationships across space occur before perceptual-cognitive events.

Multisensory Versus Unisensory Integration: Contrasting Modes in the Superior Colliculus

Alvarado JC, Vaughn JW, Stanford TR, Stein BE. Multisensory versus unisensory integration: contrasting modes in the superior colliculus. *J Neurophysiol* 97: 3193–3205, 2007. First published February 28, 2007; doi:10.1152/jn.00018.2007. The present study suggests that the neural computations used to integrate information from different senses are distinct from those used to integrate information from within the same sense. Using superior colliculus neurons as a model, it was found that multisensory integration of cross-modal stimulus combinations yielded responses that were significantly greater than those evoked by the best component stimulus. In contrast, unisensory integration of within-modal stimulus pairs yielded responses that were similar to or less than those evoked by the best component stimulus. This difference is exemplified by the disproportionate representations of superadditive responses during multisensory integration and the predominance of subadditive responses during unisensory integration. These observations suggest that different rules have evolved for integrating sensory information, one (unisensory) reflecting the inherent characteristics of the individual sense and, the other (multisensory), unique supramodal characteristics designed to enhance the salience of the initiating event.

Synthesis of Information Concerning Somatosensory and Auditory Multisensory Stimulation and Integration

Human beings in their interaction with the world do not perceive sensory events as singular events. Sound, touch, sight, taste, smell, proprioception, and vestibular information interact to form the processes and mechanics by which humans learn and experience. Integration of sensory information provides a foundation on which behavior and cognition develop and mature. Centers previously believed to be unisensory are in fact multisensory. Schurmann M, Caetano G, Hlushchuk Y, Jousmaki V, Hari R. Touch activates human auditory cortex. *NeuroImage.* 2006;30:1325-1331.

While primary auditory and somatosensory centers in the brain exist, areas of their sensory overlap are well documented. The location of the primary auditory cortex and belt is in the superior temporal gyri.

1. Ozcan M, Baumgartner U, Vucurevic G, Stoeter P, Treede R. Spatial resolution of fMRI in the human parasylvian cortex: Comparison of somatosensory and auditory activation. *NeuroImage.* 2005;25(3):877- 887.
2. Kayser C, Petkov C, Augath M, Logothetis N. Integration of touch and sound in the auditory cortex. *Neuron.* 2005;48:373-384.
3. Levanen S, Jousmaki V, Hari R. Vibration-induced auditory-cortex activation in a congenitally deaf adult. *Curr Biol.* 1998;8:869-872.

Auditory information in conjunction with tactile input assists with making tactile decisions. Jousmaki V, Hari R. Parchment-skin illusion: sound-biased touch. *Curr Biol.* 1998;8(6):R190.

Early cortical centers are no longer thought to be unisensory. Findings of multisensory stimulation research provide solid footing for clinical sensory practices. When combined with theories of neural plasticity, sensory and multisensory experiences may assist with neural development or rehabilitation. For instance, tactile information provides stimulation of the auditory cortices in individuals with hearing impairments; multisensory stimulation results in greater activation of cortical centers; and sound permits individuals to make tactile decisions. The integration of somatosensory and auditory stimulation activates the auditory cortex of the brain. This multisensory stimulation affords more intense cortical activation than unisensory stimulation. Somatosensory and auditory integration is a feed forward process, not dependent on higher centers,

and occurs early in the auditory center. Tactile and auditory stimulation simultaneously and individually may positively impact neuroplastic changes in individuals with neurological deficits or impairments. Foxe J, Wylie G, Martinez A, et al. Auditory-somatosensory
multisensory processing in auditory cortex: an fMRI study. *J Neurophysiol.* 2002;88:540-543.

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Sensory Integration by Dana Nicholls OTR/L and Peggy Syvertson M.A. Johns Hopkins School of Education

“Learning and paying attention is dependent upon the ability to integrate and organize information from our senses. Everyone knows the five basic senses; seeing, hearing, taste, smell and touch. But there are other senses that are not as familiar including the sense of movement (vestibular), and sense of muscle awareness (proprioception). Unorganized sensory input creates a traffic jam in our brain making it difficult to pay attention and learn. To be successful learners, our senses must work together in an organized manner. This is known as sensory integration. The foundation for sensory integration is the organization of tactile, proprioceptive and vestibular input. A person diagnosed with ADD or ADHD, due to their difficulty paying attention, may in fact have an immature nervous system causing sensory integration dysfunction. This makes it difficult for him/her to filter out nonessential information, background noises or visual distraction and focus on what is essential. The relationship between sensory integration, learning and attention will be discussed below.

Tactile sense is our ability to learn from our environment through our sense of touch. This includes knowing how heavy, smooth, rough, big or small an object is just by holding it. In addition, this sense has a protective component which causes us to pull our hand away from a hot stove. Tactile integration is important for the development of body awareness, fine motor skills, motor planning and being comfortable with touch. Examples of unorganized processing of tactile input may be seen as someone who has trouble in crowds, pulls away from hugs, is bothered by certain clothes or foods, or has to touch everything. If someone is attending to the tags in their clothes or the seams in their socks, they are not able to focus on what you are saying; they are not ready to learn.

Vestibular sense provides information related to movement and head position. The vestibular sense is important for development of balance, coordination, eye control, attention, being secure with movement, emotional security and some aspects of language development. Disorganized processing of vestibular input may be seen when someone has difficulty with attention, coordination, following directions, reading (keeping eyes focused on the page or board) or eye-hand coordination. Disorganization may also be seen in someone who is constantly in motion, has an extreme fear of movement, or is described as an overly sensitive, lazy or sedentary person. Immature language skills can often be the reason a child is initially referred for therapy, but the language delay may be the result of immature sensory processing.

Proprioception is our ability to know where our muscles and joints are in space and how they are moving. This is very important for the development of body awareness. Our proprioceptive sense cannot work in isolation, but requires constant input from our tactile and vestibular systems. Unorganized processing of proprioceptive input may be seen as someone who is clumsy, falls or stumbles frequently, is overly aggressive (e.g., tackles people), walks on toes, constantly chewing on food or objects, has difficulty motor planning, or is messy at mealtime. Someone who is unconsciously worried about where their body is on the chair or how they will walk around the table without bumping into it, will not be able to focus their attention on what is being said or what they are carrying.

When the above sensory systems are intact, learning is effortless and easy. Immature systems make paying attention and therefore learning difficult and frustrating."

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Peggy Syvertson CCC-SLP, is a Speech and Language Pathologist in Washington State. She has her Master's and an Interdisciplinary Certificate as an Early Intervention Specialist. She is currently working in private practice and within the schools in the greater Puget Sound area. Peggy can be reached via email at pksslp@hotmail.com.

Vestibular and visual stimulation together, especially the vestibular part, may benefit children with ADHD

Arnold, L. E., Clark, D. L., Sachs, L. A., Jakim, S., & Smithies, C. (1985). Vestibular and visual rotational stimulation as treatment for attention deficit and hyperactivity. American Journal of Occupational Therapy, 39, 84–91.

Motor learning relies on integrated sensory inputs in ADHD, but over-selectively on proprioception in autism spectrum conditions. Slower rate of adaptation and anomalous bias towards proprioceptive feedback during motor learning are characteristics of autism, whereas increased variability in execution is a characteristic of ADHD. Autism Res. 2012 Apr;5(2):124-36. doi: 10.1002/aur.1222. Epub 2012 Feb 22. Izawa J, Pekny SE, Marko MK, Haswell CC, Shadmehr R, Mostofsky SH.

Sensory Modulation Dysfunction in Children with ADHD, Mangeot, et al, Colorado health Science Center; Summary: Children with ADHD symptoms displayed greater abnormalities in sensory modulation.

Eric Courchesne, Ph.D., of the Neurosciences Department, University of California at San Diego, has found significant impairments in auditory processing in autistic individuals using P300 brain wave technology (see Courchesne, 1987 for a review). The P300 brain wave occurs 300 milliseconds after the presentation of a stimulus. (The ‘P’ refers to the positive polarity of the brain wave.) The P300 is associated with cognitive processing, and this brain wave is considered an indication of long-term memory retrieval (Donchin, Ritter, & McCallum, 1978). Edelson et al. (1999) examined auditory P300 activity prior to and three months following auditory integration training (AIT). Three subjects with autism participated in the experimental AIT group and two others participated in a placebo group. Prior to AIT, all five individuals had abnormal auditory P300 activity, indicating problems. Three months following AIT, the results showed dramatic improvement in P300 activity for those who received AIT (i.e., a normalization of P300 activity) and found no change in those who received the placebo.

Atypical sensory-based behaviors are a ubiquitous feature of autism spectrum disorders (ASDs). In this article, we review the neural underpinnings of sensory processing in autism by reviewing the literature on neurophysiological responses to auditory, tactile, and visual stimuli in autistic individuals. We review studies of unimodal sensory processing and multisensory integration that use a variety of neuroimaging techniques, including electroencephalography (EEG), magnetoencephalography (MEG), and functional MRI. We then explore the impact of covert and overt attention on sensory processing. With additional characterization, neurophysiologic profiles of sensory processing in ASD may serve as valuable biomarkers for diagnosis and monitoring of therapeutic interventions for autism and reveal potential strategies and target brain regions for therapeutic interventions. *Pediatric Research* (2011) 69, 48R–54R; doi:10.1203/PDR.0b013e3182130c54

Sensory Processing in Autism: A Review of Neurophysiologic Findings, Elysa J Marco[1], Leighton B N Hinkley[2], Susanna S Hill[2] and Srikantan S Nagarajan[3]

Autism spectrum disorders (ASDs) are defined clinically by impairment in communication, social interaction, and behavioral flexibility (1). There is mounting evidence for disruption of the auditory and visual processing pathways and a surging interest in multisensory integration (MSI). of page

There is literature suggesting measurable differences in early auditory pathways, especially with increasingly complex stimuli. Understanding the nature of this fundamental step in the auditory sensory stream is crucial because the ability to acquire and parse a variety of incoming sounds forms the foundation for language and communication.

In general, the neurophysiologic study of auditory processing in autism does suggest atypical neural activity as early in the processing stream as the primary auditory cortex. However, as Whitehouse and Bishop (24) suggest, these differences may be a result of top-down inhibitory processes mediating encoding and early sound processing. It is probable that the atypical processing is related to the unusual behavioral responses so commonly observed in children on the autism spectrum such as covering of the ears to seemingly benign sounds such as the vacuum cleaner and the blender. Furthermore, one might conjecture that if the auditory input is perceived as unpleasant or noxious, affected individuals will learn to avoid auditory input, and thus curtail the learning that comes from listening to the people and world around them. Comprehension of the potentially atypical auditory processing in children with autism may be key to parsing different etiologies of autism, targeting treatments to children with auditory hyper/hypo-sensitivities, and ameliorating overwhelming auditory sensory input to facilitate learning.ctile Sensory Processing

Although tactile sensitivity is commonly reported in ASD, it has received far less attention in the neuroscience literature than auditory sensitivity (25). Common clinical complaints are avoiding light touch to the head and body as occur with grooming and particular clothing. The psychophysical tactile studies look at thresholds and sensitivity using vibrotactile stimuli. Adults with AS showed lower tactile perceptual thresholds for 200 Hz but not 30 Hz vibrotactile stimuli, implying a specific hypersensitivity in the Pacinian corpuscles receptor pathway (3). Tactile hypersensitivity was again shown to vibrotactile stimuli as well as thermal stimuli but not to light touch in adults with autism (26). In contrast, in a small sample of children with autism, there were no tactile perceptual threshold differences for vibrotactile (40 and 250 Hz) detection (27). However, this study did suggest a correlation between a measure of behavioral tactile sensitivity phenotype and emotional/social reaction. (This trend is considerably underpowered with a sample size of only six boys.) Beyond threshold investigation, Miyazaki *et al*. (28) demonstrate an enhanced early (low-level) somatosensory evoked potential peak in young autistic children using median nerve stimulation that was most prevalent in the right hemisphere response. Coskun *et al*. (29) most recently investigated somatosensory mapping in high functioning adults with autism using MEG. High functioning adults with autism appear to have a disrupted cortical representation of their face and hand. Again, because of the heterogeneity of ASD, the electrophysiology and functional imaging work in this domain should include behavioral measures so that within group differences do not obscure real between group differences. There is a tremendous need for further exploration in this domain as atypical tactile sensitivity appears with particularly high frequency in the autism population.of page

Individuals with ASD also exhibit atypical visual behavior that can be construed as attempting to avoid visual input (*e.g.* covering eyes at bright lights) or to seek additional visual stimuli (*e.g.* twisting fingers in front of eyes) (4). Similar to the auditory and tactile domains, there is considerable discrepancy in neurophysiological findings. There are suggestive reports in the visual domain of enhanced detail perception, particularly for simple stimuli with impairment in more complex tasks (30). Some visual-evoked potential studies indicate that individuals with ASD possess atypical early peaks with impairments in object boundary detection (33), decreased contrast detection ability in both still and moving stimuli at a range of signal/noise ratios (34), and undifferentiated responses for mid- and high spatial frequency gratings (35). Local motion processing studies show differences in second order (texture defined) motion processing but intact first-order (luminance defined) processing, suggesting difficulties with effective integration of incoming stimuli that is magnified with more nuanced tasks (36).

One of the most well-studied aspects of visual perception in autism is that of face processing given the pertinence of this skill for human social interaction (37). As Klin (38) suggests, the literature is heavily confounded by differences in the familiarity of the face, attention, gaze direction and fixation, and the type/complexity of the stimulus. A functional MRI study with eye tracking shows that activation of the fusiform gyrus and the amygdala is reduced in an ASD cohort, as well as their unaffected siblings, but correlates positively with fixation time on the eye region of the face (39,40). An ERP study again highlights group differences that are dependent on directed attention such that ASD individuals do not show the expected increase in the N170 (face processing) wave with directed attention (41). An EEG study assessing γ-band activity, thought to represent the binding of visual information, gives convergent evidence for a neurophysiologic difference in AS face processing (42). Furthermore, the type of visual information matters; children with autism may respond more robustly than controls to neutral and detailed, high spatial frequency information and less robustly to the rapid low-frequency processing that is so critical to our fast-paced social world (43). The emotional valence of face processing has been investigated with a recent study suggesting hyperactivity in the right amygdala with altered connectivity between the frontal and temporal lobes (44). It is a challenge to interpret whether these differences represent primary cortical abnormalities, result from decreased visual exploration in early infancy, or are secondary to a primary social cognitive deficit.

Deficits in simple stimuli and faces extend to studies of biological motion, such that children with autism show impairments in the processing of dynamic noise, motion coherence, and form-from-motion detection (45). There are suggestions that this observed deficit may result in part from atypical processing of emotional information as children with autism were found to differ from control children only in their ability to name emotional point-light displays and not point-light displays of everyday objects (46). This finding suggests a potential disconnection from the limbic or “emotion” neural networks that inform primary sensory processing. Speaking to a genetic underpinning for these differences, inefficient motion processing has been found in siblings of individuals with ASD as well (47). In accordance with theories of increased local cortical activity (48) with impaired long-range connectivity (49), individuals with autism appear to be over-recruiting their left primary cortex compared with typicals during a motion coherence functional MRI study (50). Taken as a whole, these studies further support a disruption in the processing of basic unimodal sensory information that forms the backbone of higher order cortical abilities such as socialization.Low-Level Multisensory Integration

Similar to the aforementioned deficits in unimodal sensory processing in children with ASD, these individuals may also perform poorly during conditions that require collapsing information across multiple modalities (or MSI). Many of the atypical perceptual experiences reported in those with ASD are believed to be due to an inability to properly filter or process simultaneous channels of visual, auditory, and tactile inputs (51). There is evidence that sensory illusions that require the proper concatenation of inputs across multiple domains operate at a different level in ASD, compared with typically developing individuals. In the “flash-beep” illusion, multiple auditory tones paired with a single transient visual stimuli can induce the perception that multiple flashes are present. At a cursory level, it appears that the integration necessary to produce this illusion is preserved in ASD, as demonstrated through a lack of difference between patients and Intelligence Quotient (IQ)-matched typical individuals (52). However, when the timing between stimulus sets is perturbed during presentation, deficits in processing begin to emerge in subjects with autism. Typically, disparity between the auditory and visual stimulus onset times will impact the effect of the illusion, until they appear uncoupled at a certain threshold. Foss-Feig *et al*. (53) were able to demonstrate that, in subjects with autism, the time duration between stimuli that continue to produce the illusion are broader than in typically developing individuals. The observation that broader temporal gaps continue to produce a “flash-beep” illusion in individuals with ASD suggests a level of inefficiency in the MSI in this population.

Electrophysiological studies probe the neural mechanisms of ASD that can manifest as behavioral multisensory deficits. EEG studies of multisensory processing have reported abnormal timing and level of activity within electrophysiological signatures of brain processing. Courchesne *et al*. (54,55) report that in individuals with ASD, a reduction in response amplitude (compared with typically developing children) is evident when concurrent auditory and visual stimuli streams are presented. The sequence of activity in the brain during MSI seems to deviate in children with autism, particularly within the later stages of processing when sensory information is collapsed. When auditory and somatosensory stimuli are presented in parallel, early (<100 ms) electrical potentials in primary sensory cortices are relatively spared in ASD; however, responses that follow this initial stage of activity in the cortex (at around 175 ms) are limited and delayed in ASD (56). These investigations indicate that both the magnitude and the latency of activity in the brain may contribute to multisensory processing deficits in ASD.

Although both behavioral and neurophysiological processing impairments in simple MSI have been reported in ASD, salient differences in sensory integration are also evident at a complex level, particularly during speech comprehension and production. When audio and visual speech stimuli are staggered and presented to individuals with autism, performance drops to a chance level and indicates deficits in speech comprehension (57). Multimodal illusions of linguistic processing in ASD, such as the McGurk effect, suggest that improper timing of sensory integration contributes to observable deficits in communication in ASD. In the McGurk effect, visual processing (*e.g.* lip reading) is combined with auditory processing (phoneme perception) to produce the comprehension of spoken language. Although both typically developing and ASD individuals perform well during this task, typical individuals show a greater dependence on visual feedback (lip reading) compared with ASD (58,59). When both groups are trained on the visual feedback component of the McGurk effect, ASD participants fail to show improvements in performance (60,61). Furthermore, a reliance on visual feedback in noisy auditory environments is unattainable for ASD participants (61). An inability to “fall back” on certain sets of sensory stimuli in the presence of challenging environmental stimuli may contribute to the communication deficits that are well characterized in this disorder.

MSI investigations exploring the specific neurophysiological mechanisms that are compromised in ASD is just beginning (62). Many of the regions known to integrate multiple sensory inputs have been implicated, including prefrontal cortex and association regions of the temporal lobe. At the cellular level, postmortem studies of ASD have illustrated that the columnar density in the neocortex is dense in autism, potentially facilitating local processing (63). It has also been hypothesized that the cerebellum, a structure that shows significant changes in neuronal density in autism (64), may play a role in impaired sensory integration in the disorder. This mediation could occur through atypical filtering of afferent inputs, although these exact mechanisms are unclear (65). Many of the neocortical fields that play a role in MSI are also part of a putative “mirror neuron” network, first identified in homologues of these regions in nonhuman primates (66). Given the observable deficits in imitation and empathy known to be a core feature of the autism spectrum, it has been proposed that communication deficits arise from an inability of multisensory “mirror neurons” to concatenate information to facilitate higher order cognitive function (67). However, others propose that as sensory integration is dependent on the rapid exchange of information between distinct cortical and subcortical regions, disruptions in connectivity likely play the causative role (68). The ASD literature suggests both direct axonal disconnection such as has been implied by the abnormalities of the corpus callosum (69) and indirect disruption of long-range firing synchrony (70,71).

Processing

The discussion of sensory processing in ASD would be incomplete without the consideration of the role of attention on cognitive processing. In their review, Allen and Courchesne (72) suggest that that the clinical observation of heightened reactivity to seemingly meaningless stimuli (*e.g.* intense tantrums in response to the hum of a blender) may be related to a neurobehavioral driven distractibility. Furthermore, narrowed interest and repetitive behaviors may represent deficits in attentional shifting. However, even defining attention is a challenging matter. According to Talsma *et al*. (73), “attention is a relatively broad cognitive concept that includes a set of mechanisms that determine how particular sensory input, perceptual objects, trains of thought, or courses of action are selected for further processing from an array of concurrent possible stimuli, objects, thoughts and actions.” Functionally, an individual must be able to select certain sensory inputs for enhanced processing while either filtering out or suppressing others. This selective attention can be further subdivided in operations such as attentional switching and sustained attention over time (74–76). Many brain regions are involved in processing, modulating, and integrating sensory information. There has been a particular focus on the superior colliculus, the cerebellum, and the frontal lobes in understanding this rapid and multidirectional flow of information, which is mediated by attentional demands and resources (77,78). We suggest that this multidirectional flow of information is impaired for individuals with ASD and that this disruption in cortical communication underlies the individual's inability to attend to their environment in a flexible, productive, and meaningful way. In the following sections, we will focus on two aspects of attending: first, the ability to shift focus from stimuli of one type to another (attentional switching); and second, the effect of increasing the array of information presented to measure the subject's ability to select what information needs to be attended to and what needs to be ignored (selective attention).

In this section, we will focus on studies in which the subject shifts their attention to changes in the stimuli. In ASD neurophysiologic research, the most common form of attentional switch is between a repeated stimulus and an unfamiliar or novel stimulus within the same sensory modality (exogenous attention). However, shifting paradigms can also require the subject to move from one modality to another or to shift visual or auditory focus in space (endogenous attention). In the auditory domain, researchers have primarily used the oddball paradigm to investigate attentional shift. In the oddball paradigm, a stimulus that varies on a single parameter (deviant) such as duration, frequency or intensity, is randomly inserted into a train of repeated (standard) stimuli. This deviance leads to the generation of a negative deflection on an evoked potential recording at 150–200 ms, which is best recorded from the fronto-central sites (79). This paradigm can be extended from covert (preattentive) to overt attention with a task requiring a response to the deviant (target), and other variations of this paradigm include a third rare stimuli as a nontarget (novel) comparison. In the oddball paradigm, the difference between the neural response to the standard stimuli and the deviant stimuli is called the mismatch negativity (MMN) when using an EEG recording technique or the mismatch field when using MEG. MMN/mismatch field wave forms have generated widely disparate results from normal in an ERP study of high functioning children with autism (80) to completely absent in an MEG study of low-functioning individuals with autism (81). Although there are conflicting data from other studies (82–85), Gomot *et al*. (86,87) report faster MMN latencies for pitch variation and atypical activation of the left anterior cingulate. This location has been implicated in attentional switching and correlated with a behavioral measure of intolerance to change. This reduced mismatch latency to pitch variation in conjunction with superior pitch recognition has been interpreted to support the theory of perceptual enhancement, whereby local processing networks are over connected at the expense of long-range connections with integration and attention networks (88–90).

Conflicting findings have also been reported for auditory MMN amplitudes. Several groups have found increased MMN amplitude in samples of adults and children with AS and ASD (19,91,92), whereas Dunn *et al*. (12) found reduced MMN amplitudes using a passive paradigm. Attention shifting for individuals with autism has received less focus in the visual and somatosensory domains, perhaps related to the intense interest in the auditory domain as the gateway for understanding the language and communication deficits that are central to ASDs. When Kemner *et al*. (93) assessed the role of visual attention using an oddball paradigm with both a passive condition and an active counting task, they found that children with autism did not differ from controls in the passive condition, but they did show a larger response to the deviant stimuli during the active task condition.

The importance of directed or overt attention on the effects of cortical processing of novelty is further highlighted by the work of Whitehouse and Bishop (24). To clarify previous findings, suggesting that orienting deficits in autism might be speech-sound specific (80), Whitehouse and Bishop performed a layered study of boys with high functioning autism examining whether processing deficits were due to a perceptual impairment (in acoustic encoding or discrimination of different speech sounds) or a function of cognitive factors (such as reduced attention). They found that, during a passive condition, children with autism showed attenuated early cortical responses to speech sounds but not complex tones. However, when the children were instructed to attend to and respond to the deviant condition, these amplitude differences were no longer evident. Similarly, Dunn *et al*. (12) found that the decreased MMN to simple stimuli, apparent during a passive condition, normalized with directed attention. These studies suggest that a “top down” process mediated by directed attention influences basic sensory processing for individuals on the autism spectrum.age

Beyond the effects of attentional shifting, there is interest in how individuals with ASD select what information to attend to, what to ignore, and how this guides their ability to make sense of the changing world around them. In EEG/MEG studies of attentional shift, one response property of interest is the P300. The P3a is a positive deflection culminating around 300 ms that is thought to reflect orienting to changes in the environment that may underlie attentional switching; the P3b is a component of the late attention peak that reflects task-related cortical activity and may underlie working memory. The P3b is thought to emanate from temporal and parietal neural sources (94). The earliest autism study reporting a P300 attention wave targeted attention by presenting a train of stroboscopic flashes with an occasional missing flashes (95). In the three individuals investigated, the study investigators found good accuracy in the behavioral task but small or absent late positive waves. This suggests, as has been seen in the auditory literature, that in simple tasks, behavioral performance can be similar between groups while the cortical activity differs. In a series of visual oddball studies, Courchesne *et al*. (54) first used a letter mismatch and found normal P3b amplitudes; in a later study, they used blue and red squares (color mismatch) and again found typical P3b responses with targeted attention (54,55). In a subsequent study, they added an additional level of spatial complexity to the task—there were five empty squares, one of which was designated to be attended to; when the circle appeared in the attended box (target), the participant responded with a button press; when the circle appeared in an “un”attended box, the condition was ignored. In this visual-spatial selective attention task, they found a delay in the frontal P3a (attention orienting) and a diminution in the parietal P3b (96). With this degree of spatial challenge, this cohort of high functioning ASD males had difficulty in both speed and accuracy relative to matched controls. This series suggests that increasing the attention and capacity demands of this visual task leads to both behavioral and physiologic differences in individuals with autism versus controls, whereas simple visual attention tasks may fail distinguish them. Other visual oddball studies support this finding of diminished P3 amplitudes and have correlated a shorter visual fixation period with the P3 diminution (93,97). These investigations suggest that the density and complexity of the incoming stimuli may affect the degree to which the attention neural networks are recruited for processing of incoming sensory information.

Our ability to attend appears to have a limited capacity (*i.e.* there is a finite quantity of information that can be considered simultaneously), and we therefore need to selectively concentrate on one aspect of the environment while ignoring other features to effectively and efficiency process sensory input (75). This capacity may be even more limited in certain subgroups of individuals with ASD. An ERP auditory task with selected spatial attention demonstrates this capacity effect: high functioning adults with autism showed both behaviorally diminished ability to selectively tune into a specified sound source as well as an ERP signature of this deficit with relatively broader N1 and shallower P3 peaks when compared with a typical control group (98). This finding was only evident with increased task complexity (*i.e.* more speakers and a continuous, rapid stream of complex tone distractors). In a task of divided attention between visual and auditory stimuli, the failure of the autism group to modulate the slow negative wave in response to focused/divided/ignored conditions is thought to indicate a potential deficit in selective inhibition and attention (99). This finding echoes the anecdotal reports of parents that children with autism can function typically in a well-controlled environment but decompensate in the face of challenging sensory environments such as a grocery store or an animated birthday party. Children with autism may have more difficulty with automatic processing of information and may already rely more heavily on already overloaded attention and working-memory based networks, such that when the stimuli reach and exceed capacity, the processing system fails (12,90).

Given the ubiquitous nature of sensory behavioral differences for individuals with autism, understanding the neural underpinnings of basic sensory processing in ASDs is an important task. Furthermore, as the neurophysiologic data mount, we suggest that differences in sensory processing may actually cause core features of autism such as language delay (auditory processing) and difficulty with reading emotion from faces (visual processing). Interpreting the neuroscience has been complicated by the heterogeneity of the disorder as well as the difficulty in designing tasks that can precisely probe our finely tuned and intricately connected sensory neural networks. Despite these challenges, tremendous gains have been made over the past 30 years and will guide both our understanding of the disorder as well as provide insights into how to strengthen basic processing and attention for affected individuals.

Going forward, studies of infant siblings of individuals affected with ASD can provide an understanding of whether sensory processing differences are a primary feature of the disorder or a result of learned behaviors. Behavioral intervention trials, such as computerized training modules and self-regulation programs, need to be studied both for efficacy and to determine whether there is normalization of neural activity in affected individuals. Psychopharmacology studies targeting attention and arousal paired with functional imaging assessments hold great promise in providing valuable treatment models. Finally, careful sensory behavioral phenotyping is essential for both understanding our neurophysiologic research as well as tailoring appropriate and effective treatments.

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