Published in final edited form as:

Cogn Neurosci. 2019 July ; 10(3): 160–162. doi:10.1080/17588928.2019.1592141.

The Role of Regulation and Attention in Atypical Sensory Processing

Shulamite A. Green, Ph.D.^{1,2} and Emily T. Wood, M.D., Ph.D.^{1,2}

¹Jane and Terry Semel Institute for Neuroscience & Human Behavior

²Psychiatry and Biobehavioral Sciences, University of California Los Angeles

Abstract

Ward (this issue) proposes four (non-mutually-exclusive) theories for how sensory sensitivity, as commonly seen in autism and other neurodevelopmental disorders, may be linked to atypical neural responses to sensory stimuli. As presently laid out, these theories do not fully account for the complexity and heterogeneity of neural responses to sensory information seen in autism. We describe the important role of attention and regulation in atypical neural and behavioral responses to sensory stimuli, and how these higher-order functions might fit into some of the proposed theories.

Keywords

autism; sensory processing; fMRI

Commentary:

The brain response to sensory stimuli is complex and sensory over-responsivity (SOR), at least in autism, appears to be related to higher-order cognition such as attention and regulation. Ward proposes that, at Marr's computational level¹ the sensory system attempts to maximize behavioral sensitivity while minimizing metabolically costly neural sensitivity. This simplified view assumes that greater discriminatory and detection ability is functionally adaptive while neglecting that successful navigation and interaction with the environment requires higher-level interpretation and regulation of emotional responses to sensory information.

SOR is defined by responding too much, for too long, or to stimuli of weak intensity, and is exhibited by sensitivity to and/or avoidance of sensations such as loud or unpredictable noises. While Ward's "subjective sensory sensitivity" is related to SOR, the majority of SOR data has been collected using either parent report or experimenter observation of behavioral responses that children have to sensory stimuli, thus the focus on observable behavior.^{2,3} For

Corresponding author: Shulamite A. Green, Ph.D., University of California, Los Angeles, Semel Institute for Neuroscience and Human Behavior, Ahmanson-Lovelace Brain Mapping Center 660 Charles E. Young Drive South, Los Angeles, CA 90095, shulamite@ucla.edu.

Author Disclosures: Drs. Green and Wood report no biomedical financial interests or potential conflicts of interests.

years, autism researchers tried and failed to find consistent evidence that there were basic physiological arousal differences underlying SOR in autism⁴ such as event-related brain potentials⁵ and electrodermal response.⁶ These inconsistent findings are likely attributable to measurement issues, not accounting for within-autism heterogeneity in SOR, and failure to consider the complexity of the brain response involved in SOR, which includes brain differences in regions implicated in attention, salience detection, and regulation, in addition to primary sensory processing regions.

Our research reveals involvement of the amygdala in SOR in autism^{7,8} suggesting that SOR is related to increased attention, attribution of salience, and/or emotional response to sensory stimuli. Youth with autism who have higher levels of SOR have greater resting-state functional connectivity between the salience network (a resting-state network implicated in decisions about where an individual directs attention), sensory cortex and the amygdala.⁹ Importantly, there are no differences in initial amygdala response to sensory stimuli but rather a failure of amygdala habituation over time.¹⁰ A subgroup of individuals with autism and low SOR demonstrate resilience through top-down regulation of the amygdala with typical amygdala habituation to sensory stimuli and *increased* prefrontal-amygdala connectivity in response to sensory stimuli.⁸ These findings suggest that diminished amygdala habituation is related to deficits in top-down regulation, perhaps leading to increased attention to (or difficulty “tuning out”) extraneous sensory stimuli. This idea is further supported by evidence that individuals with autism had difficulty maintaining brain activity in key auditory-language and social cognition regions when completing a social inference task presented simultaneously with a distracting tactile stimulus. However, when their attention was subsequently explicitly directed to the important social cues for solving the task (i.e. helping them “tune out” the sensory stimuli and “tune in” on the social stimuli), they engaged medial prefrontal cortex and sustained brain activity in the auditory-language regions.¹¹ This prefrontal activation was *negatively* correlated with SOR symptoms and may be related to other findings of increased connectivity between primary sensory and subcortical networks correlated with autism severity,¹² suggesting that individuals with SOR show deficits in prefrontal regulation of attentional systems during sensory stimulation.

Therefore, Ward’s theories should be considered in relation to attention and regulation systems. For example, while the **excitation-to-inhibition ratio** in sensory cortex may play a role in some basic sensory processes such as poor frequency discrimination,^{13,14} it has not been studied in brain regions important for attention and regulation with respect to SOR. Many studies have demonstrated atypical thalamic connectivity with sensory cortices in ASD,^{12,15–17} decreased local thalamic functional connectivity,¹⁸ and increases in transient thalamic-sensory connectivity.¹⁹ An abnormal excitation-to-inhibition ratio in the amygdala/thalamus could be associated with reduced regulatory abilities and greater attentional focus on extraneous sensory stimuli. In this way, the excitation-to-inhibition theory could be related to the **altered network connectivity theory**, in which Ward alludes to the possible role of an “amygdala-driven attentional alerting mechanism” in relation to SOR. However, an important aspect of this theory involves top-down regulation of the amygdala, likely involving both the prefrontal cortex and the thalamus.

While the majority of research conducted on the role of regulation and attention in sensory over-responsivity has been done within autism, SOR is highly prevalent in other neurodevelopmental conditions involving regulatory deficits (e.g., anxiety,²⁰ ADHD²¹). Thus, future studies should consider whether the role of regulation and attention in SOR is shared across these different conditions.

References

1. Marr D Vision: A Computational Investigation into the Human Representation and Processing of Visual Information. Cambridge, Massachusetts: W.H. Freeman and Company; 1982.
2. Minshew NJ, Hobson JA. Sensory sensitivities and performance on sensory perceptual tasks in high-functioning individuals with autism. *J Autism Dev Disord* 2008;38(8):1485–1498. doi:10.1007/s10803-007-0528-4 [PubMed: 18302014]
3. Ben-Sasson A, Hen L, Fluss R, Cermak SA, Engel-Yeger B, Gal E. A meta-analysis of sensory modulation symptoms in individuals with autism spectrum disorders. *J Autism Dev Disord* 2009;39(1):1–11. doi:10.1007/s10803-008-0593-3 [PubMed: 18512135]
4. Rogers SJ, Ozonoff S. Annotation: what do we know about sensory dysfunction in autism? A critical review of the empirical evidence. *J Child Psychol Psychiatry*. 2005;46(12):1255–1268. doi: 10.1111/j.1469-7610.2005.01431.x [PubMed: 16313426]
5. Ceponiene R, Lepistö T, Shestakova A, et al. Speech-sound-selective auditory impairment in children with autism: they can perceive but do not attend. *Proc Natl Acad Sci U S A*. 2003;100(9): 5567–5572. doi:10.1073/pnas.0835631100 [PubMed: 12702776]
6. Schoen SA, Miller LJ, Brett-Green BA, Nielsen DM. Physiological and behavioral differences in sensory processing: a comparison of children with autism spectrum disorder and sensory modulation disorder. *Front Integr Neurosci* 2009;3(13):29. doi:10.3389/neuro.07.029.2009 [PubMed: 19915733]
7. Green SA, Rudie JD, Colich NL, et al. Overreactive brain responses to sensory stimuli in youth with autism spectrum disorders. *J Am Acad Child Adolesc Psychiatry*. 2013;52(11):1158–1172. doi: 10.1016/j.jaac.2013.08.004 [PubMed: 24157390]
8. Green SA, Hernandez L, Tottenham N, Krasileva K, Bookheimer SY, Dapretto M. Neurobiology of Sensory Overresponsivity in Youth With Autism Spectrum Disorders. *JAMA Psychiatry*. 2015;72(8):778–786. doi:10.1001/jamapsychiatry.2015.0737 [PubMed: 26061819]
9. Green SA, Hernandez LM, Bowman HC, Bookheimer SY, Dapretto M. Sensory over-responsivity and social cognition in ASD: Effects of aversive sensory stimuli and attentional modulation on neural responses to social cues. *Dev Cogn Neurosci* 2016. doi:10.1016/j.dcn.2017.02.005
10. Swartz JR, Wiggins JL, Carrasco M, Lord C, Monk CS. Amygdala habituation and prefrontal functional connectivity in youth with autism spectrum disorders. *J Am Acad Child Adolesc Psychiatry*. 2013;52(1):84–93. doi:10.1016/j.jaac.2012.10.012 [PubMed: 23265636]
11. Green SA, Hernandez LM, Bowman HC, Bookheimer SY, Dapretto M. Sensory over-responsivity and social cognition in ASD: Effects of aversive sensory stimuli and attentional modulation on neural responses to social cues. *Dev Cogn Neurosci* 2018;29:127–139. doi:10.1016/j.dcn.2017.02.005 [PubMed: 28284787]
12. Cerliani L, Mennes M, Thomas RM, Di Martino A, Thioux M, Keyzers C. Increased functional connectivity between subcortical and cortical resting-state networks in Autism spectrum disorder. *JAMA Psychiatry*. 2015;72(8):767–777. doi:10.1001/jamapsychiatry.2015.0101 [PubMed: 26061743]
13. Puts NAJ, Edden RAE, Evans CJ, McGlone F, McGonigle DJ. Regionally Specific Human GABA Concentration Correlates with Tactile Discrimination Thresholds. *J Neurosci* 2011;31(46):16556–16560. doi:10.1523/JNEUROSCI.4489-11.2011 [PubMed: 22090482]
14. Puts NAJ, Wodka EL, Tommerdahl M, Mostofsky SH, Edden RAE. Impaired tactile processing in children with autism spectrum disorder. *J Neurophysiol* 2014;111(9):1803–1811. doi:10.1152/jn.00890.2013 [PubMed: 24523518]

15. Woodward ND, Giraldo-Chica M, Rogers B, Cascio CJ. Thalamocortical Dysconnectivity in Autism Spectrum Disorder: An Analysis of the Autism Brain Imaging Data Exchange. *Biol Psychiatry Cogn Neurosci Neuroimaging*. 2017;2(1):76–84. doi:10.1016/j.bpsc.2016.09.002 [PubMed: 28584881]
16. Gilmore JH. NIH Public Access. *North*. 2008;29(10):1883–1889. doi:10.3174/ajnr.A1256.Functional
17. Green SA, Hernandez L, Bookheimer SY, Dapretto M. Reduced modulation of thalamocortical connectivity during exposure to sensory stimuli in ASD. *Autism Res Off J Int Soc Autism Res* 2017;10(5):801–809. doi:10.1002/aur.1726
18. Tomasi D, Volkow ND. Reduced Local and Increased Long-Range Functional Connectivity of the Thalamus in Autism Spectrum Disorder. *Cereb Cortex N Y N 1991*. 2019;29(2):573–585. doi: 10.1093/cercor/bhx340
19. Fu Z, Tu Y, Di X, et al. Transient increased thalamic-sensory connectivity and decreased whole-brain dynamism in autism. *NeuroImage*. 2018;(June):1–14. doi:10.1016/j.neuroimage.2018.06.003
20. Ben-Sasson A, Carter AS, Briggs-Gowan MJ. Sensory Over-Responsivity in Elementary School: Prevalence and Social-Emotional Correlates. *J Abnorm Child Psychol* 2009;37(5):705–716. doi: 10.1007/s10802-008-9295-8 [PubMed: 19153827]
21. Parush S, Sohmer H, Steinberg A, Kaitz M. Somatosensory function in boys with ADHD and tactile defensiveness. *Physiol Behav* 2007;90(4):553–558. doi:10.1016/j.physbeh.2006.11.004 [PubMed: 17198716]