Target Article: “Origins of music in credible signaling” by Samuel A. Mehr, Max M. Krasnow, Gregory A. Bryant, & Edward H. Hagen

Title: A neurodevelopmental disorders perspective into music, social attention, and social bonding

Names: Anna Kasdan[1], Reyna L. Gordon[2,1,] & Miriam D. Lense[2,1]

Institution: [1]Vanderbilt Brain Institute, Vanderbilt University, Nashville, TN, USA
[2]Department of Otolaryngology – Head and Neck Surgery, Vanderbilt University Medical Center, Nashville, TN, USA

Abstract:

Our commentary addresses how two neurodevelopmental disorders, Williams syndrome and Autism spectrum disorder, provide novel insights into the credible signaling and music and social bonding hypotheses presented in the two target articles. We suggest that these neurodevelopmental disorders, characterized by atypical social communication, allow us to test hypotheses about music, social bonding, and their underlying neurobiology.

Main Text:

Neurodevelopmental disorders characterized by atypical social profiles provide a unique window into the relationship between sociability, music, and the evolutionary origins of music. Here, we focus on two neurodevelopmental disorders characterized by atypical development of social communication – Williams syndrome and Autism spectrum disorder (ASD). We 1) provide additional consideration about music as a credible signal for parent-infant interactions (Mehr et al., 2020) and 2) extend neurobiological predictions about Music and Social Bonding (MSB; Savage et al., 2020).

Individuals with WS, a genetic neurodevelopmental disorder caused by the deletion of ~28 genes on chromosome 7, exhibit marked hypersociability accompanied by difficulties in social pragmatics (Barak & Feng, 2016). Individuals with ASD, an etiological heterogenous set of neurodevelopmental disorders, exhibit deficits in social communication and interactions (Barak & Feng, 2016). Music is a relative strength and interest in both Williams syndrome and ASD. Individuals with Williams syndrome exhibit increased emotional responsiveness to music and increased neural responses to musical stimuli compared to typical peers (Kasdan et al., 2020; Lense et al., 2014), though behavioral studies of musical skills show mixed findings and substantial individual differences (Hopyan et al., 2001; Martens et al., 2010). Individuals with ASD generally exhibit age-appropriate melody and rhythm skills (Jamey et al., 2019; Tryfon et al., 2017) and better pitch interval detection compared to controls (Heaton, 2005). Additionally, individuals with ASD show preserved emotional processing of music at

both behavioral and neural levels, despite overall impairments in emotion recognition (Caria et al., 2011; Molnar-Szakacs & Heaton, 2012).

As in typical development, music is used in these populations to leverage social attention and bonding, including during parent-child interactions (Steinberg et al., 2020). Due to impaired social communication of children with ASD and Williams syndrome, parents adapt and increase their social signaling in order to capture and modulate their children's attention and emotions; this frequently involves adapting the "musicality" of the social signal such as through increased rhythmic predictability and pitch contours (e.g., increased use of infant-directed speech (Cohen et al., 2013; Quigley et al., 2016)). Music and song activities provide an ecologically valid means for scaffolding parental signaling during these shared social interactions (Lense & Camarata, 2020). This is consistent with and extends the idea of music as a credible signal for parent-infant interactions (Mehr et al., 2020). The core features of music (e.g., discrete pitches, predictable and hierarchical rhythms) incorporated into both credible signaling and MSB hypotheses can predictably, reliably, and efficiently structure social rhythmic signals such as vocalizations, movement, gaze, and touch (Lense & Camarata, 2020).

The two hypotheses for the evolution of musicality, which highlight the social attention components of musical activities, also inform directions regarding the therapeutic use of music in ASD and Williams syndrome. Investigations of music and social bonding must consider the bidirectionality of the interaction and the needs and goals of both social partners. For example, musical activities between parents and their child with a neurodevelopmental disability are increasingly recognized as modulating *parent* behaviors like parent responsiveness (e.g., physically supporting child's play through contingent imitation) (Boorom et al., 2020; Thompson et al., 2019) and parent mood (Williams et al., 2012), thus enhancing the likelihood of child engagement downstream. Music and song may be a particularly meaningful platform for social communication in light of the altered language and social communication abilities in ASD and Williams syndrome (Mervis & Velleman, 2011; Tager-Flusberg, 2000). Consistent with tenets of the MSB hypothesis for the efficacy of music in large groups, music-based activities may scale to larger interaction contexts beyond the parent-child dyad, and to new interaction partners, due to the effective and rewarding aspects of musical activities for participants (Lense & Camarata, 2020).

Neurobiologically, individuals with Williams syndrome and ASD exhibit brain structural and functional differences in regions important for rhythm processing (e.g., basal ganglia; somatomotor connectivity (Campbell et al., 2009; Estes et al., 2011; Vega et al., 2015)). These differences in brain structure and connectivity may be functionally linked to social and musical profiles. Children with ASD who underwent a music intervention exhibited higher communication scores and functional connectivity between auditory and motor regions (cortical and subcortical) compared to a non-music intervention control group following the intervention (Sharda et al., 2018). In addition, individuals with ASD exhibit increased functional connectivity between left frontal and temporal regions for song compared to speech (Lai et al., 2012). Different neural mechanisms for processing music and language may provide a basis for using music-

based activities in these populations (Sharda et al., 2015). Additionally, behavioral work suggests links between beat perception and adaptive communication abilities in Williams syndrome (Lense & Dykens, 2016) and appropriate sensorimotor rhythmic synchronization under some circumstances in ASD (Tryfon et al., 2017). These behavioral studies further support investigation into if and how musical rhythm activities may modulate neural connectivity between sensorimotor and reward related regions in these populations. The neuroanatomical hubs of the MSB hypothesis (e.g., basal ganglia, implicated in both the reward system and in processing "beat-based" rhythms (Matthews et al., 2020)) provide a relevant framework for assessing how these regions may relate to music's social bonding function in individuals with atypical social communication.

Brain-to-brain synchrony (i.e., "neural resonance" component of the MSB hypothesis) is an important neurobiological mechanism for successful communication (Hasson et al., 2012; Nguyen et al., 2020). When considering music as a credible signal for parent-infant interactions, social interactions emphasizing musical elements (e.g., song) may strengthen neural synchrony across the dyad. This may be particularly effective for individuals with Williams syndrome or ASD for whom music may be a more salient cue for social interactions. Predictable musical experiences paired with salient social signals (e.g., eye gaze (Leong et al., 2017)) may facilitate rewarding interactions between dyads. Populations with neurodevelopmental disorders may offer a unique lens into how brain-to-brain synchrony in parent-child dyads is modulated by musical and non-musical activities. Both the credible signaling (Mehr et al., 2020) and MSB (Savage et al., 2020) hypotheses provide relevant frameworks for understanding the neurobiology underlying musicality and social communication in Williams syndrome and ASD.

Conflict of interest and funding statements: The authors declare no conflicts of interest. This work was supported in part by the National Institute of Mental Health (NIMH), National Center for Complementary and Integrative Health (NCCIH) [R61MH123029], National Institute on Deafness and Other Communication Disorders (NIDCD) [R21DC016710], the National Institutes of Health Office of the Director (DP2HD098859), National Endowment for the Arts Research Lab (1863278-38), and the National Science Foundation (NSF) [1926794] and NSF GRFP. The content is solely the responsibility of the authors and does not necessarily represent the official views of the funders.

References:

Barak, B., & Feng, G. (2016). Neurobiology of social behavior abnormalities in autism and Williams syndrome. *Nature Neuroscience*, *19*(6), 647–655. https://doi.org/10.1038/nn.4276.Neurobiology

Boorom, O., Muñoz, V., Xin, R., Watson, M., & Lense, M. D. (2020). Parental responsiveness during musical and non-musical engagement in preschoolers with ASD. *Research in Autism Spectrum Disorders*, *78*(September). https://doi.org/10.1016/j.rasd.2020.101641

Campbell, L. E., Daly, E., Toal, F., Stevens, A., Azuma, R., Karmiloff-Smith, A., Murphy,

D. G. M., & Murphy, K. C. (2009). Brain structural differences associated with the behavioural phenotype in children with Williams syndrome. *Brain Research*, *1258*, 96–107. https://doi.org/10.1016/j.brainres.2008.11.101

Caria, A., Venuti, P., & De Falco, S. (2011). Functional and dysfunctional brain circuits underlying emotional processing of music in autism spectrum disorders. *Cerebral Cortex*, *21*(12), 2838–2849. https://doi.org/10.1093/cercor/bhr084

Cohen, D., Cassel, R. S., Saint-Georges, C., Mahdhaoui, A., Laznik, M. C., Apicella, F., Muratori, P., Maestro, S., Muratori, F., & Chetouani, M. (2013). Do Parentese Prosody and Fathers' Involvement in Interacting Facilitate Social Interaction in Infants Who Later Develop Autism? *PLoS ONE*, *8*(5). https://doi.org/10.1371/journal.pone.0061402

Estes, A., Shaw, D. W. W., Sparks, B. F., Friedman, S., Giedd, J. N., Dawson, G., Bryan, M., & Dager, S. R. (2011). Basal ganglia morphometry and repetitive behavior in young children with autism spectrum disorder. *Autism Research*, *4*(3), 212–220. https://doi.org/10.1002/aur.193

Hasson, U., Ghazanfar, A. A., Galantucci, B., Garrod, S., & Keysers, C. (2012). Brain-to-brain coupling: A mechanism for creating and sharing a social world. *Trends in Cognitive Sciences*, *16*(2), 114–121. https://doi.org/10.1016/j.tics.2011.12.007

Heaton, P. (2005). Interval and contour processing in autism. *Journal of Autism and Developmental Disorders*, *35*(6), 787–793. https://doi.org/10.1007/s10803-005-0024-7

Hopyan, T., Dennis, M., Weksberg, R., & Cytrynbaum, C. (2001). Music skills and the expressive interpretation of music in children with Williams-Beuren syndrome: Pitch, rhythm, melodic imagery, phrasing, and musical affect. *Child Neuropsychology*, *7*(1), 42–53. https://doi.org/10.1076/chin.7.1.42.3147

Jamey, K., Foster, N. E. V., Sharda, M., Tuerk, C., Nadig, A., & Hyde, K. L. (2019). Evidence for intact melodic and rhythmic perception in children with Autism Spectrum Disorder. *Research in Autism Spectrum Disorders*, *64*, 1–12. https://doi.org/10.1016/j.rasd.2018.11.013

Kasdan, A., Gordon, R. L., & Lense, M. D. (2020). Neurophysiological correlates of dynamic beat tracking in individuals with Williams syndrome. *Biological Psychiatry: Cognitive Neuroscience and Neuroimaging*. https://doi.org/10.1016/j.bpsc.2020.10.003

Lai, G., Pantazatos, S. P., Schneider, H., & Hirsch, J. (2012). Neural systems for speech and song in autism. *Brain*, *135*(3), 961–975. https://doi.org/10.1093/brain/awr335

Lense, M. D., & Camarata, S. (2020). PRESS-Play: Musical Engagement as a Motivating Platform for Social Interaction and Social Play in Young Children with ASD. *Music & Science*, *3*, 205920432093308. https://doi.org/10.1177/2059204320933080

Lense, M. D., & Dykens, E. M. (2016). Beat perception and sociability: Evidence from Williams syndrome. *Frontiers in Psychology*, *7*(JUN), 1–13. https://doi.org/10.3389/fpsyg.2016.00886

Lense, M. D., Gordon, R. L., Key, A. P. F., & Dykens, E. M. (2014). *Neural correlates of cross-modal affective priming by music in Williams syndrome*. https://doi.org/10.1093/scan/nst017

Leong, V., Byrne, E., Clackson, K., Georgieva, S., Lam, S., & Wass, S. (2017). Speaker gaze increases information coupling between infant and adult brains. *Proceedings of the National Academy of Sciences of the United States of America*, *114*(50), 13290–13295. https://doi.org/10.1073/pnas.1702493114

Martens, M. A., Reutens, D. C., & Wilson, S. J. (2010). Auditory cortical volumes and musical ability in Williams syndrome. *Neuropsychologia*, *48*(9), 2602–2609. https://doi.org/10.1016/j.neuropsychologia.2010.05.007

Matthews, T. E., Witek, M. A. G., Lund, T., Vuust, P., & Penhune, V. B. (2020). The sensation of groove engages motor and reward networks. *NeuroImage*, *214*(November 2019), 116768. https://doi.org/10.1016/j.neuroimage.2020.116768

Mehr, S., Krasnow, M. M., Bryant, G., & Hagen, E. (2020). Origins of music in credible signaling. *Behavioral and Brain Sciences*. http://eprints.soton.ac.uk/252625/2/bbs.html

Mervis, C. B., & Velleman, S. L. (2011). Children With Williams Syndrome: Language, Cognitive, and Behavioral Characteristics and Their Implications for Intervention. *Perspectives on Language Learning and Education*, *18*(3), 98–107. https://doi.org/10.1044/lle18.3.98

Molnar-Szakacs, I., & Heaton, P. (2012). Music: A unique window into the world of autism. *Annals of the New York Academy of Sciences*, *1252*(1), 318–324. https://doi.org/10.1111/j.1749-6632.2012.06465.x

Nguyen, T., Schleihauf, H., Kayhan, E., Matthes, D., Vrtička, P., & Hoehl, S. (2020). Neural synchrony in mother–child conversation: Exploring the role of conversation patterns. *Social Cognitive and Affective Neuroscience*, *December 2019*, 1–10. https://doi.org/10.1093/scan/nsaa079

Quigley, J., McNally, S., & Lawson, S. (2016). Prosodic patterns in interaction of low-risk and at-risk-of-autism spectrum disorders infants and their mothers at 12 and 18 months. *Language Learning and Development*, *12*(3), 295–310.

Savage, P. E., Loui, P., Tarr, B., Schachner, A., Glowacki, L., Mithen, S., & Fitch, W. T. (2020). Music as a coevolved system for social bonding. *Behavioral and Brain Sciences*.

Sharda, M., Midha, R., Malik, S., Mukerji, S., & Singh, N. C. (2015). Fronto-Temporal connectivity is preserved during sung but not spoken word listening, across the autism spectrum. *Autism Research*, *8*(2), 174–186. https://doi.org/10.1002/aur.1437

Sharda, M., Tuerk, C., Chowdhury, R., Jamey, K., Foster, N., Custo-Blanch, M., Tan, M., Nadig, A., & Hyde, K. (2018). Music improves social communication and auditory-motor connectivity in children with autism. *Translational Psychiatry*, *8*(1), 231. https://doi.org/10.1038/s41398-018-0287-3

Steinberg, S., Shivers, C. M., Liu, T., Cirelli, L. K., & Lense, M. D. (n.d.). *Musical Engagement and Parent-Child Attachment in Children with and without Developmental Disabilities*. 1–35.

Tager-Flusberg, H. (2000). Understanding the language and communicative impairments in autism. *International Review of Research in Mental Retardation*, *23*, 185–205. https://doi.org/10.1016/s0074-7750(00)80011-7

Thompson, G. A., Shanahan, E. C., & Gordon, I. (2019). The role of music-based parent-child play activities in supporting social engagement with children on the

autism spectrum: A content analysis of parent interviews. *Nordic Journal of Music Therapy*, *28*(2), 108–130. https://doi.org/10.1080/08098131.2018.1509107

Tryfon, A., Foster, N. E., Ouimet, T., Doyle-Thomas, K., Anagnostou, E., Sharda, M., & Hyde, K. L. (2017). Auditory-motor rhythm synchronization in children with autism spectrum disorder. *Research in Autism Spectrum Disorders*, *35*, 51–61. https://doi.org/10.1016/j.rasd.2016.12.004

Vega, J. N., Hohman, T. J., Pryweller, J. R., Dykens, E. M., & Thornton-Wells, T. A. (2015). Resting-state functional connectivity in individuals with down syndrome and williams syndrome compared with typically developing controls. *Brain Connectivity*, *5*(8), 461–475. https://doi.org/10.1089/brain.2014.0266

Williams, K. E., Berthelsen, D., Nicholson, J. M., Walker, S., & Abad, V. (2012). The effectiveness of a short-term group music therapy intervention for parents who have a child with a disability. *Journal of Music Therapy*, *49*(1), 23–44. https://doi.org/10.1093/jmt/49.1.23