Developmental and Cognitive Neuroscience (PSGY4069)
Assessment (4000-word limit)

ID – 20701954 [1]
[1] School of Psychology, University of Nottingham, Nottingham, UK

Are Music, Rhythmic Capabilities, and Timing affected in People with Autism?

Use of generative AI: Generative AI (Copilot) was used briefly as a conversation partner early in the research process. However, responses were subsequently found not to accurately reflect academic literature. Generative AI was not used to write any parts of the essay and/or blog.

Word-count: Total: 4000
(Essay [incl. title]: 3267 / Blog: 733)

Introduction

> *Strangely, I'm not really able to hear what Mark is saying – not the meaning of the words anyhow – for I am transfixed by their musicality, their poetry, the choreography of their presentation… (W)hat has happened to this autistic child, what has changed, and what did that brief but profound musical encounter [bongo drumming] of just minutes ago have to do with it all?* (Bakan, 2018 p.17 [parenthesis added])

This essay examines whether music, rhythmic capabilities, timing are affected in people with autism, and questions if rhythm in music constitutes a communicative difference or system-based strength in ASD.

Autism

Autism Spectrum Disorder (ASD) is a developmental neurodiversity directly affecting roughly 1.5% of individuals in the UK across their lifespan (Tafolla et al, 2025). It is diagnosed and defined in DSM-5 by persistent social communication impairments; and restricted and repetitive behaviours (including hyper-sensitivities). DSM-5 further specifies three severity levels based on the degree of support required, as well as specifiers and modifiers to identify co-occurring genetic or medical conditions (American Psychological Association, 2013; see Lord & Bishop, 2015). Despite this seemingly categorical framework it is essentially a complex multifaceted diagnosis (see Attwood, 2006; Happe & Ronald, 2008) and, consequently, a hugely diverse and heterogeneous population. Autism is no longer understood as a sharp partition, but rather as a spectrum of autistic traits across neurotypical (NT) and ASD populations (Wing, 1997). Baron-Cohen (2008) stresses that autism is disability and difference, and highlights that some differences constitute relative strengths or talents especially in terms of attention to detail, understanding systems (2010), pattern seeking/detection (2020), and creative problem-solving (2026).

Music, Musicality, and Rhythm

Music is a universal feature of human community (Trehub et al, 2015). It is cognitively complex, emotionally intense, and an integral part of our capacity for culture (Cross, 2008). It is fundamentally an act of communication, connection, and affect regulation (Cross, 2001; 2014). It is also highly structured – a system of humanly patterned sound and action moulded by forces of cultural invention (Blacking, 1973; 1995). Specific features of musical pitch, musical pulse, and musical motivation provide a shared quasi-architectural structure for interaction, thus affording a degree of regularity, predictability, and mutual attunement (Bispham, 2009; 2018).

This raises the question of whether we should expect music to constitute a communicative challenge or system-based strength for autistic individuals? Alternatively, might autistic individuals engage with music in a slightly diverse way? If so, we can also ask if music can

serve as a therapeutic scaffold to aid in navigating the subtleties of social interaction, and whether effects of musical training transpose to understanding inherent musicalities in other forms of interaction?

The latter question supposes an important distinction between music and musicality. Music is a particular social and cultural construct built upon a complex mosaic of capabilities, most shared with other communicative suites (Bispham, 2012). Musicality, in turn, is much broader, pointing to innate human predispositions and abilities that afford music-making and appreciation (Trehub, 2001; 2003), but are also involved in other forms of graceful action, communication, and co-regulation (Honing, 2018; Honing et al, 2015).

In terms of pitch-processing and production studies have reported enhanced sensitivity to fine-grained pitch perception (Hisaizumi & Tantam, 2024; cf. Ong et al, 2024), higher prevalence of absolute pitch processing (Wenhart et al, 2019), and distinctive prosodic features in speech in autistic groups (Ashgari et al, 2021). Emotion recognition in music is also maintained in ASD (Molnar-Szakacs & Heaton, 2010). This essay will, however, focus the above questions on rhythmic capabilities and the functions of rhythm in movement, interaction, and music.

The discussion will gradually progress from expressions of musicality in movement and interaction towards increasingly situated "musical" forms of rhythm that can be understood to generate and incur a sense of "beat" (see Levitin et al, 2018; Synder et al, 2024). The course of argument will highlight that motor timing and social timing are often affected in ASD; that beat-based rhythm processing is relatively preserved; that structured rhythmic engagement can scaffold social and motor functioning; and that musical rhythm is meaningful and often highly valued in autistic lived experience.

Rhythm, Action, Intention, and Affect

The neurological and behavioral foundations of rhythmic capabilities are rooted in motor timing and coordination. These are frequently co-occurring areas of challenge in ASD and could potentially cascade to impact on social and musical timing.

The Rhythms of Movement

Rhythmic perceptions and behaviors are fundamentally a form of movement, an embodied act rooted in broader action timing capabilities (Cameron & Grahn, 2016; Thaut, 2013). The brain's motor systems and neurological connections between auditory and motor regions are critical to rhythm perception and production (Chen et al, 2008; Grahn & Brett, 2007). This applies to irregular patterns, suggesting that the motor system mediates generalised timing functions, and notably to an even greater extent with regular patterns that induce a sense of "beat" (Grahn & Rowe, 2009).

Rhythmic Auditory Stimulation

A stark illustration of the connection between rhythmic processing and movement was a study on gait in Parkinson's patients showing marked improvements when keeping pace to a metronomic pulsed pattern (Thaut et al, 1996). Research in this 'rhythmic auditory stimulation' (RAS) paradigm has since been extended to other neurological disorders with further positive results (see Thaut & Abiru, 2010), and to a range of neurodevelopmental differences where rhythm and timing are thought to be common vulnerabilities (Lense et al, 2021), including ASD. Although not currently a diagnostic criterion for ASD, an estimated 50-88% of autistic individuals exhibit difficulties with motor functioning (Kangarani-Farahani et al, 2024), with many receiving a co-occurring diagnosis of developmental coordination disorder (Miller et al., 2021). RAS has been proposed as a therapeutic tool in ASD (Hardy & LaGasse, 2013) and has been shown to result in significant improvements in bilateral coordination and balance, in 8–10-year-old autistic children (El-Shemy & El-Sayed, 2018), and in reported general motor functioning (Richard-Williams et al, 2024). It is currently unclear whether the effect of RAS is the result of engaging relevant brain regions for movement or whether engaging with a regular pulse acts a kind of cognitive scaffolding to manage broader timing difficulties.

Musicality and the Intrinsic Motive Pulse

Rhythmic processes of perception and movement also support our communicative acts from infancy onwards. Trevarthen and colleagues describe innate and dynamic patterns of interaction structured around an energy-regulating and time keeping *intrinsic motive pulse* that underpins our most fundamental capacities for human expression and for intersubjective resonance (Trevarthen, 1999; Malloch & Trevarthen, 2009). They have posited subsequently that the rhythmic impulses of motor control that express expectations of action and enable communication of emotion are an early developmental weakness in autistic individuals (Trevarthen & Delafield, 2013) with resulting disorganised rhythms and synchrony in interaction (Trevarthen & Daniel, 2005). This theoretical premise would appear to be supported in recent studies of technologies that can detect consistently an autism diagnosis exclusively from movement differences (Torres et al., 2013; Milano et al., 2023).

Rhythm in Social Interaction

In social timing—the inherent temporal dynamics of non-musical interactions—autistic individuals typically exhibit reduced interpersonal synchrony, slower turn-taking, and difficulty adapting to temporal irregularities.

Relating in Time

The rhythm of utterances and accompanying gestures is vital to successful social interaction across our lifetimes (Duerden et al, 2025). Even in early protoconversations and attunements between infants and caregivers, temporal structures and timings are constructed and mutually adapted to afford the co-regulation of affect and sharing of intentions. (Malloch & Trevarthen, 1999).

Rhythms inherent in adult speech production appear not to be based upon a steady underlying beat (Nolan & Jeon, 2014; Patel, 2006; 2010). Nevertheless, timing and prediction are crucial in navigating turn-taking and interpersonal exchanges of all kinds (Denis et al, 2025). Individuals with ASD often employ longer pauses between responses (Ochi et al, 2019; Carmo, 2023), take longer to align pace with NT partners, and show less appropriate correction after surprising interjections (Wehrle et al, 2023). In a recent study, individuals with ASD, and their parents, also displayed reduced rhythmic coordination of syllable rates with conversational partners in a collaborative task paradigm (Patel et al, 2022).

Interpersonal Synchrony

More broadly still, the term interpersonal synchrony is used to describe a plethora of time- and form-aligned behaviors that occur in social interactions. Research into this concept has widely investigated motor synchrony, conversational synchrony, physiological synchrony, and neural synchrony in normal development and ASD (see MacNaughton & Redcar, 2020). Of principal relevance here is social motor synchrony (SMS), which depends on predictions generated within the rhythmic flow of interaction and, in turn, facilitates the continuation and elaboration of those rhythms (Daniel et al., 2022). Studies on SMS range from mirror games (Brezis et al (2017), to book sharing activities (Liu et al, 2022), to chair rocking (Marsh et al, 2013)[1]. With such varied approaches, varying measures, populations, and controls, the results are, unsurprisingly, mixed. Meta-analyses, however, report overall lower SMS in interactions when one or both participants are autistic, and that autistic people are less likely to adapt their movements to facilitate synchrony (Bowsher-Murray et al, 2022; Glass & Yoill, 2024). These findings persist even more clearly when we exclude sustained repetitive tasks that generate or incur a sense of "beat". An interesting caveat is that this effect is broadly attenuated when both participants are autistic. This suggests a potential double empathy problem (Milton, 2012) wherein different neurotypes struggle to adapt mutually to a putatively different communication style[2]. Glass & Yoill (2024) conclude that the

[1] The terminology notably overlaps with more restricted definitions of 'synchronisation' in other research areas. SMS incorporates explicitly beat-based tasks, such as clapping a steady beat with a collaborative partner. These "musical" rhythms have distinct underlying features (see Bispham, 2006; 2018; 2021) and are discussed in the following section as a form of sensorimotor synchronization (e.g. Repp, 2005) [see glossary].

[2] It is also not exclusively behavioural with a recent study reporting SMS having less effect on rapport in autistic dyads (Eftimiou et al, 2025).

experimental literature broadly supports an SMS model for ASD (Fitzpatrick et al, 2016; 2017), in which social challenges associated with autism are rooted in difficulties with SMS.

Rhythm Perception and Production

The differences in social timing are contrasted with evidence that core capabilities for processing musical ("beat-based") rhythms remain relatively preserved in ASD. Despite slower adaptation to variable timing, and attenuated links between synchrony and prosocial outcomes, autistic children and adults typically perform comparably to neurotypical peers on tasks involving rhythmic grouping, meter categorisation, and synchronous tapping with non-variable partners.

Processing, Predicting, and Timing

Rhythms in music are distinct in their composition around a sustained, regular, and future-directed attentional pulse (see Bispham, 2018; 2021). They generate and incur a phenomenological sense of "beat" or "groove" (Pressing, 2002) and afford a particular form of predictive coding by providing a high degree of anticipatory certainty and by operating at multiple temporal levels (Koelsch et al, 2019; London, 2012).

Despite lower overall music perception performance[3], autistic children equaled NT children -matched in age, cognitive ability, and musical experience/interest – in categorising meters (DePape et al, 2012) and perceptual tasks of rhythmic groupings (Jamey et al., 2019; Sota et al., 2018). These results were not correlated with ASD social symptom severity, although a later study reported a positive link between phonological awareness and beat perception in ASD children (Rimmer et al, 2024). In terms of "feeling" the beat neither ASD nor NT children (age 6-13) performed above a statistical chance threshold (70%) in a Beat Alignment Test (BAT - Iverson & Patel, 2008) (Dahary et al, 2024). Notably, however, both groups were equally accurate in detecting on-beat alignments, with the NT group more precise in recognising misalignments. The authors speculate, supporting a hyper-volatility hypothesis of autism (Palmer et al, 2017), that this was due to greater multisensory integration required in the off-beat condition.

Sensorimotor Synchronisation

Our capacity for regular beat-based action and coordination is described as sensorimotor synchronisation in controlled experimental studies (see Repp, 2005; Repp & Su, 2013;

[3] Measured using a 'Short Montreal Battery of Evaluation of Amusia' (MBEA-s) (Peretz et al, 2003; Nunes-Silva & Haase, 2012).

Iverson & Balasubramaniam, 2016), or interpersonal entrainment in situated music performance analyses (Clayton et al, 2020)[4].

From early infancy onwards beat-based synchrony promotes prosocial behaviour (Philips-Silver & Keller, 2012) and is a contingent component in learning to share action goals, attention, and intersubjectivity (Trainor & Cirelli, 2015). This roots subsequent prosocial effects of group music-making, rhythmic drumming, or even simply marching in time (Kirschner & Tomasello, 2009; 2010; Rabinowitch et al, 2013; 2015; McNeill, 1995).

ASD adults and children typically perform similarly to matched NT participants in synchronous tapping to a non-variable computer partner (600-800ms)[5] and in free continuation phases (Kawasaki et al. 2017). However, they have been reported to be less precise in tapping with a variable human partner, and to be slower in adjusting to unexpected events (Kasten et al 2023), typically requiring 6-7 beats to readjust internal models to a tempo change (compared to 1-2 in NT or dyslexic controls) (Vishne et al 2021).

In terms of prosocial correlates, Yoo and Kim (2018) identified, using factor analysis, four key correlates of interactive drumming precision in ASD—self-regulation (unique to ASD), embodied intersubjectivity, motor representation, and anticipatory adjustment. An earlier tapping study (Koehne et al, 2024) described also a positive, albeit attenuated, association between dyadic synchrony and reported empathy in ASD adults.

Rhythmic Therapy/Intervention in ASD

A review of therapeutic music- and rhythm-based interventions suggests consistent benefits in motor organisation, affect regulation, and social communication. These gains are proposed to transpose to non-musical domains, suggesting that the scaffolding of a regular musical pulse may aid in subsequently understanding inherent temporal dynamics in other forms of action and/or social interaction.

Music therapy is provided in two main forms: a) Neurologic techniques that focus on distinctive functional behaviours in areas of cognition, motor skills, and speech and language (e.g. RAS [see above]) (see Thaut & Hoemberg, 2025); and b) Holistic approaches that invite musical interaction—communication games, structured improvisation, drumming, singing, and/or songwriting—to support emotional, physical, or developmental needs (see Edwards, 2016; Wheeler, 2015). The latter can vary substantially depending on individual demands, capabilities, and/or expressive freedoms (Dunn et al, 2019).

[4] This is typically studied through motion-capture analysis of embodied action (e.g. Moran, 2013). However, comparative studies with autistic musicians have not yet been published.

[5] An exception to this is in tapping at longer duration (1500ms), where ASD children derive less assistance from multisensory cues (Hou et al, 2026).

Treatments for autistic people have been reasoned to improve sensorimotor organisation and timing (Bharathi et al, 2019; LaGasse et al, 2024), social interaction, verbal communication, emotion regulation, and quality of life (Navarro et al, 2025; Wu et al, 2025). Neurological studies are still rare, but Sharda and colleagues (2018) highlight correlated improvements in social communication and auditory–motor connectivity in 6–12-year-old autistic children following 12 weeks of improvisational song and rhythm[6]. It is perhaps not feasible to isolate the effects of rhythmic features in this context. Nevertheless, a meta-analysis targeting specifically rhythmic (music and dance) interventions found medium effects on overall social skills and large effects on emotion regulation, verbal and non-verbal communication and on initiating and maintaining social interactions (Ding et al, 2024). Furthermore, a study on dyadic drumming reported significant overall improvements in social skills (K-SSRS scores [Moon, 2003]), particularly in cooperation and self-control (Yoo and Kim, 2018).

Musical Rhythm in Context

Situated music-making is inherently valuable in the lived experiences of autistic people, with many describing music and rhythmic activity as intrinsically meaningful and socially enabling.

In the lives of many autistic people, the rhythms of music are much more than a therapeutic intervention. People with autism are frequently highly intrinsically motivated to engage with music (see Bakan, 2018). Musical time is valued for its own sake as a culturally respectful, inclusive practice that promotes autism acceptance and neurodiversity as natural human variation rather than pathology (Bakan, 2015). Where musical engagement is not constrained by the severity of symptoms, or co-occurring limitations, well-being, human connection, and cultural integration are inherent (Bailey & Davidson, 2005; Camlin et al, 2020; Bispham, 2006; Cross et al, 2007). Fram and colleagues (2024) illustrate this broad point from a developmental perspective with behavioral reports collected from parents of young autistic and nonautistic children (1-3 years old). Their analysis charts a course in autistic toddlers of independent, indirect pathways from rhythmic musical engagement to expressive communication via general social skills and parent-infant interactions.

Across cultures music functions in regulating emotional, cognitive and physiological states; mediating between ‘self’ and ‘other’; representing cultural symbolisms; and in coordinating action/social bonding (see Clayton, 2016). These all are mirrored in qualitative research describing reported cognitive, emotional, social, and identity functions of music for young

[6] Specifically, they showed increased functional connectivity between auditory regions (Heschl's gyrus) and subcortical/motor regions, which are often reduced in ASD (Nair et al, 2013), and reduced over-connectivity between auditory and visual-association regions, a pattern known to be over-connected, and associated with social deficit severity, in ASD (Rudie & Dapretto, 2013; Supekar et al, 2013).

people on the autistic spectrum (Kirby & Burland, 2022), and in themes of well-being, identity, self-development, and social connection in interviews of autistic adults discussing lived experiences with music[7] (Korosec et al, 2024). Similarly, focusing specifically on the impact of music listening in autistic adults, Venter and colleagues (2022) highlight coping with auditory sensitivity, getting lost in the music, companionship, self-regulation, and connection[8].

Summary

Together, the strands of evidence discussed suggest that musical rhythm constitutes both a relative strength and a pathway for supporting well-being, social participation, and human connection.

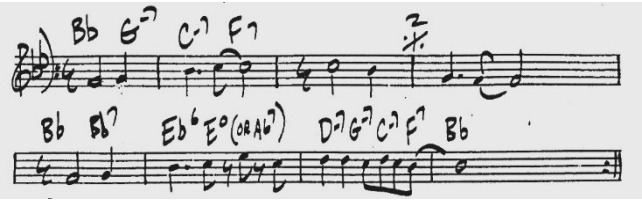
The above discussion developed progressively from the inherently rhythmic nature of movement to social timing, musical capacities, rhythmic therapy, and lived experience, showing that the structured nature of rhythm in music appears highly relevant in ASD. Despite consistent challenges with motor timing and navigating the dynamics of temporal nuances in non-musical social interaction, rhythm perception and production seems to be a relatively maintained strength in autistic people (with some evidence for slower adaptation to change and attenuated links to prosocial correlates). Furthermore, benefits of therapeutic rhythmic training are shown to extend to more general social skills. Crucially "musicking" (Small, 1999) in all its forms, whether predominantly rhythmically (e.g. drumming) or within wider musical styles, is immensely valued by many autistic people who report benefits on aspects of life they can find challenging—cognitive management, affect regulation, and feelings of human connection.

A notable limitation, especially given the comparative approach taken, is that the supporting literature necessarily spans several disciplinary fields and hence varying populations samples, experimental paradigms, and philosophical approaches. Despite attempts to nuance the argument, there remains a risk of confounding approaches and theoretical frameworks. Evidence would be considerably strengthened by inclusive studies directly comparing aspects of rhythmic behaviour and timing across contextual boundaries. Furthermore, some of the research topics discussed are relatively recent areas of interest, so perspectives and interpretations may yet develop. In particular, discussion on the therapeutic benefits of rhythmic interventions in ASD was based on studies with frequently low sample sizes and differing procedural and analytic applications and would benefit from larger, analytically consistent projects in the future (Geretsegge et al, 2022; Marquez-Garcia et al, 2022).

[7] This study also identifies 'negative experiences' with unpleasant genres, excessive volume, and overstimulation in public spaces. These are certainly concerns to consider in promoting autism-friendly inclusivity (e.g. Hammel & Hourigan, 2020).

[8] The authors propose that the use of music to mask or cope with sensory overload is more pronounced in autism.

Reflective Blog



Reflections on Music and Rhythm in Autism.

- **Main Theme**

Although motor and social timing can be areas of difference and challenge for autistic people, musical rhythm is a retained strength.

- **Prelude**

    - The Rhythms of Life

Rhythm grounds our ability to operate in time with the world around us. This is explicit in music, where a regular pulse structures our actions and attention (musical rhythm). Rhythm is, however, more subtly all around us — in our movements, speech, and social lives. It is inherent in the graceful coordination of movement, in expressing emotion and intent[1] (motor timing), and in the dynamics of coordinating and interacting with others (social timing). In short, rhythm structures human communication and connection.

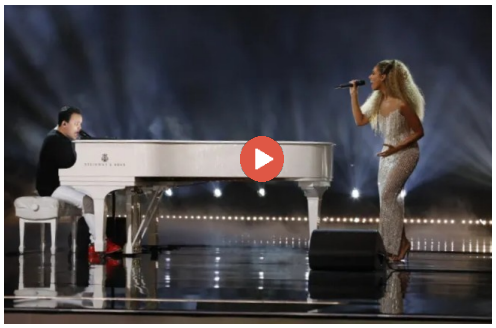
    - Autism

Autism is a neurodevelopmental disability and difference[i] characterized by persistent challenges in social communication and social interaction and restricted, repetitive patterns of behavior, interests, or activities[2]. The autistic population is hugely diverse with varying challenges and talents[3].

- **Musical Moments**

In researching for the accompanying essay to this post, I was particularly struck by a report – by ethnomusicologist Michael Bakan[4] – of an impromptu drumming experience with Mark (pseudonym) – a young autistic boy. Mark is described as carrying a lot of tension in his body, moving stiffly/awkwardly, and as typically speaking in a monotone, with little apparent intention of communicating. However, as Michael starts drumming an improvised *rumba*, Mark's eyes light up, he joins in, shifts the groove, and begins to sing. They revel in what Michael describes as the beauty and magic of the moment.

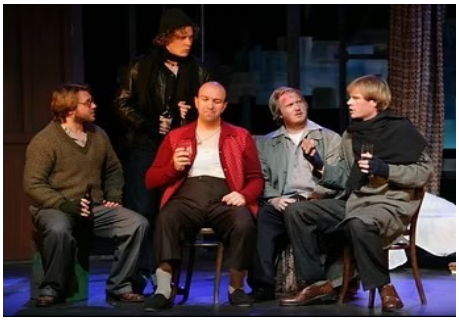
In my career as musician[a] and singing teacher[b] I have had the pleasure of kindred experiences with talented autistic musicians, and have often marveled at an emerging postural comfort, connection, and rhythmic fluency that seems absent in other activities. For a remarkable example I would urge readers to watch and listen to Kodi Lee – an autistic American singer-songwriter and pianist[ii-v].



- **<u>Social Timing vs Musical Rhythm</u>**

Research documented in the accompanying essay supports the observation that people with autism often find social timing challenging – typically exhibiting slower turn-taking, reduced synchrony with others, and challenges adapting to irregularities. Musical rhythm – "beat-based" timing – is, however, shown to be a relative strength in both beat perception and production tasks. This may be because musical rhythm is inherently more clearly structured and predictable than social timing. A notable caveat (that fits this hypothesis) is that in tapping to a regular beat, autistic people generally need longer than neurotypical controls to adapt to unexpected changes or the natural variability of human tapping.

It is a substantial leap to the real-world of musical performance and expression. However, the experimental results are perhaps reflected (and I say this very tentatively) in a difference in rhythmic musicality. In my music teaching practice, for example, I have noted a consistent preference among students on the spectrum towards a steady tempo, and for planning expressive and/or collaborative timings in advance.



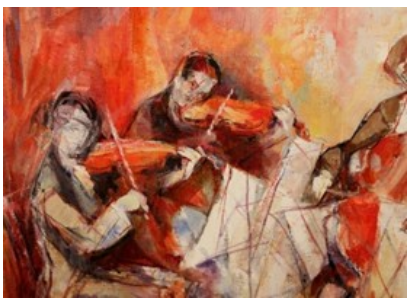
- **Musical Rhythm as Therapy**

One of the most fascinating parts of the account of Mark's drumming was that the effects carried over (briefly) to other areas. Bakan[4] reports that after the improvisation he was speaking lucidly and expressively, emphasizing his words with illuminating hand gestures and body language. It had been a form of therapy.

Studies support the notion that music/rhythmic therapy for autistic children and adults can improve motor timing, emotion regulation, and social connection, and that the effects extend to more general communication skills. Although further research is needed, the idea here is that the regularity of a musical beat acts an architectural scaffold – a predictable structure to organise movement and communication around – to help better understand the subtle dynamics of interacting in time with others.

- **Coda – Living with Music**

Despite the reported benefits of music therapy, I found myself again attuned with Michael Bakan[5] in the view that a therapeutic or deficit-model for music/rhythm and autism is often misplaced and can be a barrier to the acceptance of neurodiversity and inclusivity. Although experiences and motivations of course vary, it is clear to me that music is much more than that for many autistic people – the therapeutic aspects are already baked in. In qualitative studies, autistic and non-autistic people often describe music as meaningful, regulating, and socially enabling. For readers who would like to explore further, these points are beautifully illustrated in the account by Maureen Pytlik of her deeply transformative experiences studying and performing West African drumming[4].



References (Essay)

American Psychiatric Association. (2013). Autism Spectrum Disorder. In *Diagnostic and statistical manual of mental disorders* (5th ed.). https://doi.org/10.1176/appi.books.9780890425596.dsm05

Asghari, S. Z., Farashi, S., Bashirian, S., & Jenabi, E. (2021). Distinctive prosodic features of people with autism spectrum disorder: a systematic review and meta-analysis study. *Scientific reports*, *11*(1). https://doi.org/10.1038/s41598-021-02487-6

Attwood, T. (2006). *The Complete Guide to Asperger's Syndrome.* (1st ed.). Jessica Kingsley

Bailey, B. A., & Davidson, J. W. (2005). Effects of group singing and performance for marginalized and middle-class singers. *Psychology of music*, *33*(3), 269-303. https://doi.org/10.1177/0305735605053

Bakan, M. B. (2015). Being applied in the ethnomusicology of autism. In *The Oxford handbook of applied ethnomusicology* (Ed. S. Pettan & J. Titon), p. 338-385 (Ch.8). Oxford University Press

Bakan, M. B., Chasar, M., Gibson, G., Grace, E. J., Hamelson, Z., Nitzberg, D., ... & Sequenzia, A. (2018). *Speaking for ourselves: Conversations on life, music, and autism*. Oxford University Press.

Baron-Cohen, S. (2008). *Autism and Asperger syndrome*. Oxford university press.

Baron-Cohen, S. (2010). Empathizing, systemizing, and the extreme male brain theory of autism. *Progress in brain research*, *186*, 167-175. https://doi.org/10.1016/B978-0-444-53630-3.00011-7

Baron-Cohen, S. (2020). *The pattern seekers: A new theory of human invention*. Penguin UK.

Baron-Cohen, S. (2026). The Origins of Invention and Its Link with Autism. In *Psychiatry after Kraepelin: Ambition Images Practices 1926-2026* (pp. 139-149). Cham: Springer Nature Switzerland. https://doi.org/10.1007/978-3-032-09475-9_9

Bharathi, G., Jayaramayya, K., Balasubramanian, V., & Vellingiri, B. (2019). The potential role of rhythmic entrainment and music therapy intervention for individuals with autism spectrum disorders. *Journal of exercise rehabilitation*, *15*(2), 180. https://doi.org/10.12965/jer.1836578.289

Bispham, J. (2006). Rhythm in music: What is it? Who has it? And why?. *Music perception*, *24*(2), 125-134. https://doi.org/10.1525/mp.2006.24.2.125

Bispham, J. C. (2009). Music's "design features": musical motivation, musical pulse, and musical pitch. *Musicae Scientiae*, *13*(2_suppl), 41-61. https://doi.org/10.1177/1029864909013002

Bispham, J. (2012). How musical is man? An evolutionary perspective. *Sound musicianship: understanding the crafts of music*, 126-137 (Ch.11). Cambridge Scholars Press

Bispham, J. C. (2018). *The Human Faculty for Music: What's special about it?* (Doctoral dissertation). Department of Biological Anthropology, University of Cambridge. https://doi.org/10.17863/CAM.3183

Bispham, J. C. (2021). Music, Evolution, and the Experience of Time. *The Oxford Handbook of Time in Music*, 149-168 (Ch. 9). Oxford University Press

Blacking, J. (1973). *How musical is man?*. University of Washington Press.

Blacking, J. (1995). *Music, culture, and experience: Selected papers of John Blacking*. University of Chicago Press.

Bowsher-Murray, C., Gerson, S., Von dem Hagen, E., & Jones, C. R. (2022). The components of interpersonal synchrony in the typical population and in autism: A conceptual analysis. *Frontiers in Psychology*, *13*, 897015. https://doi.org/10.3389/fpsyg.2022.897015

Brezis, R. S., Noy, L., Alony, T., Gotlieb, R., Cohen, R., Golland, Y., & Levit-Binnun, N. (2017). Patterns of joint improvisation in adults with autism spectrum disorder. *Frontiers in psychology*, *8*, 1790. https://doi.org/10.3389/fpsyg.2017.01790

Cameron, D. J., & Grahn, J. A. (2016). The neuroscience of rhythm. *The Oxford handbook of music psychology*, (2nd Ed). Oxford University Press

Camlin, D. A., Daffern, H., & Zeserson, K. (2020). Group singing as a resource for the development of a healthy public: a study of adult group singing. *Humanities and Social Sciences Communications*, *7*(1), 60. https://doi.org/10.1057/s41599-020-00549-0

Carmo, J. C., Magyari, L., & Filipe, C. N. (2023). Conversational turn-taking in autism spectrum disorder. *PsyArXiv*. https://doi.org/10.31234/osf.io/42e6j

Chen, J. L., Penhune, V. B., & Zatorre, R. J. (2008). Listening to musical rhythms recruits motor regions of the brain. *Cerebral cortex*, *18*(12), 2844-2854. https://doi.org/10.1093/cercor/bhn042

Clayton, Martin (2016). The Social and Personal Functions of Music in Cross-Cultural Perspective. *The Oxford Handbook of Music Psychology*, (2nd Ed.) (Ch.4). https://doi.org/10.1093/oxfordhb/9780198722946.013.8

Clayton, M., Jakubowski, K., Eerola, T., Keller, P. E., Camurri, A., Volpe, G., & Alborno, P. (2020). Interpersonal entrainment in music performance: Theory, method, and model. *Music Perception: An Interdisciplinary Journal*, *38*(2), 136-194. https://doi.org/10.1525/mp.2020.38.2.136

Cross, I. (2001). Music, cognition, culture, and evolution. *Annals of the New York Academy of sciences*, *930*(1), 28-42. https://doi.org/10.1111/j.1749-6632.2001.tb05723.x

Cross, I. (2008). Musicality and the human capacity for culture. *Musicae Scientiae*, *12*(1_suppl), 147-167. https://doi.org/10.1177/1029864908012001071

Cross, I. (2014). Music and communication in music psychology. *Psychology of music*, *42*(6), 809-819. https://doi.org/10.1177/0305735614543968

Dahary, H., Rimmer, C., & Quintin, E. M. (2024). Musical beat perception skills of autistic and neurotypical children. *Journal of Autism and Developmental Disorders*, *54*(4), 1453-1467. https://doi.org/10.1007/s10803-022-05864-w

Daniel, S., Wimpory, D., Delafield-Butt, J. T., Malloch, S., Holck, U., Geretsegger, M., ... & Amos, P. (2022). Rhythmic relating: Bidirectional support for social timing in autism therapies. *Frontiers in Psychology*, *13*, 793258. https://doi.org/10.3389/FPSYG.2022.793258

Denis, M., Mazzocconi, C., Da Fonseca, D., & Schön, D. (2025). Temporal Predictions in Music and Language: The Case of Autism Spectrum Disorder. *Annals of the New York Academy of Sciences*, *1552*(1), 53-65. https://doi.org/10.1111/nyas.70084

DePape A-MR, Hall GBC, Tillmann B, Trainor LJ (2012) Auditory Processing in High-Functioning Adolescents with Autism Spectrum Disorder. *PLoS ONE* *7*(9). https://doi.org/10.1371/journal.pone.0044084

Ding, X., Wu, J., Li, D., & Liu, Z. (2024). The benefit of rhythm-based interventions for individuals with autism spectrum disorder: a systematic review and meta-analysis with random controlled trials. *Frontiers in Psychiatry*, *15*. https://doi.org/10.3389/fpsyt.2024.1436170

Duerden, E. G., Neufeld, J., & Crafa, D. (2025). Social perception and cognition in autism. *Scientific Reports*, *15*(1), 38660. https://doi.org/10.1038/s41598-025-26432-z

Dunn, H., Coombes, E., & Maclean, E. (eds.) (2019). *Music Therapy and Autism Across the Lifespan: A Spectrum of Approaches*. Jessica Kingsley Publishers: London

Edwards, J. (Ed.). (2016). *The Oxford handbook of music therapy*. Oxford University Press.

Efthimiou, T. N., Wilks, C. E., Foster, S., Dodd, M., Sasson, N. J., Ropar, D., ... & Crompton, C. J. (2025). Social motor synchrony and interactive rapport in autistic, non-autistic, and mixed-neurotype dyads. *Autism*, 13623613251319585. https://doi.org/10.1177/13623613251319

El-Shemy, S. A., & El-Sayed, M. S. (2018). The impact of auditory rhythmic cueing on gross motor skills in children with autism. *Journal of physical therapy science*, *30*(8), 1063-1068. https://doi.org/10.1589/jpts.30.1063

Fitzpatrick, P., Frazier, J. A., Cochran, D. M., Mitchell, T., Coleman, C., & Schmidt, E. R. (2016). Impairments of social motor synchrony evident in autism spectrum disorder. *Frontiers in psychology*, *7*, 1323. https://doi.org/10.3389/fpsyg.2016.01323

Fitzpatrick, P., Romero, V., Amaral, J. L., Duncan, A., Barnard, H., Richardson, M. J., & Schmidt, R. (2017). Evaluating the importance of social motor synchronization and motor skill for understanding autism. *Autism Research*, *10*(10), 1687-1699. https://doi.org/10.1002/aur.1808

Fram, N. R., Liu, T., & Lense, M. D. (2024). Social interaction links active musical rhythm engagement and expressive communication in autistic toddlers. *Autism Research*, *17*(2), 338-354. https://doi.org/10.1002/aur.3090

Geretsegger, M., Fusar-Poli, L., Elefant, C., Mössler, K. A., Vitale, G., & Gold, C. (2022). Music therapy for autistic people. *Cochrane Database of Systematic Reviews*, (5). https://doi.org/10.1002/14651858.CD004381.pub4

Grahn, J. A., & Brett, M. (2007). Rhythm and beat perception in motor areas of the brain. *Journal of cognitive neuroscience*, *19*(5), 893-906. https://doi.org/10.1162/jocn.2007.19.5.893

Grahn, J. A., & Rowe, J. B. (2009). Feeling the beat: premotor and striatal interactions in musicians and nonmusicians during beat perception. *Journal of Neuroscience*, *29*(23), 7540-7548. https://doi.org/10.1523/JNEUROSCI.2018-08.2009

Hammel, A. M., & Hourigan, R. M. (2020). *Teaching music to students with autism*. Oxford University Press.

Happé, F., & Ronald, A. (2008). The 'fractionable autism triad': a review of evidence from behavioural, genetic, cognitive and neural research. *Neuropsychology review*, *18*(4), 287-304. https://doi.org/10.1007/s11065-008-9076-8

Hardy, M. W., & LaGasse, A. B. (2013). Rhythm, movement, and autism: using rhythmic rehabilitation research as a model for autism. *Frontiers in integrative neuroscience*, *7*, 19. https://doi.org/10.3389/fnint.2013.00019

Hisaizumi, M., & Tantam, D. (2024). Enhanced sensitivity to pitch perception and its possible relation to language acquisition in autism. *Autism & Developmental Language Impairments*, *9*. https://doi.org/10.1177/23969415241248618

Honing, H. (Ed.). (2018). *The origins of musicality*. MIT Press.

Honing, H., Ten Cate, C., Peretz, I., & Trehub, S. E. (2015). Without it no music: Cognition, biology and evolution of musicality. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *370*(1664). https://doi.org/10.1098/rstb.2014.0088

Hou, W., Zhang, L., & Li, J. (2026). Sensorimotor synchronization in children with autism spectrum disorder: The role of timing and modality. *Psychonomic Bulletin & Review*, *33*(1), 29. https://doi.org/10.3758/s13423-025-02806-2

Iversen, J. R., & Balasubramaniam, R. (2016). Synchronization and temporal processing. *Current Opinion in Behavioral Sciences*, *8*, 175-180. https://doi.org/10.1016/j.cobeha.2016.02.027

Iversen, J. R., & Patel, A. D. (2008). The Beat Alignment Test (BAT): Surveying beat processing abilities in the general population. In K. Miyazaki, M. Adachi, Y. Hiraga, Y. Nakajima, & M. Tsuzaki (Eds.), *Proceedings of the 10th International Conference on Music Perception and Cognition* (ICMPC10) 465–468.

Jamey, K., Foster, N. E., 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

Janzen, T. B., & Thaut, M. H. (2018). Rethinking the role of music in the neurodevelopment of autism spectrum disorder. *Music & Science*, *1*. https://doi.org/10.1177/2059204318769

Kangarani-Farahani, M., Malik, M. A., & Zwicker, J. G. (2024). Motor impairments in children with autism spectrum disorder: A systematic review and meta-analysis. *Journal of autism and developmental disorders*, *54*(5), 1977-97. https://doi.org/10.1007/s10803-023-05948-1

Kasten, K., Jacoby, N., & Ahissar, M. (2023). Poor synchronization yet adequate tempo-keeping in adults with autism. *Autism Research, 16*(6), 1161–1173. https://doi.org/10.1002/aur.2926

Kawasaki, M., Kitajo, K., Fukao, K., Murai, T., Yamaguchi, Y., & Funabiki, Y. (2017). Frontal theta activation during motor synchronization in autism. *Scientific Reports*, *7*(1). https://doi.org/10.1038/s41598-017-14508-4

Kirby, M. L., & Burland, K. (2022). Exploring the functions of music in the lives of young people on the autism spectrum. *Psychology of Music*, *50*(2), 562–578. https://doi.org/10.1177/03057356211008968

Kirschner, S., & Tomasello, M. (2009). Joint drumming: Social context facilitates synchronization in preschool children. *Journal of experimental child psychology*, *102*(3), 299-314. https://doi.org/10.1016/j.jecp.2008.07.005

Kirschner, S., & Tomasello, M. (2010). Joint music making promotes prosocial behavior in 4-year-old children. *Evolution and human behavior*, *31*(5), 354-364. https://doi.org/10.1016/j.evolhumbehav.2010.04.004

Koelsch, S., Vuust, P., & Friston, K. (2019). Predictive processes and the peculiar case of music. *Trends in cognitive sciences*, *23*(1), 63-77. https://doi.org/10.1016/j.tics.2018.10.006

Koehne, S., Hatri, A., Cacioppo, J. T., & Dziobek, I. (2016). Perceived interpersonal synchrony increases empathy: Insights from autism spectrum disorder. *Cognition*, *146*, 8-15. https://doi.org/10.1016/j.cognition.2015.09.007

Korošec, K., Osika, W., & Bojner-Horwitz, E. (2024). "It is more Important than food sometimes"; Meanings and Functions of Music in the Lives of Autistic Adults Through a hermeneutic-phenomenological Lense. *Journal of autism and developmental disorders*, *54*(1), 366-378. https://doi.org/10.1007/s10803-022-05799-2

LaGasse, B., Yoo, G. E., & Hardy, M. W. (2024). Rhythm and music for promoting sensorimotor organization in autism: Broader implications for outcomes. *Frontiers in Integrative Neuroscience*, *18*. https://doi.org/10.3389/fnint.2024.1403876

Lense, M. D., Ladányi, E., Rabinowitch, T. C., Trainor, L., & Gordon, R. (2021). Rhythm and timing as vulnerabilities in neurodevelopmental disorders. *Philosophical Transactions of the Royal Society B*, *376*(1835), 20200327. https://doi.org/10.1098/rstb.2020.0327

Levitin, D. J., Grahn, J. A., & London, J. (2018). The psychology of music: Rhythm and movement. *Annual review of psychology*, *69*, 51-75. https://doi.org/10.1146/annurev-psych-122216-011740

Liu, T., Schultz, B. G., Dai, D., Liu, C., & Lense, M. D. (2022). Parent-child nonverbal engagement during spoken versus sung book-sharing in preschoolers with and without autism. *Psychology of Music*, *50*(6), 1721-1739. https://doi.org/10.1177/03057356211058781

Lord, C., & Bishop, S. L. (2015). Recent advances in autism research as reflected in DSM-5 criteria for autism spectrum disorder. *Annual review of clinical psychology*, *11*(1), 53-70. https://doi.org/10.1146/annurev-clinpsy-032814-112745

McNaughton, K. A., & Redcay, E. (2020). Interpersonal synchrony in autism. *Current psychiatry reports*, *22*(3), 12. https://doi.org/10.1007/s11920-020-1135-8

Malloch, S. N. (1999). Mothers and infants and communicative musicality. *Musicae scientiae*, *3*(1_suppl), 29-57. https://doi.org/10.1177/10298649000030S104

Malloch, S., & Trevarthen, C. (2009). Musicality: Communicating the vitality and interests of life. *Communicative musicality: Exploring the basis of human companionship*, *1*, 1-10. https://psycnet.apa.org/record/2008-14595-000

Marsh, K. L., Isenhower, R. W., Richardson, M. J., Helt, M., Verbalis, A. D., Schmidt, R. C., & Fein, D. (2013). Autism and social disconnection in interpersonal rocking. *Frontiers in integrative neuroscience*, *7*, 4. https://doi.org/10.3389/fnint.2013.00004

McNeill, W. H. (1997). *Keeping together in time: Dance and drill in human history*. Harvard University Press.

Milano, N., Simeoli, R., Rega, A., & Marocco, D. (2023). A deep learning latent variable model to identify children with autism through motor abnormalities. *Frontiers in Psychology*, *14*. https://doi.org/10.3389/fpsyg.2023.1194760

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.

Moon, S. W. (2003). The Validity and the Utility of the Korean Version of Social Skill Rating System-Secondary Level, Student Form (K-SSRS: Secondary Level, Student Form I). *한국심리학회지: 상담 및 심리치료*, *15*(2), 235-258.

Moran, N. (2013). Music, bodies and relationships: An ethnographic contribution to embodied cognition studies. *Psychology of music*, *41*(1), 5-17. https://doi.org/10.1177/0305735611400174

Nair, A., Treiber, J. M., Shukla, D. K., Shih, P., & Müller, R. A. (2013). Impaired thalamocortical connectivity in autism spectrum disorder: a study of functional and anatomical connectivity. *Brain*, *136*(6), 1942-1955. https://doi.org/10.1093/brain/awt079

Navarro, L., Mallah, N. E. Z., Nowak, W., Pardo-Seco, J., Gómez-Carballa, A., Pischedda, S., ... & Salas, A. (2025). The effect of music interventions in autism spectrum disorder: a systematic review and meta-analysis. *Frontiers in Integrative Neuroscience*, *19*, 1673618. https://doi.org/10.3389/fnint.2025.1673618

Nolan, F., & Jeon, H. S. (2014). Speech rhythm: a metaphor?. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *369*. https://doi.org/10.1098/rstb.2013.0396

Nunes-Silva, M., & Haase, V. G. (2012). Montreal battery of evaluation of Amusia: Validity evidence and norms for adolescents in Belo Horizonte, Minas Gerais, Brazil. *Dementia & neuropsychologia*, *6*(4), 244-252. https://doi.org/10.1590/S1980-57642012DN06040008

Ochi, K., Ono, N., Owada, K., Kojima, M., Kuroda, M., Sagayama, S., & Yamasue, H. (2019). Quantification of speech and synchrony in the conversation of adults with autism spectrum disorder. *PloS one*, *14*(12). https://doi.org/10.1371/journal.pone.0225377

Ong, J. H., Zhao, C., Bacon, A., Leung, F. Y. N., Veic, A., Wang, L., ... & Liu, F. (2024). The relationship between autism and pitch perception is modulated by cognitive abilities. *Journal of Autism and Developmental Disorders*, *54*(9), 3400-3411. https://doi.org/10.1007/s10803-023-06075-7

Palmer, C. J. Lawson, R. P. & Hohwy, J. Bayesian Approaches to Autism: Towards Volatility, Action, and Behavior. *Psychological Bulletin* 143(5) 521–542. https://doi.org/10.1037/bul0000097

Patel, A. D. (2006). Musical rhythm, linguistic rhythm, and human evolution. *Music Perception*, *24*(1), 99-104.

Patel, A. D. (2010). *Music, language, and the brain*. Oxford university press.

Patel, S. P., Cole, J., Lau, J. C., Fragnito, G., & Losh, M. (2022). Verbal entrainment in autism spectrum disorder and first-degree relatives. *Scientific reports*, *12*(1), 11496. https://doi.org/10.1038/s41598-022-12945-4

Peretz, I., Champod, A. S., & Hyde, K. (2003). Varieties of musical disorders: the Montreal Battery of Evaluation of Amusia. *Annals of the new York Academy of Sciences*, *999*(1), 58-75. https://doi.org/10.1196/annals.1284.006

Phillips-Silver, J., & Keller, P. E. (2012). Searching for roots of entrainment and joint action in early musical interactions. *Frontiers in human neuroscience*, *6*, 26. https://doi.org/10.3389/fnhum.2012.00026

Pierce, K., Wen, T. H., Zahiri, J., Andreason, C., Courchesne, E., Barnes, C. C., ... & Cheng, A. (2023). Level of attention to motherese speech as an early marker of autism spectrum disorder. *JAMA network open*, *6*(2). https://doi.org/10.1001/jamanetworkopen.2022.55125

Pressing, J. (2002). Black Atlantic rhythm: Its computational and transcultural foundations. *Music Perception*, *19*(3), 285-310. https://doi.org/10.1525/mp.2002.19.3.285

Rabinowitch, T., Cross, I., & Burnard, P. (2013). Long-term musical group interaction has a positive influence on empathy in children. *Psychology of music*, *41*(4), 484-498. https://doi.org/10.1177/0305735612440609

Rabinowitch, T., & Knafo-Noam, A. (2015). Synchronous rhythmic interaction enhances children's perceived similarity and closeness towards each other. *PloS one*, *10*(4). https://doi.org/10.1371/journal.pone.0120878

Repp, B. H. (2005). Sensorimotor synchronization: A review of the tapping literature. *Psychonomic bulletin & review*, *12*(6), 969-992. https://doi.org/10.3758/BF03206433

Repp, B. H., & Su, Y. H. (2013). Sensorimotor synchronization: A review of recent research (2006–2012). *Psychonomic bulletin & review*, *20*(3), 403-452. https://doi.org/10.3758/s13423-012-0371-2

Richard-Williams, N., Hurt-Thaut, C., Brian, J., Tremblay, L., Pranjić, M., Teich, J., ... & Thaut, M. (2024). Improved motor skills in autistic children after three weeks of neurologic music therapy via telehealth: A pilot study. *Frontiers in Psychology*, *15*. https://doi.org/10.3389/fpsyg.2024.1355942

Rimmer, C., Dahary, H., & Quintin, E. M. (2024). Links between musical beat perception and phonological skills for autistic children. *Child Neuropsychology*, *30*(3), 361-380. https://doi.org/10.1080/09297049.2023.2202902

Rudie, J. D., & Dapretto, M. (2013). Convergent evidence of brain overconnectivity in children with autism?. *Cell reports*, *5*(3), 565-566. https://doi.org/10.1016/j.celrep.2013.10.043

Sharda, M., Tuerk, C., Chowdhury, R., Jamey, K., Foster, N., Custo-Blanch, M., ... & 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

Small, C. (1998). *Musicking: The meanings of performing and listening*. Wesleyan University Press.

Snyder, J. S., Gordon, R. L., & Hannon, E. E. (2024). Theoretical and empirical advances in understanding musical rhythm, beat and metre. *Nature Reviews Psychology*, *3*(7), 449-462. https://doi.org/10.1038/s44159-024-00315-y

Supekar, Kaustubh, et al. "Brain hyperconnectivity in children with autism and its links to social deficits." *Cell reports* 5.3 (2013): 738-747. https://doi.org/10.1016/j.celrep.2013.10.001

Tafolla, M., Singer, H., & Lord, C. (2025). Autism spectrum disorder across the lifespan. *Annual Review of Clinical Psychology*, *21*(1), 193-220. https://doi.org/10.1146/annurev-clinpsy-081423-031110

Thaut, M. (2013). *Rhythm, music, and the brain: Scientific foundations and clinical applications*. Routledge.

Thaut, M. H., & Abiru, M. (2010). Rhythmic auditory stimulation in rehabilitation of movement disorders: a review of current research. *Music perception*, *27*(4), 263-269. https://doi.org/10.1525/mp.2010.27.4.263

Thaut, M. H., & Hoemberg, V. (Eds.). (2025). *Handbook of neurologic music therapy*. Oxford University Press.

Thaut, M. H., McIntosh, G. C., Rice, R. R., Miller, R. A., Rathbun, J., & Brault, J. M. (1996). Rhythmic auditory stimulation in gait training for Parkinson's disease patients. *Movement disorders: official journal of the Movement Disorder Society*, *11*(2), 193-200. https://doi.org/10.1002/mds.870110213

Torres, E. B., Brincker, M., Isenhower, R. W., Yanovich, P., Stigler, K. A., Nurnberger, J. I., ... & José, J. V. (2013). Autism: the micro-movement perspective. *Frontiers in integrative neuroscience*, *7*, 32. https://doi.org/10.3389/fnint.2013.00032

Trainor, L. J., & Cirelli, L. (2015). Rhythm and interpersonal synchrony in early social development. *Annals of the New York Academy of Sciences*, *1337*(1), 45-52. https://doi.org/10.1111/nyas.12649

Trehub, S. E. (2001). Musical predispositions in infancy. *Annals of the New York Academy of Sciences*, *930*(1), 1-16. https://doi.org/10.1111/j.1749-6632.2001.tb05721.x

Trehub, S. E. (2003). The developmental origins of musicality. *Nature neuroscience*, *6*(7), 669-673.

Trehub, S. E., Becker, J., & Morley, I. (2015). Cross-cultural perspectives on music and musicality. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *370*(1664), 20140096. https://doi.org/10.1098/rstb.2014.0096

Trevarthen, C. (1999). Musicality and the intrinsic motive pulse: evidence from human psychobiology and infant communication. *Musicae scientiae*, *3*(1_suppl), 155-215. https://doi.org/10.1177/10298649000030S109

Trevarthen, C., & Daniel, S. (2005). Disorganized rhythm and synchrony: Early signs of autism and Rett syndrome. *Brain and development*, *27*, S25-S34. https://doi.org/10.1016/j.braindev.2005.03.016

Trevarthen, C., & Delafield-Butt, J. T. (2013). Autism as a developmental disorder in intentional movement and affective engagement. *Frontiers in integrative neuroscience*, *7*, 49. https://doi.org/10.3389/fnint.2013.00049

Venter, F., Morelli, J., & Erasmus, E. (2023). Understanding the lived music listening experiences of adults on the autism spectrum. *Psychology of Music*, *51*(3), 971-985. https://doi.org/10.1177/03057356221126201

Vishne, G., Jacoby, N., Malinovitch, T., Epstein, T., Frenkel, O., & Ahissar, M. (2021). Slow update of internal representations impedes synchronization in autism. *Nature communications*, *12*(1), 5439. https://doi.org/10.1038/s41467-021-25740-y

Wehrle, S., Cangemi, F., Janz, A., Vogeley, K., & Grice, M. (2023). Turn-timing in conversations between autistic adults: Typical short-gap transitions are preferred but not achieved instantly. *PLoS One*, *18*(4). https://doi.org/10.1371/journal.pone.0284029

Wenhart, T., Bethlehem, R. A., Baron-Cohen, S., & Altenmueller, E. (2019). Autistic traits, resting-state connectivity, and absolute pitch in professional musicians: shared and distinct neural features. *Molecular autism*, *10*(1), 20. https://doi.org/10.1186/s13229-019-0272-6

Wheeler, B. L. (Ed.). (2015). *Music therapy handbook*. Guilford Publications.

Wing, L. (1997). The autistic spectrum. *The lancet*, *350*(9093). https://doi.org/10.1016/S0140-6736(97)09218-0

Wu, L., Zhang, X., Liu, S., Gao, X., & Wang, J. (2026). Effectiveness of music therapy for children with autism spectrum disorder: meta-analysis and potential biological mechanisms. *Frontiers in Psychiatry*, *16*. https://doi.org/10.3389/fpsyt.2025.1722874

Yoo, G. E., & Kim, S. J. (2018). Dyadic drum playing and social skills: Implications for rhythm-mediated intervention for children with autism spectrum disorder. *Journal of music therapy*, *55*(3), 340-375. https://doi.org/10.1093/jmt/thy013

References (Blog)

1. Malloch S, Trevarthen C. Musicality: Communicating the vitality and interests of life. *Communicative musicality: Exploring the basis of human companionship*. Oxford University Press; 2009 Jan: 1-10.
2. American Psychiatric Association. *Diagnostic and Statistical Manual of Mental Disorders. 5th ed*. Arlington, VA: American Psychiatric Association; 2013.
3. Baron-Cohen S. *The pattern seekers: A new theory of human invention*. Penguin UK; 2020 Nov 10.
4. Bakan MB, Chasar M, Graeme G, Grace EJ, Hamelson Z, Nitzberg D, et al. *Speaking for ourselves: Conversations on life, music, and autism*. New York, NY: Oxford University Press; 2018.
5. Bakan MB. Being applied in the ethnomusicology of autism. *The Oxford handbook of applied ethnomusicology*. Oxford University Press; 2015 Aug: 278.

Website Links (Blog)

a. www.johnbispham.com/performance (Personal Website)
b. www.classicalsinging.co.uk (Cambridge Voice Studio)

Media Links (Blog)

- On Autism

i. Kisin, K & Foster, F. [Triggernometry]. (2025, October 8). *The World's Leading Autism Expert – Professor Sir Simon Baron-Cohen* [Video]. YouTube. https://youtu.be/VJg2_EVheY4?si=16LbQcU10vk1HYeY

- Kodi Lee – American singer-songwriter and pianist

ii. https://www.youtube.com/watch?v=g7yqx8p0zJI ("You are the Reason" by Calum Scott [ft. Leona Lewis])
iii. https://www.youtube.com/watch?v=p12tV_mYWoU ("Biblical" by Calum Scott)
iv. https://www.youtube.com/watch?v=DAPkOxRnh4c ("A Song for You" by Leon Russell/Donny Hathaway)
v. https://youtu.be/6mQDVHPyJwA?si=qfV9Z_VVCKjyPJqV ("My Escape" by Kodi Lee)

Images (Blog)

Sheet Music
'I've got rhythm' by George Gerschwin (1930) [score in the public domain].
Co-Opera Co
Performance of 'La Boheme' (2010) featuring Michael Scott (Rodolpho), Hakan Vramsmo (Marcello), Simon Schmidt (Schaunard), John Bispham (Colline), and Robert-John Edwards (Alcindoro) (https://cooperaco.wordpress.com/) [printed with permission].
Cambridge Wind Band
Performance at West Road Concert Hall (2025) conducted by Viv Halton [printed with permission].
African Drum
Photograph taken by the author (2026).
Keyboard
Photograph taken by the author (2026).
William Meyerowitz
Modernist Oil Painting of a Musical String Quartet (1921) [image in the public domain].

Appendix

Contents

Abstract (Essay)

Rhythm is a fundamental component of human movement, communication, and musical engagement. This essay examines whether rhythm perception and production are affected in autism spectrum disorder (ASD). It first outlines the neurological and behavioral foundations of rhythmic capabilities in movement, noting that ASD frequently co-occurs with challenges in motor timing and coordination. The discussion then turns to social timing in non-musical interaction, where autistic individuals often show reduced interpersonal synchrony and difficulty adapting to temporal irregularities. These differences are contrasted with evidence that core capabilities for processing musical ("beat-based") rhythms remain relatively preserved in ASD. Despite slower adaptation to irregular timing and attenuated links between synchrony and prosocial outcomes, autistic children and adults typically perform comparably to neurotypical peers on tasks involving rhythmic grouping, meter categorisation, and synchronous tapping with non-variable partners. The essay then reviews research on music- and rhythm-based interventions, suggesting that gains in motor organisation, affect regulation, and social communication may generalise to broader forms of interaction. Finally, it considers lived experiences of musical rhythm, noting that many autistic people describe music and rhythmic activity as intrinsically meaningful and socially enabling. Together, these strands suggest that rhythm constitutes both a relative strength and a pathway for supporting well-being, social participation, and human connection.

Keywords

Autism, Music, Rhythm, Timing, Interaction, Therapy

Glossary:

Rhythm
A patterned organisation of temporal events, characterised by recurring durations, accents, or movement patterns that structure perception and action in time.

Pulse
A regular, isochronous temporal reference that listeners or interactants perceive as the underlying beat supporting rhythmic organisation.

Meter
A hierarchical framework that groups pulses into recurring cycles of strong and weak beats, providing a higher-order structure for predicting temporal regularities.

Entrainment
The dynamic process by which two or more oscillatory systems adjust their timing to achieve temporal alignment, typically through continuous mutual influence.

Interpersonal Entrainment
The process by which two or more individuals mutually adjust the timing and dynamics of their movements, vocalisations, or physiological rhythms, leading to sustained temporal alignment through continuous mutual coupling.

Musical Rhythm
A culturally shaped sustained patterning of temporal events around a common attentional pulse that builds on humans' general capacities for periodic movement, predictive timing, and entrainment, enabling coordinated perception, action, and social interaction.

Interpersonal Synchrony
The coordinated alignment of timing, movement, or affect between individuals during social interaction, emerging from reciprocal adaptation over time.

Social Motor Synchrony
A form of interpersonal synchrony involving the precise temporal coordination of bodily movements between interaction partners, supported by predictive motor and perceptual processes.

Sensorimotor Synchronisation
The coupling of perception and action in which an individual times their movements to external rhythmic stimuli, such as tapping to a beat or coordinating movement with another person.