Exploring musical skills and other strength-based approaches for supporting autistic children with different developmental profiles

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Abstract

Much like all children, autistic children have areas of interest and skill in addition to areas of challenge, and it is through the study of their strengths and how to harness them that we become better equipped to ensure that autistic children thrive in a society that is largely built on the preferences of children without disabilities. Accordingly, the overarching intention of my dissertation is to elucidate strength-based approaches that hold the potential to support the socialization and general learning of autistic children in inclusive environments.

In Manuscript 1, I present a systematic review of inclusive social activity-based interventions (e.g., music, Lego, theatre) that leverage autistic children's preference for structure and predictability for facilitating positive social outcomes for autistic children and their peers. I found that shared social activities yielded improvements in, for example, theory of mind, peer engagement, and shared enjoyment. I also found that activities that capitalized on interests or skills in addition to structure and that did not necessarily rely on peer or adult mediation strategies to facilitate therapeutic gains were effective for younger and older autistic children with varying support needs. Overall, some inclusive strength-based activity contexts appear to be accessible to children with different developmental profiles and suitable for promoting cross-group positive affect and collaboration, which are important for cultivating genuine friendships.

Playing music as a group holds incredible promise as an effective strength-based social activity for autistic children and their peers. Interactive musical experiences are ubiquitous and enjoyable in childhood and are associated with gains in non-musical areas of learning (i.e., far transfer effects), likely because engaging with music's highly salient beat modulates attention to less salient non-musical information (e.g., social, linguistic, motor), scaffolds the timing of non-musical behaviours (e.g., to-and-fro exchanges in social interactions), and drives cortical

plasticity, enabling children to understand and navigate their environments more successfully overtime. However, while many autistic children show well-developed musical pitch, melodic, and emotion perception, their ability to perceive the salient beat of music to be able to benefit from its therapeutic potential is not fully understood.

Manuscripts 2 and 3 were designed to elucidate the musical rhythm (beat) perception skills of autistic children to better characterize their musical profiles and inform on the ecological validity of utilizing shared beat-based musical activities for supporting autistic children in reaching their full learning potential. In Manuscript 2, I found that autistic children (aged 6-13 years) matched in chronological age and nonverbal and verbal mental ages to neurotypical children were successful at identifying when the tempo of a metronome aligned with the tempo of the musical beat (i.e., musical beat alignments), which is an essential skill to have when singing or playing instruments in harmony with the beat of the music and with other people. In Manuscript 3, I also found evidence of beat sensitivity in a larger, more diverse group of autistic children (aged 6-16 years) for which musical beat perception was uniquely predicted by age and nonverbal cognitive ability but not by verbal cognitive ability, auditory working memory, or the degree of autistic characteristics.

Taken together, the findings of my dissertation serve to create a more balanced perspective of autism as a condition that comes with strengths as well as challenges. It also informs on the utility of using shared social activities, and in particular beat-based musical activities, to support autistic children with heterogeneous profiles to flourish in their personal development, and in various inclusive learning and social environments.

Résumé

Comme la plupart des enfants, les enfants autistes présentent des intérêts et des habiletés, mais aussi des difficultés. C'est par l'étude de leurs forces que nous pouvons cultiver celles-ci et les aider à s'outiller afin de s'assurer qu'ils s'épanouissent au sein d'une société largement bâtie sur les préférences des enfants neurotypiques. En conséquence, le but principal de ma thèse était d'élucider les approches basées sur les forces qui ont le potentiel de favoriser la socialisation et l'apprentissage général des enfants autistes dans des environnements inclusifs.

Dans le manuscrit 1, je présente une revue systématique des interventions basées sur des activités sociales inclusives (par exemple, la musique, les Legos, le théâtre) qui mettent en évidence la préférence des enfants autistes pour des activités structurées et prévisibles, ce qui facilite la socialisation des enfants autistes et de leurs pairs. J'ai constaté que les activités sociales de groupe permettaient d'améliorer, par exemple, la théorie de l'esprit, l'engagement des pairs et le partage du plaisir de l'activité au sein du groupe. J'ai également constaté que les activités qui mettaient l'accent sur les intérêts ou les compétences, qui étaient structurées et qui ne nécessitaient pas d'intervention provenant des pairs ou des adultes facilitaient les gains thérapeutiques pour les enfants autistes de tout âge et ayant de différents besoins de soutien. Certains contextes d'activités inclusives basées sur les forces semblent être accessibles aux enfants ayant divers profils de développement et peuvent promouvoir des émotions positives et un esprit de collaboration inter-groupes, ce qui permet de cultiver de réelles amitiés.

Jouer de la musique en groupe est une activité sociale très prometteuse pour les enfants autistes et leurs pairs. Les expériences musicales interactives sont populaires et plaisantes lors de l'enfance et sont associées à des gains dans des domaines d'apprentissage non musical (c'est-à-dire des effets de transfert), notamment parce que l'engagement dans le rythme musical module

aussi l'attention pour des informations non musicales (par exemple, sociales, linguistiques, motrices), ce qui facilite la synchronisation de comportements non musicaux (par exemple, les échanges de va-et-vient dans les interactions sociales) et stimule la plasticité cérébrale, permettant aux enfants de mieux comprendre et naviguer leur environnement au fil du temps. Cependant, alors que de nombreux enfants autistes présentent une perception développée des notes de musique, de la mélodie et de l'émotion associée à la musique, leur capacité à percevoir les rythmes musicaux n'est pas bien compris ce qui, en retour, ne nous permet pas de comprendre les bénéfices thérapeutiques associés aux activités musicales rythmiques.

Les manuscrits 2 et 3 ont été conçus afin d'élucider les capacités de perception du rythme musical des enfants autistes afin de mieux caractériser leurs profils musicaux. Ceci permet d'en apprendre davantage sur la validité écologique de l'utilisation d'activités musicales de groupe basées sur le rythme afin d'aider les enfants autistes à atteindre leur plein potentiel d'apprentissage. Dans le manuscrit 2, j'ai découvert que les enfants autistes (âgés de 6 à 13 ans), dont l'âge chronologique et l'âge mental non-verbal et verbal correspondaient à ceux d'enfants neurotypiques, parvenaient à identifier le moment où le tempo d'un métronome s'alignait sur le tempo du rythme musical (c'est-à-dire, les alignements sur le rythme musical), ce qui est une compétence essentielle permettant de chanter ou jouer des instruments en harmonie avec le rythme de la musique et avec d'autres personnes. Dans le manuscrit 3, j'ai également trouvé des preuves de sensibilité au rythme dans un groupe plus large et plus diversifié d'enfants autistes (âgés de 6 à 16 ans) pour lesquels la perception du rythme musical était uniquement prédite par l'âge et les capacités cognitives non-verbales, mais pas par les capacités cognitives verbales, la mémoire de travail auditive ou le degré de caractéristiques autistiques.

En somme, les résultats de ma thèse servent à créer une perspective plus nuancée de l'autisme en tant que condition comportant des forces et des défis. Ma thèse met en évidence la pertinence d'utiliser des activités sociales de groupe et des activités musicales basées sur le rythme afin d'aider les enfants autistes aux profils variés à s'épanouir dans leur développement personnel et dans divers environnements sociaux et d'apprentissage inclusifs.

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Contribution to Original Knowledge

The overarching intention of my dissertation was to advance our understanding of the positive attributes of children on the autism spectrum[1] and inclusive neurodiversity-affirming supports that harness their areas of competence to facilitate their learning and development in inclusive environments. Contrary to the deficit lens traditionally associated with autism (as critiqued by Pellicano & den Houting, 2022), the three manuscripts that compose my dissertation shift attention from what autistic children cannot do to what they can do, contributing significantly to strengths-focused autism research that is still very much in its infancy. Moreover, I avoided contributing to selection bias practices in autism research (e.g., excluding autistic children with co-occurring intellectual and language difficulties in study samples) (Russell et al., 2019) and attempted to represent the heterogeneity inherent to autism as best as possible by including autistic children with diverse characteristics.

In Manuscript 1 (Dahary et al., 2022), I conducted an original systematic review that evaluated the effectiveness of involving autistic children and their peers in structured social activities to support their social development. The limited available research suggested that several shared structured social activity-based interventions are associated with increased social cognitive and communication skills. In addition, social activities that incorporate the strengths and abilities of autistic children beyond their innate preference for structure accommodate children with different developmental profiles, empower children to play equally, promote shared enjoyment, and are considered feasible to implement and socially valid. The synthesis of results in Manuscript 1 contributes to strengths-focused work with autistic children by

[1] I use a mix of identity-first ("autistic") and neutral terminologies (e.g., "autism" and "on the autism spectrum") throughout my dissertation to respect the current diversity of voices of the autism community (Bottema-Beutel, 2021; Monk et al., 2022).

reinforcing the notion that their interest and aptitude for highly structured and predictable hobbies, such as musical activities (Heaton, 2009; Quintin, 2019), can serve as accessible and inexpensive platforms for autistic and non-autistic children to learn how to socialize with each other on an equal playing field (Koegel, Matos-Freden et al., 2012). Manuscript 1 also demonstrates a need for future work to continue exploring the skills of autistic children in specific activity modalities (e.g., music) to understand more fully how particular features of shared social activities (e.g., the beat of musical activities) can be utilized as a strengths-based tool for supporting the general learning and well-being of children across the spectrum.

In Manuscripts 2 and 3, I executed two original empirical studies that assessed whether children on the autism spectrum are perceptually sensitive to the salient beat of music within the context of a beat alignment task paradigm. Many autistic children have an affinity for music and display musical skills (Heaton, 2009; Quintin, 2019), but musical beat perception skills, specifically, have only been explored among neurotypical children (e.g., Einarson & Trainor, 2015, 2016; Nave-Blodgett et al., 2021; Nave et al., 2022) and non-autistic-clinical-populations (e.g., Bégel et al., 2022). Interactive beat-based musical activities are proposed to potentially produce far-transfer effects to non-musical areas of functioning for children on the autism spectrum because rhythm and beat serve as an accessible non-verbal framework for modulating attention to less salient non-musical rhythms and for scaffolding the timing of non-musical behaviours (Daniel et al., 2022; Lense & Camarata, 2020). In addition, beat processing shares mechanisms and cognitive resources implicated in several learning and developmental processes (Fiveash et al., 2021) and, thus, regularly engaging with the beat in music leverages cortical plasticity for non-musical learning (e.g., Bharathi et al., 2019; Hardy & LaGasse, 2013). In Manuscript 2 (Dahary et al., 2023), I found that an autistic group aged 6-13 was just as successful as an age-matched neurotypical group at identifying when the tempo of a superimposed metronome aligned with the tempo of the musical beat. Such sensitivity to musical beat alignments is required for participating in group music-making activities that involve singing or playing instruments on the beat of the music and in synchrony with other people. I also found evidence of beat sensitivity in group analyses with a larger and more diverse sample of autistic children aged 6-16 (n = 23 overlapped with Manuscript 2) and that musical beat perception was uniquely impacted by children's age and nonverbal cognitive ability but not by their verbal cognitive ability, auditory working memory, and level of autistic traits. Therefore, the empirical findings in Manuscripts 2 and 3 contribute to our understanding of the musical skills of autistic children with different abilities and shed light on the ecological validity of utilizing shared beat-based musical activities as a non-verbal strengths-based approach for promoting the social, learning, and personal development of children across the autism spectrum.

Overall, this doctoral research counteracts common deficit perspectives associated with autism by studying the strengths of autistic children and emphasizing accessible strengths-based approaches, including shared structured social activities (e.g., musical activities), for addressing the various learning objectives of autistic children in a manner that feels rewarding to them. These contributions to autism and strengths-focused research are elaborated in Chapter 6.

Contribution of Authors

Chapter 1 (Introduction) was written and edited by Hadas Dahary (HD) with feedback from Eve-Marie Quintin (EMQ).

Chapter 2 (Literature Review) was written and edited by HD with feedback from EMQ.

Chapter 3 (Manuscript 1) is an exact reproduction of the article entitled, “A systematic review of shared social activities for children on the autism spectrum and their peers”, published in the peer-review journal, *Review Journal of Autism and Developmental Disorders,* in May 2022. It is authored by HD, Charlotte Rimmer (CR), Mira Kaedbey (MK), and EMQ. HD conceptualized the scope of the systematic review with EMQ. HD performed the literature search, synthesized the results, and wrote and edited the manuscript with input from EMQ. CR and MK independently completed a second literature search and data extraction for verification. All authors read and approved the final manuscript.

Chapter 4 (Manuscript 2) is an exact reproduction of the article entitled, “Musical beat perception skills of autistic and neurotypical children”, published in the peer-review journal, *Journal of Autism and Developmental Disorders,* in January 2023. It is authored by HD, CR, and EMQ. HD and EMQ had the research idea for this study. HD created the adapted version of the experimental task and HD spearheaded the data collection and formal analysis process in partnership with CR. EMQ provided supervision and critically revised the work. HD wrote and edited the manuscript with input from EMQ. All authors read and approved the final manuscript.

Chapter 5 (Manuscript 3) is comprised of a manuscript entitled, “Musical beat perception skills of autistic children increase with age and nonverbal cognitive ability”, and is authored by HD, CR, and EMQ. HD and EMQ had the research idea for this study. HD created the adapted version of the experimental task as well as spearheaded the data collection and formal analysis process in partnership with CR. The work was supervised and reviewed by EMQ. HD wrote and edited the manuscript with input from EMQ. All authors read and approved the final manuscript.

Chapter 6 (**Discussion**) was written and edited by HD with feedback from EMQ.

Chapter 7 (Final Conclusion and Summary) was written and edited by HD with feedback from EMQ.

Note: The manuscripts that compose Chapters 4 and 5 of my dissertation represent original contributions to the field of autism and music empirical research. The present dissertation was supported by the Joseph-Armand Bombardier Canada Graduate Scholarships Program - Doctoral Scholarship (2018-2021) and Fonds de Recherche du Québec - Santé via the Transforming Autism Care Consortium Fellowship (2021-2022) awarded to HD.

List of Tables and Figures

Chapter 3: Manuscript 1

Chapter 4: Manuscript 2

Chapter 5: Manuscript 3

List of Abbreviations

The following abbreviations appear in the text of my dissertation. Abbreviations only used in tables/figures are defined in the note section under each table/figure:

ADOS-2	Autism Diagnostic Observation Schedule-2nd edition
ANOVA	Analysis of Variance
APA	American Psychiatric Association
ASD	Autism Spectrum Disorder
BAT	Beat Alignment Test
BF	Bayes factor
CAHS	Canadian Academy of Health Sciences
DS	Digit Span
DSM	Diagnostic and Statistical Manual of Mental Health Disorders
ERIC	Education Resources Information Center
ES	Effect Size
GMSI	Goldsmiths Musical Sophistication Index
Hits-FAs	Hits minus False Alarms
LEAP	Learning Experiences and Alternative Program for Preschoolers and Their Parents
MBEMA	Montreal Battery for the Evaluation of Musical Abilities
NAC	National Autism Center
NAP	Nonoverlap of pairs of effect size
NCAEP	National Clearhouse on Autism Evidence and Practice
NPDC	National Professional Development Centre
NSP	National Standard Project
PHAC	Public Health Agency of Canada
PIQ	Performance Intelligence Quotient
PRISM	Processing Rhythm in Speech and Music
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
SCQ	Social Communication Questionnaire
SRS-2	Social Responsiveness Scale, 2nd Edition
TD	Typically Developing
VIQ	Verbal Intelligence Quotient
WASI-II	Wechsler Abbreviated Scale of Intelligence, 2nd Edition
WISC-V	Weschler Intelligence Scale for Children, 5th Edition

Chapter 1: Introduction

Inclusion is a top priority for action in Canada that is increasingly supported by our policy landscape. The Accessible Canada Act came into force in July 2019 (Bill C-81, 2019), which builds on the *Charter of Rights and Freedoms* (1985) and international policies, such as the *Convention on the Rights of Persons with Disabilities* (United Nations, 2006), to ensure that people with disabilities, including people on the autism spectrum[2] can fully access resources and meaningfully participate alongside people without disabilities in society. The government of Canada has declared an intention to become completely accessible to people with disabilities by 2040 (Bill C-81, 2019). In keeping with the goal of a fully accessible Canada, the Canadian Academy of Health Sciences (CAHS) recently conducted a 19-month-long assessment of autism to inform the development of a National Autism Strategy. The assessment process involved consultation with pan-Canadian stakeholders and a comprehensive review of the autism literature, which revealed social and environmental barriers that many autistic people face as well as the breadth of aspirations of the autism community, such as a yearning for the creation of spaces that empower autistic people to socialize and learn in a manner that feels genuinely inclusive and meaningful to them (CAHS, 2022).

Children on the autism spectrum possess general interests and skills (Clark & Adams, 2020), such as enjoyment and aptitude for music (Heaton, 2009; Quintin, 2019). Through the lenses of neurodiversity (Sonuga-Barke & Thapar, 2021), positive education (Galloway, 2020; Seligman et al., 2009), and resilience (McCrimmon & Montgomery, 2014), the strengths of all children should be celebrated and capitalized on to support optimal learning, social, and personal

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[2] I use a mix of identity-first ("autistic") and neutral terminologies (e.g., "autism" and "on the autism spectrum") throughout my dissertation to respect the current diversity of voices of the autism community (Bottema-Beutel, 2021; Monk et al., 2022).

outcomes in inclusive settings. In autism research, however, it is only in the last decade or so that attention has shifted away from studying challenges associated with autism (i.e., what they *cannot* do) and how to remediate them to learning about their interests and skills (i.e., what they *can* do) and how to leverage these positive attributes in interventions (Sonuga-Barke & Thapar, 2021), leaving strengths-focused work in the autism literature still very much in its infancy.

Therefore, the overarching aim of my manuscript-based dissertation was to expand our knowledge of strengths-based approaches that facilitate optimal functioning for autistic children in a neurodiversity-affirming way. Following the present introductory chapter, Chapter 2 constitutes a literature review of topics that are relevant to my dissertation, such as autism, inclusion, social development, interventions that involve autistic children and their neurotypical peers, the musical skills of autistic children, and the therapeutic potential of shared beat-based musical activities.

In Chapter 3, I evaluate shared structured social activity-based interventions as a strengths-based approach for supporting the social development of autistic children and their peers in inclusive school and community environments. Children socialize at their best when they are engaged in activities that they find enjoyable (Koegel et al., 1987). Social activities that are sufficiently structured are particularly accessible to children on the autism spectrum because this structure can be leveraged to plan and execute interactions with others effectively (DeKlyen & Odom, 1989; Gunn et al., 2014). Such accessible social contexts allow autistic children and their peers to experience successful social exchanges with each other and to share positive affect as they work as a team to attain common enjoyable goals through the same means of effort (e.g., making music or building a model together). Spaces that elicit positive emotions and a sense of equality between children are optimal for teaching neurodiverse children how to socialize with each other and for increasing perceived similarities (e.g., shared interests) as opposed to differences between children, which promotes cross-group acceptance and friendships (Allport, 1954; Therrien & Light, 2016). While previous systematic reviews have examined the effectiveness of incorporating peers in interventions involving peer-mediation strategies (e.g., Chang & Locke, 2016; Watkins et al., 2015; Gunning et al., 2018) or play-based activities on social/play outcomes for autistic children (Fedewa et al., 2022), these works have not exclusively examined shared structured social activity-based interventions, precluding conclusions about the ecological validity of this type of strengths-based approach. In the systematic review presented in Manuscript 1 of Chapter 3, I evaluate whether shared structured social activity-based interventions 1) improve social outcomes for autistic children and their peers, 2) are accessible for autistic children of different ages and with varying needs of support, 3) encourage autistic children and their peers to be equal partners, and 4) have sufficient evidence supporting their social validity.

Inclusive musical activities (e.g., group music making) hold incredible promise for supporting the learning objectives of autistic children in inclusive settings. Listening to and creating music is a general interest and strength of all children (Campbell, 2002), including children on the autism spectrum (e.g., Clark & Adams, 2020; Heaton, 2009) and is associated with far-transfer effects to non-musical areas of learning (Hyde et al., 2009). Active musical participation is found to improve the social communication skills of autistic children (e.g., Kim et al., 2008; LaGasse, 2015; Sharda et al., 2018) as well as prosocial emotions (Cook et al., 2019), cooperation (Wan & Zhu, 2021) and social bonding (Cirelli et al., 2014) among neurotypical children. Musical training is also shown to hone musical abilities (e.g., musical beat processing), which has cascading effects on language, executive functioning, and motor development for neurotypical (Kausel et al., 2020) and neurodivergent people (Flaugnacco et al., 2015; Moritz et al., 2013), demonstrating that music may be ideal for reducing other developmental challenges (e.g., language, attention, and motor difficulties) that often co-occur with autism and impact social functioning (e.g., Bhat et al., 2011).

The benefits associated with regular musical participation may be explained (at least partially) by the presence of music's salient and predictable beat (Lense & Camarata, 2020). Engaging with music's beat may accentuate the structure and predictability of non-musical rhythms (e.g., the to-and-fro in conversation and play) that are less accessible to autistic children (Lense & Camarata, 2020) and may facilitate sensorimotor integration through entrainement of auditory-motor neural networks (Sharda et al., 2018). Based on reviews of work with adults with Parkinson's disease (Hardy & LaGasse, 2013) and pediatric populations with developmental speech and language disorders (Fiveash et al., 2021), beat-based musical experiences modulate attention to non-musical beat-based sensory signals and scaffold the timing of behaviours, all while stimulating brain plasticity.

Although autistic children are found to have musical skills, including well-developed musical memory and musical pitch and emotion processing skills (e.g., DePape et a., 2012; Jamey et al., 2019; Quintin et al., 2011; Quintin et al., 2013; Stanutz et al., 2014), their musical beat processing skills are not yet fully understood, making it difficult to conclude that autistic children can leverage the beat of the music for therapeutic gain. Even though autistic children can discriminate between sequentially presented musical rhythms (Jamey et al., 2019; Sota et al., 2018), such same-different rhythm perception task paradigms draw on non-rhythmic skills (i.e., memory) and do not capture the multidimensionality of rhythmic abilities very well (Fiveash et al., 2022; Tranchant et al., 2021).

In Chapters 4 and 5, I assessed the musical beat perception skills of children on the autism spectrum using a beat alignment task paradigm that asked listeners to indicate whether beeps overlaid on musical excerpts are aligned or misaligned with the beat of the music, a task previously shown to correlate positively with different aspects of rhythmic abilities such as beat-based rhythm perception and production skills (e.g., Bonacina et al., 2019; Dalla Bella et al., 2017; Fiveash et al., 2022; Tierney & Kraus, 2015). In Manuscript 2 of Chapter 4 (Dahary et al., 2023), I conducted an experimental study with 23 autistic and neurotypical children matched in chronological age and verbal and nonverbal mental age, with the primary objective being to compare their performance on the beat perception task. In Manuscript 3 of Chapter 5, I conducted a second experimental study with 53 autistic children with diverse characteristics (including the 23 participants from Manuscript 2), with the primary objective being to assess musical beat perception skills as a function of age, cognitive abilities (i.e., verbal cognitive ability, nonverbal cognitive ability, and auditory working memory), and degree of autistic characteristics. It was my hope in Manuscripts 2 and 3 to understand whether children *across* the autism spectrum are perceptually sensitive to the beat of the music to inform on the ecological validity of using beat-based musical activities as a strength-based tool for supporting autistic children in building a variety of new skills and social connections in inclusive settings.

In Chapter 6, I provide the general discussion, contributions, future directions, and implications of the findings in Manuscripts 1-3. Clinical and educational implications for developing and implementing strengths-based approaches, including shared beat-based musical activities, are discussed. In Chapter 7, I provide my dissertation's final conclusions and summary.

Chapter 2: Literature Review

Autism is a neurodevelopmental condition that is increasingly being diagnosed around the world[3] (Public Health Agency of Canada [PHAC], 2019; Zeidan et al., 2022) and is currently prevalent in about 1-2% of children (Christensen et al., 2018; PHAC, 2019). It is primarily characterized by social interaction and communication differences alongside repetitive patterns of behaviours and interests (American Psychiatric Association [APA], 2022). Autism is considered highly heterogeneous because autistic people experience different combinations and intensities of autistic traits and often have co-occurring conditions that are related yet not inherent to autism (Ripamonti, 2016; Zeidan et al., 2022). Despite a focus on social communication and behaviours in the Diagnostic and Statistical Manual of Mental Health Disorders (DSM-5-TR) (APA, 2022), children on the autism spectrum display a broad range of skills in other developmental domains, such as language, cognition, and motor movement. While autistic children can present with average or enhanced abilities in cognitive and language areas, about one-third meet the criteria for intellectual developmental disability (Christensen et al., 2018; Zeidan et al., 2022), and more than half meet the criteria for a developmental speech and language disorder (Levy et al., 2010). Attention-deficit/hyperactivity disorder, specific learning disorders (e.g., reading, writing), and movement difficulties (e.g., oral-motor coordination, fine and gross motor, motor planning, and gait) are also prevalent (Ibrahim, 2020; Kangarani-Farahani et al., 2023; Stevens et al., 2016; Rau et al., 2020). Given the heterogeneity within autism, the level of support that autistic children need to benefit fully from their surroundings varies tremendously.

[3] Epidemiologists have postulated that the upward trend in autism diagnoses may reflect increased knowledge about autism and, thus, better detection of this condition, diagnostic substitutions, and changes in diagnostic practices. False positives are also possible (see Arivdsson et al., 2018; Fombonne, 2020; Yuen et al., 2018 for a thorough discussion on autism prevalence).

Autism and Inclusion

The rise in the prevalence of autism worldwide (Zeidan et al., 2022) and the fundamental right for all autistic and other neurodivergent children to receive quality learning opportunities alongside their neurotypical peers (Bill C-81, 2019; McCrimmon et al., 2019) have resulted in more neurodivergent children being placed in inclusive environments where they share the same context (e.g., daycares, classrooms, camps) and many (if not all) learning and leisure activities with their neurotypical peers. Autistic people are no different from non-autistic people, such that they often yearn to learn and socialize with their peers and to feel included and valued (Clark & Adams, 2020; Cresswell et al., 2019; Mitchell et al., 2021). Truly inclusive environments kindle a sense of belonging, acceptance, and self-determination by offering equitable access to supports and opportunities that enable active and meaningful engagement in social activities (CAHS, 2022). However, achieving genuine inclusion in school and community settings has proven to be a very complex process that inconsistently yields positive social experiences for people on the autism spectrum (Brown et al., 2022; Humphrey & Lewis, 2008; Rotheram-Fuller et al., 2010). From the lenses of neurodiversity and the social model of disability (Chapman, 2021; Sonuga-Barke & Thapar, 2021), barriers that impede genuine inclusion arise when environments are inadequately matched to the needs of autistic people (Sonuga-Barke & Thapar, 2021). Mainstream schools, for instance, include many unstructured social periods of the day, which do not align with autistic children's preference for predictable and structured social activities that convey clear behavioural expectations (Deklyn & Odom, 1989; Gunn et al., 2014; Pellicano & den Houting, 2021). Such inaccessible contexts often result in autistic children appearing less capable of participating meaningfully in social activities and create few opportunities for autistic children and their peers to discover and share their interests and skills, which is essential for promoting inclusion as well as resilience and well-being in education (Galloway, 2020; McCrimmon & Montgomery, 2014).

Social Communication, Social Cognition, and Social Functioning

Neurotypical children learn how to socialize and communicate by observing how other adults and children interact in real-life, on television, and in stories (Bandura, 1977). Through observational learning, children quickly acquire theory of mind skills (i.e., social cognition) (e.g., Carpendale & Lewis, 2015) and readily pick up on social rhythms that underlie social interactions, such as back-and-forth exchanges in conversations and play (i.e., social communication skills) (e.g., Sheridan et al., 2010). It is through proficient social cognition and communication skills that children effectively participate in mutually reinforcing interactions. As children grow older, they show a propensity to connect with peers who are in close physical proximity to them (e.g., neighbours, classmates) (i.e., propinquity) and who share commonalities (e.g., age, ethnicity, learning profile) (i.e., homophily) (Male, 2007; McPherson et al., 2001), and these connections often develop into genuine friendships (i.e., a common indication of overall social functioning).

People on the autism spectrum also learn how to socialize via observation at times (Garfinkle & Schwartz, 2002; Kohler, Strain, Hoyson, & Jamieson, 1997) and define friendships based on homophily and propinquity (Black et al., 2022). However, their social communication and cognitive skills develop differently from neurotypical children in that they show reduced or uncoordinated joint attention, gestures, and social smiling during early social interactions (e.g., Baird & Norbury, 2015; Jones et al., 2016; Ozonoff et al., 2010; Zwaigenbaum et al., 2005), make fewer spontaneous social initiations and responses to peers on the playground, or approach and respond in conversations and unstructured play activities in a manner that can be interpreted as too intense or unusual by non-autistic peers (APA, 2022; Gunn et al., 2014), which can lead to communication breakdowns between autistic and non-autistic children (Mitchell et al., 2021). The *double empathy problem* (Milton, 2012) suggests that communication breakdowns between autistic and non-autistic people reflect different social communication styles that lead to a bidirectional failure of empathy. Autistic people have an easier time understanding the mental states of other autistic people than those of neurotypical people (Crompton, Ropar, et al., 2020) and, therefore, more commonly experience high interactional rapport with other autistic people (Crompton, Sharp et al., 2020). Similarly, neurotypical people are proficient at understanding the mental states of other neurotypical people but have difficulty interpreting the social behaviours of autistic people (Edey et al., 2016; Sheppard et al., 2016), potentially leading to socially unfavourable perceptions of autistic people and a reduced inclination to pursue interactions with them (Alkhaldi et al., 2019; Sasson et al., 2017).

Unfortunately, children on the autism spectrum are often at the periphery of social networks at school and infrequently get invited to other children's social events, hang out with their classmates outside of school, and receive telephone calls from their peers (Wagner et al., 2004). Autistic children have fewer friends compared to neurotypical children and children with other disabilities (Symes & Humphrey, 2010) and often experience less security and closeness when they do develop relationships with other children (Bauminger & Kasari, 2000; Locke et al., 2010). Peer rejection, peer victimization, loneliness, and feelings of otherness are commonplace (Cresswell et al., 2019; Goodall, 2018; Hebron et al., 2015; Sterzing et al., 2012; Zeedyk et al., 2016). Because peer relationships matter to everyone, including people on the autism spectrum (Clark & Adams, 2020; Cresswell et al., 2019; Mitchell et al., 2021), and are leveraged to cope during stressful situations (Dubow & Tisak, 1989; Kiefer et al., 2015; Lasgaard et al., 2010;

Symes & Humphrey, 2010), the absence of peer support may explain (at least partially) why younger and older autistic people experience mental health difficulties at a much higher rate than the general population (Fombonne et al., 2020; Lai et al., 2019; Rydzewska et al., 2019).

Social Interventions Involving Autistic Children and Their Neurotypical Peers

Based on the double-empathy problem (Milton, 2012) and other neurodiversity-affirming perspectives (Sonuga-Barke & Thapar, 2021), it is just as crucial for neurotypical children to learn how to effectively interact with autistic children as it is for autistic children to learn normative social communication and social cognitive skills. Neurotypical children often express an interest in engaging with their autistic peers and show more positive cognitive attitudes and behavioural intentions when they learn about autism and have opportunities to interact with their autistic peers (Cook et al., 2020; Mavropoulou & Sideridis, 2014). Therefore, while the emphasis has traditionally been purely placed on autistic children to learn new skills and change their behaviours via direct instruction from adult facilitators using withdrawal methods (e.g., Reichow & Volkmar, 2010; Rodda & Estees, 2018; Sutton et al., 2019), it is becoming increasingly popular to involve autistic and neurotypical children together in interventions to help them learn how to socialize with each other. However, inclusive practices that best support autistic children with diverse characteristics in a manner feasible to implement in environments with minimal resources (e.g., schools) continue to be studied.

Peer-Mediated Interventions

Peer-mediation is considered an evidence-based practice by the National Professional Development Centre (NPDC, 2020) and the National Autism Centre (NAC) projects (NAC, 2015; NPDC, 2020) for incorporating autistic children and their peers together in intervention and forms a core component of well-known naturalistic interventions that target a comprehensive range of learning and developmental objectives such as the Learning Experiences and Alternative Program for Preschoolers and Their Parents (LEAP) (Strain & Hoyson, 2000) and Circle of Friends (Newton et al., 1996). The term, evidence-based, is used to describe interventions that are shown to positively affect learning outcomes in high-quality research studies (Reichow et al., 2008) and that appropriately reflect the interests, values, and priorities of autistic people (CAHS, 2022). Peer buddy systems in the classroom (e.g., Simpson & Bui, 2017) or peer networks at lunch, recess, or in other inclusive settings (Carter et al., 2011; Kamps et al., 2014) are examples of peer-mediation interventions that generally involve 1) selecting autistic children and peers who are likely to benefit from or are interested in interacting together, 2) delivering didactic training to peers about autism and how to coach autistic children through social situations using prompts, social modelling, and contrived reinforcement, and 3) providing regular opportunities for peers to practice coaching autistic children in their natural environment (Odom, 2019). Peer-mediation is often complemented with adult-mediation wherein adult facilitators teach autistic children how to use tools (e.g., social scripts) and/or organize the social context (e.g., interactive playgroups, free play activities) to scaffold the social communication further and play between autistic and neurotypical children (e.g., Aldabas, 2022; Hundert et al., 2014; Kent et al., 2020; Vincent et al., 2022; Wolfberg et al., 2015). However, peer-mediation interventions that do not rely too heavily on adult-mediation are preferred because adult involvement in supporting social exchanges can unintentionally shift peers' focus to the adults instead of the autistic child and, thus, reduce the natural occurrence of child-to-child interactions (Odom, 2019).

In several systematic reviews, the use of peers as social models or coaches is found to be appropriate for children aged 3 to 18 with varying support needs and to be associated with social communication and play gains, such as social initiations, social responses, peer engagement, interactive play, that are generalized to other contexts and maintained over time (Fedewa et al., 2022; Gunning et al., 2018; Watkins, Ledbetter-Cho et al., 2019; Watkins et al., 2015). Some autistic participants have viewed peer-mediation favourably (Zanuttini & Little, 2021), and neurotypical participants show an increase in positive interaction and a decrease in negative interaction with autistic children, higher self-esteem, greater overall empathy, and a deeper appreciation for diversity and social inclusion (Copeland et al., 2004; Hassani et al., 2021; Hughes et al., 2011; Oppenheim-Leaf et al., 2012). However, it is unclear if peer-mediation interventions produce observational prosocial behavioural intentions and friendships. Kasari et al. (2012) found that neurotypical participants more often rated children on the autism spectrum as a friend following a peer-mediation intervention but that these friendship nominations were not reciprocated by autistic children, perhaps indicating that a different type of approach may be needed for nurturing mutually beneficial social relationships. Moreover, favourable outcomes in education depend on both the effectiveness of the intervention itself and the effectiveness of implementing an intervention (Cook & Odom, 2013). Peer- and adult-mediation can be resource intensive because it often requires substantial training to be delivered to peers (and adults), which may not be feasible for inclusive settings that have limited support staff and time, such as schools (Barry et al., 2020; Sutton et al., 2019).

Shared Structured Social Activity-Based Interventions

Involving peers as play partners in specific social (leisure) activities that are structured and enjoyable may be an alternative peer-based intervention that offers a unique strength-based opportunity for naturally expanding children’s repertoire of social behaviours and social networks. Gunn et al. (2014) found that autistic children play at their best during structured group-based activities with clear behavioural expectations, such as singing songs, following the rules of a game, and constructing a model, compared to unstructured activities like free play on the playground. A structural framework allows autistic children to refer to the organization and predictability of the play activity to effectively plan and execute social initiations and responses (DeKlyen & Odom, 1989). Therefore, it makes sense that autistic children are more likely to experience success in social interactions that occur during structured social activities, such as having a peer continue their play action, and this success can be reinforcing in and of itself as well as have a positive bidirectional impact across social partners.

Socialization also increases for children when engaged in structured activities that they find enjoyable (Koegel et al., 1987). Music, robotics, and model building are examples of highly structured activities that many neurotypical and autistic children enjoy. Such mutual interests in activities can help facilitate autistic-neurotypical synchronicity and joint engagement (Chen, Schneider et al., 2022). In a recent systematic review and meta-analysis by Fedewa et al. (2022), the authors found that shared play-based interventions that involved the preferred interests of autistic children produced larger effect sizes (ES) for play-based outcomes (d_{sc} = 3.44, large ES) compared to other play-based interventions that did not necessarily incorporate children's interests such as peer-mediation (d_{sc} = 1.41, medium ES), script training (d_{sc}= 1.07, medium ES) and interactive play groups (d_{sc}= .86, small ES). There is also empirical evidence suggesting that structured interest-based play activities are accessible to preschool-aged children with minimal language skills (Watkins, O'Reilly et al., 2019) and to proficient autistic speakers in elementary school and high school (Koegel, Vernon et al., 2012; Koegel et al., 2013), which is relevant for inclusive settings that service children who vary in age and support needs.

Although some peer- and adult-mediation interventions are implemented during structured social/academic activities (e.g., organized games with rules, shared reading activity) (Hundert et al., 2014; Simpson & Bui, 2017), certain social activities may be sufficiently structured and naturally reinforcing for supporting the performance of social behaviours and thus, may not necessitate explicit social teaching. Music-making and other organized movement activities (e.g., dance, aquatics, martial arts) leverage the unique properties of the activity modality (e.g., rhythm in music) and are considered evidence-based (or emerging) interventions for producing gains in the social domain for children on the autism spectrum (NPDC, 2020; NAC, 2015). Aside from not requiring intensive resources for peer/adult training, certain structured social activities may permit autistic and neurotypical children to participate in intervention activities equally. It may not be necessary to assign the children hierarchical roles wherein peers are the teachers or expert players and autistic children are the followers or novice players. Allport (1954) indicates that positive intergroup outcomes are more likely to occur if interactions take place during activities that promote a feeling of equality among participants by requiring them to work as a team through the same means of effort to reach a common goal (e.g., making a musical piece, winning a sports game). Indeed, inclusive recreational programs that are executed under such optimal conditions, such as Special Olympics Unified Sports, are shown to promote social acceptance and new friendships between children with and without educational needs (Koegel et al., 2005; Rynders et al., 1993; Siperstein et al., 2009). Therefore, social activities that encourage children on the autism spectrum and their peers to collaborate on common goals similarly may elicit a sense of equality between the children and, thus, may be well-suited for promoting social learning and cross-group friendships in inclusive settings (Therrien & Light, 2016).

Objectives of Manuscript 1

Although previous systematic reviews have examined the effectiveness of incorporating peers in interventions for autistic children via peer mediation interventions (e.g., Chang & Locke, 2016; Gunning et al., 2018; Watkins et al., 2015) and inclusive play-based interventions on social/play outcomes (Fedewa et al., 2022), these works have not exclusively examined the effects of shared structured social activity-based interventions on the social development of children on the autism spectrum and their peers, which was the aim of Manuscript 1. Specifically, I assessed the empirical literature to answer four exploratory questions without putting forward formal hypotheses: 1) Do shared structured social activities improve the social cognition, social communication, and social functioning of autistic and neurotypical children? 2) Are they suitable for autistic children of different ages and support needs? 3) Can autistic and neurotypical children participate equally in activities? and 4) Are shared structured social activities considered to be socially valid? With this comprehensive systematic review, I intended to inform on the effectiveness of using shared structured social activity-based interventions as neurodiverse-friendly and cost-effective strength-based tools for supporting the social participation of children in inclusive settings.

Music as a Familiar, Enjoyable, and Strengths-Based Activity Modality

Music may be a well-suited modality for hosting inclusive, collaborative recreational activities for autistic children and their peers because musical activities are natural and ubiquitous experiences in childhood that evoke a range of emotions, stimulate the reward system, and induce a pleasurable desire to move (Matthews et al., 2019; Quintin, 2019). Neurotypical children use musical sounds to express and entertain themselves and communicate and socialize with their parents and peers (Campbell, 2002). Neurotypical infants as young as 3 to 4 months of age are capable listeners and can imitate vocal sounds and match pitch (Levinowitz, 1998). By 6-months-old, infants can discriminate between sung and spoken words and favour infant-directed singing over infant-directed speech, especially when they are in distress (Trehub et al., 2015; Tsang et al., 2017). Young children quickly become accustomed to songs they hear in their environment (e.g., at daycare, on television) and spontaneously use them to communicate and play with other children on the playground, demonstrating a preference and enjoyment for music early in development (Campbell, 2002). Autistic children and adults also show an interest in and enjoyment of music in their daily lives, listen to a variety of musical genres, display musical creativity and exploit music to alter their mood, to feel socially included, and for personal development (Allen & Heaton, 2010; Allen et al., 2009ab; Bhatara et al., 2013; Heaton, 2009; Johnson & LaGasse, 2022).

In addition, people on the autism spectrum endorse musical ability (Taylor et al., 2023) and are found to understand and respond to the emotional qualities of music (Allen et al., 2013; Heaton, Allen et al., 2008; Heaton et al., 1999; Quintin et al., 2011; Quintin, 2019; Sivathasan, Dahary et al., 2023; Stephenson et al., 2016; see however, Bhatara et al., 2010), despite showing differences in their ability to label emotions in non-musical domains (e.g., faces, speech) (e.g., Fridenson-Hayo et al., 2016; Golan et al., 2018). Consistent with the Enhanced Perceptual Functioning Model of autism, or the hypothesis that autistic people have a superior perceptual system (Mottron et al., 2001, 2006, 2009), early case studies (e.g., Kanner, 1943, 1951; Sherwin, 1953) and multiple empirical studies have shown that children on the autism spectrum are perceptually sensitive to structural components of music like pitch (Mottron et al., 2009). Autistic children and adults are often more accurate than neurotypical people at identifying, remembering, and categorizing simple tones based on their pitch (Bonnel et al., 2003, 2010;

Eigsti & Fein, 2013; Heaton et al., 1998; Heaton, Allen, et al., 2008; Heaton, Williams et al., 2008; Jones et al., 2009; O'Riordan & Passetti, 2006). Autistic children are also significantly better than their neurotypical peers at recalling and labelling pre-exposed pitches that are presented in isolation (Heaton, 2003), disembedding individual pitch tones from chords (Altgassen et al., 2005) as well as classifying pitch contour, perceiving pitch direction, discriminating pitches, and holding pitches in long-term memory in the context of melodies (Heaton, 2005; Jiang et al., 2015; Mottron et al., 2000; Stanutz et al., 2014). A high incidence rate of absolute (or perfect) pitch abilities is also frequently reported (see Ramani et al., 2021 for a review), with one study showing exceptional and instantaneous pitch-matching skills on a piano in 37 of 38 autistic participants (Kupferstein & Walsh, 2016). Average rather than enhanced musical skills are reported in other studies. For example, children on the autism spectrum are just as proficient as their neurotypical peers at remembering pitch and melodies (Heaton et al., 1998; Depape et al., 2012), perceiving harmony (Depape et al., 2012), processing local and global information in melodies (Foster et al., 2016; Germain et al., 2019), and producing and replicating musical melodies (Heaton, 2005; Quintin et al., 2013; Stanutz et al., 2014), even when controlling for musical training. In light of the musical interests and skills of many autistic children, shared musical activities offer a unique opportunity for children to discover each other's strengths and interests, which may highlight for participants in musical activities that autism is a condition that comes with areas of strength.

Music as a Highly Structured and Predictable Activity Modality

Music contains highly salient and predictable structures that may serve as excellent non-verbal frameworks for learning new skills and connecting with others. *Rhythm* is foundational for music processing and appreciation because it organizes the flow of other musical structures in time (Thaut et al., 1999; Trainor & Corrigall, 2010). While many musical genres consist of compositions with little or no variation in pitch, only some musical styles have musical pieces with no temporal framework (Trainor & Corrigall, 2010). *Rhythm perception* is the ability to perceive "the pattern of time intervals in a stimulus sequence" (Grahn, 2012, p. 586), where intervals are defined by the start and end of sounded events (e.g., musical notes) (Hannon et al., 2018). Apart from some musical styles (e.g., Georgian chant), rhythm in music is built on a salient *beat* or pulse that is readily felt (and sometimes physically heard) at periodic intervals (Grahn, 2012; McAuley et al., 2010) as observed by people nodding their head, tapping their finger, and dancing in synchrony with the beat of the music (Carlson et al., 2018; Repp & Su, 2013). *Beat perception* refers to the ability to perceive the music's primary, most salient beat (Grahn, 2012) and is the musical skill examined in Manuscripts 2 and 3. The primary beat of music is at one hierarchical level of the *meter,* another temporal regularity that contributes to a musical rhythm. *Meter perception* is the ability to hear other hierarchical time scales that multiply or subdivide the period of the beat to create periodic patterns of stronger and weaker accents (McAuley et al., 2010), such as the duple meter heard in a march (i.e., ONE two ONE two; e.g., Darth Vader theme song in Star Wars), the triple meter heard in waltzes (i.e., ONE two three, ONE two three; e.g., Waltz No. 2 by Dmitri Shostakovich), and the quadruple meter most commonly heard in pop music (i.e., ONE two three four ONE two three four; with three often more emphasized but weaker than ONE; e.g., Let It Be by The Beatles).

The Role of Rhythm and Beat in Development

Rhythm and beat processing begin to develop early in life (Cirelli et al., 2016; Suppanen, 2019; Winkler et al., 2009) and are thought to be biologically supported by neural oscillators that entrain attention to salient moments in sensory signals, enabling children to make predictions about when events will occur (i.e., predictive timing) and what events will happen next (i.e., predictive coding) (Friston, 2005; Large & Jones, 1999). Based on the Dynamic Attending Theory, predictive timing and coding facilitate the processing of important sensory information, which increase children's ability to attend and respond to the world around them (Jones, 1976; Large & Jones, 1999). Therefore, rhythm and beat sensitivity are vital for music perception (and production) and fundamentally linked to positive developmental outcomes.

Socialization, language, and body movements are built on rhythmic patterns that are less regular and salient than in music, yet are nonetheless predictable (e.g., Beier & Ferreira, 2018). Caregivers expose children to non-musical rhythms early in development when they pat, rock, and bounce their child to co-regulate and share enjoyment (see de Reus et al., 2021 for a review). Neurotypical children quickly become attuned to more complex rhythms that guide the coordination of verbal and nonverbal (e.g., eye contact, facial expressions, and motor movement) behaviours during conversations and interactive play (Daniel et al., 2022; Lense & Camarata, 2020). Rhythm in language further improves turn-taking in conversations and communication between children by accentuating articulation, phonological sequencing, and emotional prosody (Fiveash et al., 2021; Patel, 2011; Tierney & Kraus, 2014). Rhythm and beat perception and production skills are positively correlated with literacy skills, including phonological awareness and reading accuracy (e.g., Anvari et al., 2002; Lee et al., 2020; Politimou et al., 2019; Sun et al., 2022) among kindergarteners (Ozernov-Palchik et al., 2018), school-aged children (Bonacina et al., 2019) and adolescents (Tierney & Kraus, 2014).

In addition, rhythm and timing vulnerabilities co-occur with several neurodevelopmental disorders (Lense et al., 2021; Hande & Hegde, 2021). Creators of the Atypical Rhythm Risk Hypothesis propose that children with atypical rhythm processing skills may be more likely to develop speech or language disorders (Ladányi et al., 2020). Bégel et al. (2022) found that children with (versus without) dyslexia showed reduced beat perception and precision in tapping to the beat even after controlling for cognitive and motor functioning, which is consistent with the findings of earlier studies showing a positive link between rhythm and reading-related weaknesses among children with dyslexia (e.g., Colling et al., 2017; Flaugnacco et al., 2014; Goswami et al., 2013; Huss et al., 2011; Thomson & Goswami, 2008). Atypical processing of rhythm and beat are also thought to be implicated in attention deficit hyperactivity disorder (Puyjarinet et al., 2017) and movement disorders such as developmental coordination disorder in children (Puyjarinet et al., 2017; Rosenblum & Regev, 2013; Trainor et al., 2018) and Parkinson's disease in adults (Hsu et al., 2022; Puyjarinet et al., 2019).

Interactive musical activities built on a salient beat support the development of non-musical areas of functioning in many different ways by, for example, modulating attention to important sensory signals in the environment, scaffolding the timing of behaviours, and driving cortical plasticity.

The Musical Beat Entrains Attention

Sharing the musical beat with others, wherein people create music together by singing or playing musical instruments (i.e., music-making), *facilitates attentional entrainment cross-modally* (Lense & Camarata, 2020). When adults sing nursery songs, such as Twinkle Twinkle Little Star, neurotypical infants are observed to modulate their gaze to the eyes of adults around the musical beat (Lense et al., 2022), demonstrating that the musical beat increases the detection of social visual behaviours that take place at rhythmically predicted times (Daniel et al., 2022; Fiveash et al., 2021; Lense & Camarata, 2020). Because adult singers unconsciously synchronize their facial expressions with the beat of the music, increased attention to their eyes conveys multiple co-occurring social and linguistic cues to children, which supports their sensitivity to the different layers of social communication (Lense & Camarata, 2020; Lense et al., 2022). The musical beat also enhances the detection of linguistic events in oral and written language, such as grammatical markings and word segmentation (Fiveash et al., 2021; Tierney & Kraus, 2014). Indeed, children with and without speech and language difficulties show improvements in performance on various language-based tasks after musical rhythm priming (e.g., Canette et al., 2019) or rhythm-based music training (e.g., Flaugnacco et al., 2015; Moritz et al., 2013; Vidal et al., 2020).

The Musical Beat Scaffolds the Timing of Behaviours

Beat-based musical experiences *support intrapersonal and interpersonal coordination* (Daniel et al., 2022; Lense & Camarata, 2020). Auditory/musical rhythmic cueing, wherein systematic adjustments are made to the tempo of the beat of the metronome/music, scaffolds the timing of whole body and oral motor movements for remediating gross motor and speech difficulties (Dalla Bella, 2018; Devlin et al., 2019; Janzen et al., 2022). Actively engaging with the musical beat during music production further facilitates children's connection with their body rhythm as well as their connection with other children because music-making requires the integration of many different pieces of sensory information (e.g., visual, auditory, somatosensory) that are important for self-regulation and socializing (Bharathi et al., 2019; Williams, 2018; Zimmerman & Lahav, 2012). Music-making also provides a natural, transactional context where children use the beat of the music to time their initiations and responses to produce a rewarding flow of musical exchange (e.g., the back-and-forth exchange of musical phrases played on a drum) (LaGasse, 2017). The experience of interpersonal synchrony during musical activities is associated with enhanced prosociality (Wan & Zhu, 2021b).

Neurotypical children show more helpfulness and cooperation when they move synchronously (versus asynchronously) with others (Cirelli et al., 2014; Reddish et al., 2013; Kirschner & Tomasello, 2009; Wan & Zhu, 2021a) and demonstrate improvements in sharing, emotional sensitivity, and teamwork following musical play (Hallam, 2010; Rabinowitch et al., 2013; Wan & Zhu, 2021b). Since musical communication mimics the exchanges during social interactions, it allows children to easily transfer their rhythmic coordination skills to non-musical contexts (Hallam, 2010; Lense & Camarata, 2020; Pellitteri, 2000).

Engaging with the Musical Beat Drives Cortical Plasticity

Learning to play a musical instrument is a multisensory experience that activates the whole brain, *supporting brain plasticity* (Hyde et al., 2009; Peretz & Zatore, 2005). Short-term musical training in early childhood is associated with a larger anterior corpus callosum area (Schlaug et al., 2009) as well as enlargement of auditory and motor areas (Hyde et al., 2009), which increase the sensorimotor coupling in the developing brain (Fiveash et al., 2021). Participation in music enrichment programs is linked to the enlargement of brain areas implicated in music and language (Hyde et al., 2009) and enhanced neural encoding of speech (Carpentier et al., 2016; Kraus et al., 2014; Kraus & Strait, 2015). Olszewska et al. (2021) show that musical training shapes the brain more globally by increasing grey matter volume in structures located in the frontal (e.g., inferior frontal gyrus), occipital (e.g., lingual gyrus), parietal (e.g., supramarginal gyrus), and temporal lobes (e.g., superior temporal gyrus, basal ganglia, limbic system) that are necessary for visual-spatial processing, social cognition, emotion regulation, and motor learning. The involvement of the whole brain during beat-based musical experiences may also explain why children show enhanced cognitive abilities in areas like executive functioning following musical training (e.g., Chen, Scheller et al., 2022; Degé et al., 2022; Frischen et al., 2021; Guo et al., 2018; Habibi et al., 2018; James et al., 2020; Jaschke et al., 2018; Moreno et al., 2011), particularly when beat perception and production skills (versus pitch processing) are explicitly targeted (Frischen et al., 2019). Overall, sharing the musical beat with others may help facilitate social learning objectives in inclusive settings as well as target language, motor, and cognitive differences that often co-occur with autism (Christensen et al., 2018; Kangarani-Farahani et al., 2023; Zeidan et al., 2022).

Effects of Beat-Based Music Interventions for Autistic Children

The musical beat's ability to modulate attention, scaffold the timing of behaviours, and drive cortical plasticity may support non-musical areas of functioning for children on the autism spectrum. The incidental benefits of rhythmic aspects of musical activities are explored in several studies. Playing with music yields superior improvements in observable social behaviours, including eye contact, joint attention, and turn-taking, as well as social overtures and responses, compared to non-musical interventions (Finnigan & Starr, 2010; Kim et al., 2008; LaGasse, 2014; Srinivasan et al., 2016; see however Bieleninik et al., 2017). Musical engagement strengthens social relations with other autistic children (Willemin et al., 2018), non-autistic children (Kern & Albridge, 2006), and caregivers (Thompson et al., 2014). A technology called Biomusic (transforming physiological signals, such as heart rate and skin conductance, into a beat-based melody as a method of biofeedback) is found to increase emotional awareness (Cheung et al., 2016), and simply listening to beat-based music as a group may target reduced interoception skills and alexithymia (i.e., difficulty labelling emotional experiences with words) among autistic people (Pedregal & Heaton, 2021).

The impact of music on the verbal communication, sensorimotor, and cognitive abilities of children on the autism spectrum is also documented in a few empirical investigations. In two randomized controlled trials, autistic children who participated in Auditory-Motor-Mapping-Training, which involved tapping on a drum while singing, developed better consonant and vowel speech production skills than children involved in non-musical speech therapy (Chenausky et al., 2016; Chenausky et al., 2017). Another study found that parent-reported improvements in communication skills following an interactive music program involving rhythmic cueing, playing instruments, and singing correlated with increased auditory-motor brain connectivity (Sharda et al., 2018). In addition, rhythmic musical cueing is shown to improve gross motor movements, including balance, bilateral coordination and other gait parameters (Shemy & El-Sayed, 2018), and drum playing is found to facilitate impulse control, interpersonal movement synchrony (Srinivasan et al., 2015; Yoo & Kim, 2018) as well as the attention, concentration, and working memory of autistic children (Fauziah et al., 2022).

Despite a growing body of research showing the multisystem effects of musical activities, very little is known about the rhythmic musical abilities of autistic children. Is the beat of music even perceptually accessible to autistic children so that it can be leveraged to learn new skills and connect with others? An answer to this question would directly elucidate the mechanism of change underlying shared musical activities and encourage the implementation of musical frameworks like *Press-Play* (Lense & Camarata, 2020) and *Rhythm Relating* (Daniel et al., 2022) that intentionally recruit rhythm supports to extract the therapeutic potential of music fully.

Musical Rhythm and Beat Perception Skills of Autistic Children

In comparison to the large body of work suggesting well-developed pitch, melodic, and music-evoked emotion processing skills of children on the autism spectrum (see Heaton, 2009 for a review), the ability of autistic children to perceive musical rhythm and its underlying beat has been examined in very few studies using same-different rhythm discrimination tasks. On the rhythm subtest of the Montreal Battery for the Evaluation of Musical Abilities (MBEMA) (Peretz et al., 2013), school-aged autistic children were found to be just as proficient as their same-aged neurotypical peers at identifying whether two successively presented beat-based musical sequences were the same or different (Jamey et al., 2019; Sota et al., 2018). One other available study also found that autistic and neurotypical adolescents with proficient cognitive abilities (full scale > 70) did not differ in their ability to make same-different judgments of rhythmic groupings, though the autistic group showed reduced specialization in categorizing simple meters underlying Western music over complex meters (DePape et al., 2012).

Fiveash et al. (2022) indicate that same-different rhythm task paradigms do not directly assess rhythmic competencies concerning beat-based perception because they draw on non-rhythmic skills, including short-term memory, to successfully make judgments (and are even referred to as sequence memory-based tests) and do not always manipulate beat and meter (e.g., Jamey et al., 2019; Sota et al., 2018). Performance on same-different rhythm discrimination tasks is not significantly correlated with performance on musical beat-based perception (e.g., judging alignments between a metronome and musical beat) and beat-based production (e.g., tapping to the musical beat) tasks among neurotypical children (Bonacina et al., 2019) and adults (Fiveash et al., 2022; Tierney & Kraus, 2015). When it is challenging to use beat production tasks due to the presence of gross motor difficulties, as with young children (Drake, 1993; McAuley et al., 2006) and with many people on the autism spectrum (e.g., Kangarani-Farahani et al., 2023), Fiveash et al., (2022) recommend using a Beat Alignment Test (BAT) (Iversen & Patel, 2008) because it “appears the most sensitive perceptual test to capture variance related to both synchronization and tapping ability” (p. 1387).

On the beat perception subtest of the BAT (Iversen & Patel, 2008), adult listeners are asked to judge whether beeps superimposed on musical excerpts with simple meter (i.e., 3/4 or 4/4 metric signatures) are correctly aligned with the musical beat or not. Overlaid beeps that do not align with the musical beat have either a tempo error (too slow or too fast by 10% or 25%) or a phase error (onset occurs too early or too late). Among musically novice adults, Iversen and Patel (2008) found that adults were excellent at identifying when click tracks fit with the musical beat with their overall performance positively correlating with their motor synchronization skills (Iversen & Patel, 2008), a relationship that has been replicated in other studies using multiple tapping measures (Dalla Bella et al., 2017; Fiveash et al., 2022). The beat perception task of the BAT has been successfully adapted for use with children. Einarson and Trainor (2015, 2016) show that neurotypical children as young as five years old with no formal musical training perform above the theoretical chance level of 50% when selecting which of two successfully played video-recorded hand puppets are drumming in accordance with the musical beat. Children aged 5 to 17 are also shown to perceive alignments between a metronome and the musical beat without visual cues on a similar task (Nave-Blodgett et al., 2021).

Predictors of Musical Beat Perception

Musical beat perception may vary due to specific individual characteristics, including age and specific cognitive abilities. Beat sensitivity increases well into adolescence for neurotypical children (Peretz et al., 2013; Nave-Blodgett et al., 2021; Nave et al., 2022; Sun et al., 2022). This may also be the case for children on the autism spectrum, considering limited research showing positive associations between age and performance scores on rhythm discrimination and beat production tasks (Jamey et al., 2019; Tryfon et al., 2017).

A distinct discrepancy in cognitive functioning is common among autistic children, with the nonverbal cognitive domain (i.e., non-verbal reasoning abilities) often better developed than the verbal cognitive domain (i.e., verbal reasoning abilities), especially for younger autistic males (Ankenman et al., 2014). Based on the Enhanced Perceptual Functioning model of autism, well-developed nonverbal cognitive abilities may give children on the autism spectrum an advantage when processing fundamental properties of non-verbal auditory stimuli like music (Mottron et al., 2000; Mottron et al., 2006). Indeed, nonverbal cognitive abilities, more so than verbal cognitive/language abilities, are found to affect the processing of musical structures like pitch, melody, and rhythm for autistic children (e.g., Chowdhury et al., 2017; Jamey et al., 2019; Quintin et al., 2013). Another cognitive ability that may impact musical beat perception is auditory working memory (i.e., the ability to hold and manipulate auditory information in the mind). Rhythm perception (e.g., Anvari et al., 2002; Hansen et al., 2012; Strait et al., 2011; see, however, Lee et al., 2020), rhythm reproduction (Flaugnacco et al., 2014), beat perception (Matthews et al., 2016), and beat synchronization (Bailey & Pehune, 2010, 2012) among neurotypical people are associated with performance scores on span tasks that measure auditory working memory (e.g., Digit Span) (Wechsler, 2014) or with the activation of core brain regions implicated in auditory working memory, including the striatum of the basal ganglia (Grahn, 2009; Teki et al., 2011, 2012, 2016). The link between rhythmic musical skills and auditory working memory may also extend to children on the autism spectrum in light of two studies showing that auditory working memory is positively associated with general musical structure processing (Quintin et al., 2013; Sota et al., 2018).

In addition, music perception may be a unique skill that is spared across the autism spectrum based on the limited research available (Jamey et al., 2019). The degree of autistic characteristics appears unrelated to rhythm processing at the behavioural (Jamey et al., 2019) and neural levels (Knight et al., 2020) and to other music perception skills, including melodic and pitch perception (Jamey et al., 2019), except for the findings of a few studies showing that pitch processing may be inversely related to autistic traits among autistic adults (Mayer et al., 2016) or within the general population (Stewart et al., 2018).

Taken together, while the potential effect of age, cognitive abilities (i.e., nonverbal and verbal cognitive abilities and auditory working memory), and autistic characteristics on rhythm perception or general music perception of autistic children have been explored (e.g., Tryfon et al., 2017; Jamey et al., 2019; Quintin et al., 2013; Sota et al., 2018), the unique contribution of these characteristics on their musical beat perception skills within the context of a beat alignment task paradigm remains to be investigated to understand better the developmental trajectory of musical beat sensitivity and increase the generalizability of findings to autistic children with diverse characteristics.

Objectives and Hypotheses of Manuscripts 2 and 3

Manuscripts 2 and 3 were designed to elucidate the musical beat perception skills of autistic children within the context of a beat alignment task paradigm to characterize their musical profiles better and inform on the ecological validity of leveraging the musical beat during shared musical activities as a strength-based approach for supporting autistic children and their peers in inclusive learning environments.

In Manuscript 2 (Dahary et al., 2023), I directly compared the musical beat perception skills of 23 autistic and neurotypical children matched in chronological and verbal and nonverbal mental ages using an adapted version of the beat perception subtest of the BAT (Iversen & Patel, 2008). In keeping with the findings of previous studies showing intact musical rhythm perception

(Jamey et al., 2019; Sota et al., 2018) and beat production of autistic children (Tryfon et al., 2017), as well as well-developed overall music processing (Heaton, 2009), I predicted that autistic and neurotypical groups would correctly judge when beeps overlaid on musical excerpts were aligned or misaligned with the musical beat more often than would be expected by chance and that task performance would be similar between groups.

In Manuscript 3, I build on the findings in Manuscript 2 by examining the musical beat perception skills of a larger group of autistic children who vary in age, cognitive ability, and degree of autistic characteristics to extend the applicability of findings to children across the autism spectrum. First, I assessed chance performance on the musical beat perception task among an autistic group that included all 23 autistic children in Manuscript 2 and 30 new participants ($N = 53$). I predicted that the autistic group would perform above what would be expected by chance on the same beat perception task used in Manuscript 2. Second, I explored the unique contribution of age, cognitive abilities, and degree of autistic characteristics on musical beat perception. In accordance with the results of previous studies investigating musical rhythm (or beat) perception skills of autistic and neurotypical children (e.g., DePape et al., 2012; Jamey et al., 2019; Quintin et al., 2013; Sota et al., 2018; Tryfon et al., 2017), I predicted that age, nonverbal cognitive ability, and auditory working memory but not necessarily verbal cognitive ability and level of autistic characteristics would uniquely predict the musical beat perception skills of autistic children on the beat perception task.

Chapter 3: Manuscript 1

This chapter is an exact reproduction of the following article published in the *Review Journal of Autism and Developmental Disorders*.

A systematic review of shared social activities for children on the autism spectrum and their peers

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Abstract

This review synthesized the results of 15 studies (with 12 studies having strong or adequate methodological rigor) that examined the social outcomes of shared social activity-based interventions, like interest-based games, music, and theatre, involving children on the autism spectrum and typical development together. Thirteen studies yielded significant improvements in social cognition, social communication, and/or social functioning with two studies also reporting an increase in positive affect between autistic children and their peers. Overall, shared social activities that promote a sense of equality, are enjoyable, and build on the natural talents of children on the autism spectrum appear promising for increasing social learning within inclusive environments.

Keywords: autism spectrum, children, intervention, social behaviour, inclusive environments

Introduction

Many children on the autism spectrum[4] demonstrate a pervasive impairment in the areas of social cognition and social communication (American Psychiatric Association [APA], 2013), which negatively impacts their overall social functioning (Bauminger & Kasari, 2000). *Social cognition* refers to cognitive skills needed for accurately interpreting social cues, such as theory of mind and face processing skills; *social communication* refers to behavioural skills that emerge following successful social cognition processing, such as social initiations and responses, social engagement; and *social functioning* reflects the overall quality of social behaviour executed across everyday domains such as interpersonal relationships (Yager & Ehmann, 2006). Poor social cognition or communication skills can lead to negative outcomes related to social functioning such as a lack of peer support and acceptance, fewer consistent friendships, and social isolation (Symes & Humphrey, 2010). As the complexity of social cue increase and evolve over the lifespan, social challenges experienced by autistic people may become more pronounced with age and are inversely related to educational and employment success and overall quality of life (Nasamran et al., 2017; Tobin et al., 2014).

A variety of evidence-based interventions have been developed in an effort to improve the social functioning of children on the autism spectrum. Evidence-based practices are defined as having obtained sufficient empirical evidence from methodologically sound studies conducted by at least two separate research groups from different parts of the world (Reichow et al., 2008) and can be broadly classified as comprehensive treatment models or focused interventions (Odom, Boyd et al., 2010; Odom, Collet-Klingenberg et al., 2010). Comprehensive treatment models aim to provide general support for learning and development and include, for example,

[4] "Autism spectrum" and "autistic" will be used interchangeably in this paper to reflect preferred language of many members of the autism community (Canadian Autism Spectrum Disorder Alliance [CASDA], 2020).

pivotal response treatment (Koegel & Koegel, 2006), the Lovaas, LEAP, and Denver models (Cohen et al., 2006; Rogers et al., 2006; Strain & Hoyson, 2000), and the TEACCH program (Panerai et al., 2002). In contrast, focused interventions utilize strategies that target a specific learning domain, skill, or goal, and often form core components of comprehensive treatment models (Odom, Boyd et al., 2010; Odom, Collet-Klingenberg et al., 2010). According to recent reviews by the National Standard Project (NSP) (National Autism Center [NAC], 2015) and the National Clearhouse on Autism Evidence and Practice (NCAEP) (National Professional Development Center on Autism Spectrum Disorders [NPDC], 2020), examples of evidence-based focused interventions include cognitive behavioural instructional strategies, self-management, social narratives, sensory integration, and social skills training. The aim of the current systematic review is to understand the efficacy of focused intervention practices that use shared social activities like music, Lego, or interest-based clubs within inclusive environments for facilitating social learning for autistic children and their typically developing (TD) peers.

With the rise in the number of autistic children in inclusive settings such as daycares, schools, and summer camps, greater emphasis is being placed on improving social exchanges with TD peers. TD children are more likely to form meaningful social relationships with other children who are in close proximity to them, such as attending the same classroom (i.e., propinquity), and who share similar characteristics, such as being the same age and having common interests (i.e., homophily) (Berndt, 2002; Male, 2007; McPherson et al., 2001). For children on the autism spectrum, however, proximity and commonalities alone have led to limited improvements in friendship (Kasari et al., 2011) and the tendency for autistic children to remain at the periphery of social networks in mainstream classrooms (Rotheram-Fuller et al., 2010), potentially indicating that the process for developing friendships is different for autistic children and one that requires more environmental supports. Involving TD children in interventions for autistic children is a common feature of evidence-based methods that aim to provide support to autistic children within inclusive environments (NPDC, 2020). These methods typically involve peer- or adult-mediation. In peer-mediated interventions, peers are trained to provide social skills training to autistic children via prompting, modeling, and/or reinforcement, and in adult-mediated interventions, an adult organizes the environment and delivers coaching, prompts, and reinforcement to both autistic children and their peers (NPDC, 2020). The recent NCAEP review documents 44 methodologically sound studies published between 1990 and 2017 that utilized peer-based instruction and interventions and found improvements related to social, communication, and school readiness or academic skills for children aged 3 to 18 years (i.e., preschool to highschool) as well as decreases in challenging behaviours for children aged 6 to 11 years and increases in cognitive skills and mental health outcomes for children aged 6 to 14 years (NPDC, 2020). Similarly, systematic reviews addressing interventions in inclusive settings for autistic children with low to high support needs have found that peer-mediated interventions produced mostly large effects related to social communication gains, such as initiations, responses, interactions, and peer engagement (Watkins, Ledbetter-Cho, et al., 2019), with positive generalization, maintenance, and social validity (Gunning et al., 2018; Watkins et al., 2015; Watkins, Ledbetter-Cho, et al., 2019).

In addition to peer or adult-mediated interventions within inclusive settings, there is growing evidence for the use of social activities, such as music, art, games, and robotics, to naturally cultivate positive social interactions and new friendships between children on the autism spectrum and their peers (L.K. Koegel, Matos-Freden., et al., 2012). A common component of many evidence-based naturalistic interventions is the incorporation of structure and children's interests into daily activities or routines to promote learning and to reinforce interactions that are fitting to the social context (NPDC, 2020). Structure is one of the most important characteristics of social activities when social learning is the outcome goal (DeKlyen & Odom, 1989). Autistic children tend to engage more with their peers in structured, organized, and predictable activities that have clear behavioural expectations than during unstructured (free play) contexts (Gunn et al., 2014). Social activities that are not inherently or sufficiently structured can be made to be more structured through strategies such as setting up cooperative arrangements wherein activity-related materials are dispersed in a way that promotes cooperative interdependence among participating children (R. L. Koegel et al., 2005). In addition to structure, social activities that are fun and enjoyable for all the children are likely to produce favourable outcomes given that socialization tends to increase when children are engaged in activities of interest or preference (R. L. Koegel et al., 1987). For example, there is growing evidence that many children on the autism spectrum have an interest and talent for music, robotics, and model building, which can be leveraged in group settings to increase interactions with other autistic children (LaGasse, 2014; LeGoff, 2004; Wainer et al., 2010). Music-mediated interventions and exercise and movement activities (e.g., creative dance, aquatics, martial arts, and yoga) that do not necessarily involve the participation of TD children also produce improvements within the motor and social domains and are considered evidence-based practices (and emerging interventions as per the NSP review; NAC, 2015) for autistic children across different periods of development (i.e., preschool through middle or high school) (NPDC, 2020). Among older children, circumscribed interests are another common characteristic of autism spectrum that involve highly intense focus on ordinary topics or hobbies, which limits a child's range of social participation and leisure activities (APA, 2013). From a strengths-based perspective, circumscribed interests can be leveraged to bring about social change by using them as the theme of socially appropriate games such as developing a movie trivia club for an autistic individual in high school who has a keen interest in movies (R. L. Koegel et al., 2012; R. L. Koegel & Koegel, 2006).

Shared social activities are unique in their ability to emphasize commonalities (e.g., interests, activity-related goals) between children as opposed to differences, which may nurture social acceptance and meaningful social relationships in inclusive settings (R.L. Koegel et al., 2012). Furthermore, many structured and reinforcing properties of shared social activities may be sufficient for supporting social development and may not always necessitate direct social coaching by peers or adults. Thus, potentially allowing autistic children and their peers to engage in activities in a similar manner and share common goals. Social activities that encourage the equal participation of all the children and that do not require the assignment of hierarchical roles, such as roles assigned in peer-mediated interventions (i.e., the peer being the “leader” and the autistic child being the “follower”), may generate a sense of equality between the children, which may further facilitate the development of authentic friendships in the inclusive setting (Therrien & Light, 2016). Pragmatically, social activities may be easily modified to accommodate children of different ages and support needs, which is highly relevant for educational and other settings that service children with diverse characteristics. For example, structured interest-based play activities have been shown to be appropriate for preschool-aged children with limited verbal communication skills (Watkins, O’Reilly et al., 2019) as well as for proficient autistic speakers in elementary school and high school (L. K. Koegel, Vernon, et al., 2012; R. L. Koegel et al., 2013). There is also evidence that engaging in shared social activities with autistic children may expand interpersonal skills of TD children (Cook et al., 2019) and children with other exceptionalities (Shih et al., 2014).

The purpose of the current systematic review is to evaluate the use of shared social activities for supporting the social development of children on the autism spectrum and their peers to inform future research and inclusive educational and clinical practices. For each study included in the review, the following questions were addressed related to the shared social activity intervention: 1) Does this intervention improve social outcomes (i.e., social cognition, social communication, social functioning) for autistic and TD children? 2) Is this intervention appropriate for autistic children of different ages and support needs? 3) Do autistic and TD children participate equally in this intervention? and 4) Is there sufficient evidence for the social validity of this intervention?

Methods

Systematic Search Procedures

A search was conducted on April 16, 2021 following The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines on Education Resources Information Center (ERIC), Web of Science, PsycINFO, and Medline databases (Moher et al., 2009). A combination of terms was used within the database searches that addressed the following themes: autism, social behaviour, intervention, and inclusive environment. For example, in ERIC and Web of Science, the search strategy was as follows: 1) Autis* OR Asperger* OR ASD OR "pervasive developmental disorder*", 2) "social skill*" OR "social abilit*" OR "social behavio*r*" OR "social communicat*" OR "social function*" OR "social cognit*" OR "social interact*" OR "social inclus*" OR "peer relation*" OR friendship*, 3) intervention* OR treatment* OR program*, and 4) inclus* N5 ("summer camp*" OR setting*

OR centre* OR center* OR school* OR educ* OR program* OR activit*) OR "general educ*" OR "mainstream educ*". The following restrictions were added to limit the scope of our search results: English language peer-reviewed studies (across all four databases), studies involving humans (Medline and PsychInfo), and studies involving children (Medline). A review of the reference section of studies that were identified as meeting the inclusion criteria supplemented the electronic searches to ensure relevant articles were not missed.

Inclusion and Exclusion Criteria

Empirical articles included in the current review must have described the use of a shared social activity for children on the autism spectrum and their TD peers. Activity-based interventions were operationally defined herein as structured recreational (i.e., leisure) games or activities that created opportunities for social interaction. Free play and academic- or work-related activity-based interventions were excluded. Studies that used both a shared social activity and other strategies to support interactions were considered when this support was provided within the context of the activity (e.g., peer-mediation embedded within a music intervention). However, studies were excluded if the shared social activity was not the independent variable being manipulated in the study and instead used as the context for assessing the effectiveness of support strategies within that activity (e.g., manipulating the level of peer support provided during an aquatic activity to assess the effectiveness of peer-mediation strategies within that context; Chu & Pan, 2012). Similarly, multi-step intervention packages involving a shared social activity component were excluded if intervention outcomes unique to the activity were not extracted for analysis.

In addition, articles were required to meet several other pre-determined inclusion criteria. Studies had to be published in a peer-reviewed journal in English, target children below 18 years of age, and include children diagnosed with autism spectrum condition and TD children together in a shared social activity intervention (as defined above). Studies with children with other disabilities were retained when data for autistic children were analyzed separately (e.g., Vincent et al., 2018), and studies with peers that had other disabilities or were siblings of the children on the autism spectrum were considered if TD nonfamilial children were also included (e.g., Kern & Albridge, 2006). Further, studies had to assess changes within the social domain for autistic children using outcome variables that targeted various social behaviours. Social behaviours were later grouped into three types of targeted social behaviours to facilitate interpretation: social cognition, such as theory of mind and face processing skills, social communication, such as social initiation and social response skills, and social functioning, such as social network, friendships, and overall social quality of life. Data related to peers were examined where available. Lastly, studies had to employ a group or single-subject design with true experimental control to test the effectiveness of the activity-based intervention on social behaviour. That is, the inclusion of a control or comparison group for group designs and repeated and frequent assessments of the dependent variables in the presence and absence of the intervention for single-subject designs (Reichow et al., 2008).

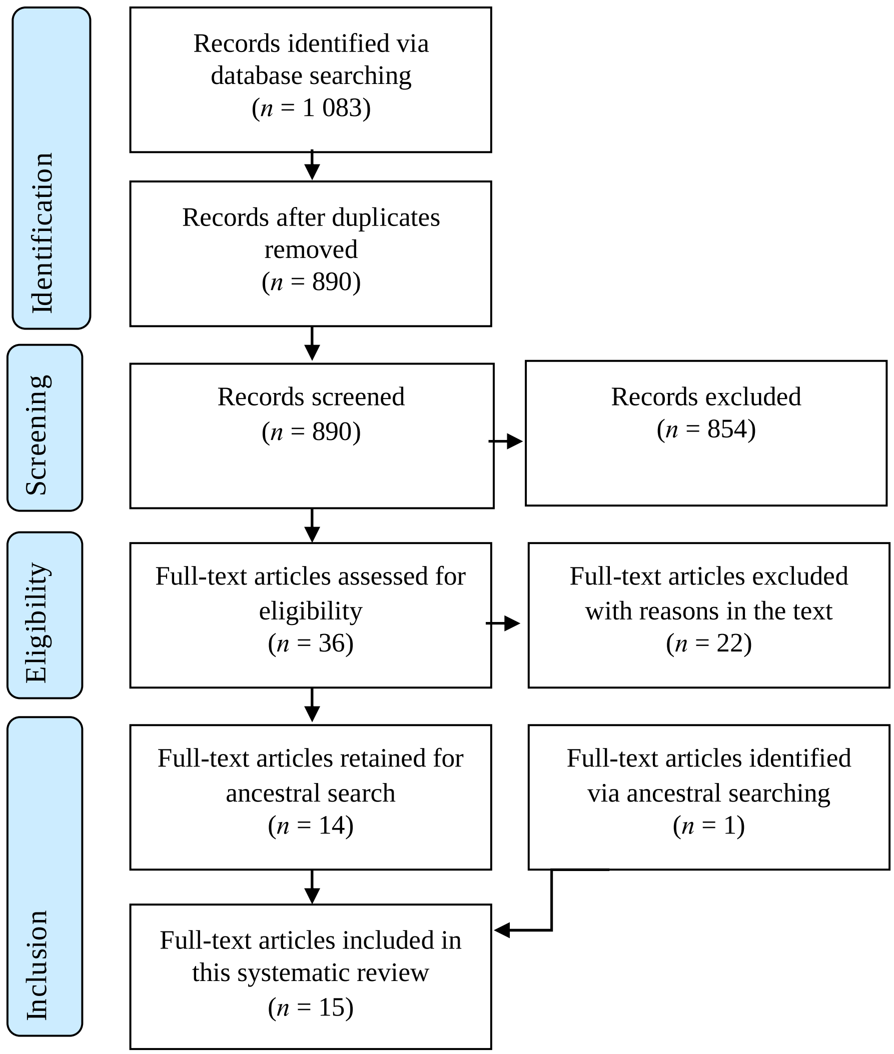
Review Process

The search process in this systematic review is outlined in Figure 1. Initially, the electronic searches yielded 1 083 articles. Once the duplicates were removed, the titles and abstracts of 890 articles were evaluated against the inclusion criteria. A total of 854 articles were eliminated at this stage because they were book chapters, editorial papers, theses, reviews, examined non-humans (i.e., animals), targeted adults or children with conditions other than autism spectrum, omitted TD peers, or did not assess the effects of a shared social activity. Of the remaining 36 full texts assessed for eligibility, nine studies either did not meet the operational definition of the interventions focused herein or did not assign it as the independent variable to directly assess its effectiveness (e.g., Chu & Pan, 2012; Crowell et al., 2020), eight studies did not include TD peers (e.g., LeGoff, 2004; MacCormack et al., 2015; Lerner et al., 2012), and five studies did not utilize a true experimental design (e.g., Chiang et al., 2004; Corbett et al., 2014; Kaboski et al., 2015). An additional article was found following a review of the reference sections of the 14 identified studies, resulting in a total of 15 studies included in this review.

Interrater Reliability. The first and second authors independently completed the searches across the four databases, removed duplicates, and evaluated the titles and abstracts of the resulting articles against the inclusion criteria. Interrater reliability was calculated by dividing the number of articles identified by both the first and second authors (i.e., the number of agreements) by the total number of unique articles identified for inclusion across the raters, which resulted in an agreement of 88% for the eligibility of 36 articles for inclusion. The first and second authors then independently evaluated the full texts of these 36 articles against the inclusion criteria, which resulted in an agreement of 100% for the inclusion of 14 articles. Following this, the third author independently reviewed the reference section of the 14 articles and found one additional article that met the inclusion criteria. The first and second authors agreed to include this additional article, for a total of 15. Overall, the inclusion of 15 studies in the current systematic review was confirmed with high interrater reliability across the stages of the search process.

Figure 1

Flowchart of Included Studies in the Current Systematic Review



Data Extraction

Each included study was summarized in terms of a) study design (i.e., type of experimental control), b) characteristics of children on the autism spectrum and TD peers, c) intervention characteristics, d) results for children on the autism spectrum and TD peers, and e) strength of research and evidence of social validity.

Characteristics of autistic children included the number, age (range or mean), gender, diagnosis and comorbidities, and support needs. Level of support required was based on the severity of autism spectrum symptomatology when results from diagnostic assessments were provided. If this data were not included but information on verbal language and/or cognitive skills was available, level of support needs was estimated based on an adapted version of the schema developed by Reichow and Volkmar (2010). Specifically, autistic children were categorized as having high support needs if they had limited-to-no verbal communication skills and/or an IQ below 55, medium support needs if they had rudimentary verbal communication skills and/or an IQ between 55 and 85, or low support needs if they had well developed verbal communication skills and/or an IQ above 85. Moreover, peers were described in terms of the number, age (range or mean), gender, type of peers (i.e., TD children only or a mix of TD children and children with disabilities other than autism), the selection process, and their similarity to autistic children.

Regarding intervention characteristics, the setting and duration (i.e., total number, length, and frequency) of sessions, activity descriptions, and type of peer and adult involvement were extracted. Peer involvement during the intervention was classified as "equal participation" when children on the autism spectrum and peers shared similar roles, or as "peer-mediation" when the peers were encouraged to lead activities and/or provide social skill instruction. Adult involvement was categorized as "activity-oriented" when the type of support was related to the activity such as introducing and clarifying questions about an activity and/or setting up cooperative arrangements. In contrast, adult involvement was categorized as "socially-oriented" when a social training strategy was used to facilitate social behaviours such as prompting social interactions or positively reinforcing appropriate social participation. Pre-intervention training associated with peer and adult involvement was indicated where applicable.

Furthermore, targeted behaviours, outcome measures, and results were described for autistic children and peers. A targeted social behaviour was categorized as *social functioning*, *social cognition*, or *social communication*, and a targeted non-social behaviour was categorized as *other*. Outcome measures associated with each targeted behaviour category were specified as well. For studies employing a single-subject design, results were evaluated using the trichotomous scale developed by Machalicek et al. (2008) and coded as *positive*, *mixed*, or *negative (or no change)*. A positive result indicated that all the children demonstrated an increase trend in the target behaviour following baseline. A mixed result signified that the target behaviour for one or more children increased following baseline, but the target behaviour of other children declined or remained unchanged. A negative (or no change) result meant that the target behaviour of all the children declined after baseline or remained unchanged. An adapted dichotomous version of this scale was created to describe results of studies employing a group design. A result was coded as positive if a significant increase in a targeted behaviour was found or coded as negative (or no change) if less of an improvement or no change in a targeted behaviour was found when compared to a waitlist comparison group or another type of intervention. Effect sizes were also reported where available. The data summarized for each study related to study design, participant and intervention characteristics, and results were extracted by the first author and independently verified by the second and third authors. Inconsistencies were discussed until an agreement of 100% was achieved.

The strength of research was evaluated using two rubrics developed by Reichow et al. (2008) for single-subject research and group research, respectively. The rubrics include a trichotomous scale (i.e., high, acceptable, or unacceptable quality) for assessing primary quality indicators, which are elements of a study that are considered essential for demonstrating validity (e.g., participant characteristics, independent and dependent variables, statistical or visual analysis), and a dichotomous scale (i.e., presence or absence) for assessing secondary quality indicators, which are elements of a study that add strength but are not considered necessary for establishing validity (e.g., generalization or maintenance, interobserver agreement, intervention fidelity, social validity). Rigor ratings of strong, adequate, or weak were assigned to each study based on results from the rubrics. A study rated as strong received high quality ratings on all primary indicators with no unacceptable quality ratings and showed evidence of at least three (single-subject research) or four (group research) secondary indicators. A study rated as adequate received high quality ratings on at least four primary indicators with no unacceptable quality ratings and showed evidence of at least two secondary indicators. A study rated as weak received high quality ratings on less than two primary indicators and showed evidence of less than two secondary indicators. The presence or absence of social validity measures was also coded as outlined by Reichow et al. (2008). Studies that demonstrated social validity included at least four of the following features: an intervention conducted in a natural context, socially relevant outcome variables, clinically significant changes in social behaviour, comparisons between autistic and TD children to establish a normative range of social behaviour, intervention agents from the children's natural context, time and cost intervention effectiveness, and participant satisfaction. The first and second authors independently evaluated the strength of research for all the articles included in this review and discrepancies were discussed until an agreement of 100% was obtained.

Results

Research design and participant and intervention characteristics for the studies reviewed are presented in Table 1. Of the 15 articles included in the current review, four employed a between-group design where participants were randomly allocated to the intervention condition and 11 were single-subject research studies that utilized a multiple baseline or probe experimental design.

Characteristics of Children on the Autism Spectrum

A total of 197 children on the autism spectrum received an activity-based intervention with as few as two children and as many as 80 children within a study. Of these children, 22% were female (n = 44) and 78% were male (n = 153). The age of children ranged from 3 to 16 years. All the children were diagnosed with ASD, autism, or pervasive developmental disorder not otherwise specified. None of the studies reported the presence of co-occurring diagnoses and only one study provided data regarding current medication use (Corbett et al., 2019). To ascertain the presence of autism spectrum, seven studies administered the Childhood Autism Rating Scale (Hu et al., 2018; Kern & Aldridge, 2006; Watkins, O'Reilly, et al., 2019), the Social Communication Questionnaire, and/or the Autism Diagnostic Observation Schedule (Corbett et al., 2016, 2019; Kasari et al., 2016; Levy & Dunsmuir, 2020), and eight studies did not confirm diagnoses of autism spectrum with a standardized instrument but instead used special education codes or class placements for autism spectrum, child observations, interviews with school staff and/or a review of the DSM criteria (Baker et al., 1998; Hu et al., 2021; R. L. Koegel et al., 2005; L. K. Koegel, Vernon, et al., 2012; R. L. Koegel et al., 2012; R. L. Koegel et al., 2013; Sansi et al., 2020; Vincent et al., 2018). Across most of the studies, autistic children were generally described as exhibiting social challenges such as self-isolation during free play, limited or poor interactions with peers, and few consistent friendships. Information pertaining to children's autism severity, cognitive and/or language skills were reported in 14 studies. As displayed in Table 1, six studies included only children who were categorized as low support needs (e.g., Corbett et al., 2016; Corbett et al., 2019; Sansi et al., 2020) and two studies included only children who were considered requiring medium support needs (Hu et al., 2021; R. L. Koegel et al., 2005). In the six studies remaining, three included children with medium and low support needs (e.g., Levy & Dunsmuir) and three included children with medium and high support needs (e.g., Watkins, O'Reilly, et al. 2019).

Characteristics of Peers

Over 400 peers participated alongside children on the autism spectrum in the activity-based interventions. Only four studies reported on the exact number, gender, and age of the peers (e.g., Hu et al., 2018; Hu et al., 2021). All the studies described peers as being *typically developing*, *without disabilities*, or *general education peers* with one study involving additional children with exceptionalities other than autism spectrum (Kern & Albridge, 2006). Studies did not report using standardized measures for characterizing participating peers such as cognitive functioning or confirming the absence of autism spectrum. Nine studies included criteria specifications related to the selection of peers such as good social communication skills, positive role model, compliant, regular school attendance, an interest in interacting with children on the autism spectrum, motivation to participate in the study (e.g., Hu et al., 2018; Kasari et al., 2016; Kern & Albridge, 2006; Watkins, O'Reilly et al. 2019), the absence of health problems, and not having previously participated in the intervention (Sansi et al., 2020). Six studies relied on the natural willingness of peers to join social activities and thus, did not systematically select them (e.g., Baker et al., 1998, R. L Koegel et al., 2012; Levy & Dunsmuir, 2020). In terms of similarity, all but two studies (Corbett et al., 2016; Corbett et al., 2019) included participating peers from the same school, class, or neighborhood as the autistic children. In addition, 10 studies specifically matched peers and autistic children by age, grade, gender, and/or common interests (*n* = 1, when possible) (e.g., Corbett et al., 2016; Hu et al., 2018; Hu et al., 2021; R. L Koegel et al. 2005; Levy & Dunsmuir, 2020).

Setting and Duration of Interventions

Interventions took place within an inclusive school (*n* = 12) or community (*n* = 3) setting. Studies conducted in a school took place within a non-academic environment including the play area of a classroom and/or the playground/courtyard (e.g., Vincent et al., 2018; Watkins, O'Reilly et al., 2019). Studies that took place within a community setting included a summer camp, an auditorium, or various indoor/outdoor activity settings such as a park, a bowling alley, and the beach (Corbett et al., 2016, Corbett et al., 2019; R. L Koegel et al., 2005). Total number of intervention sessions ranged from 3 to 160 sessions (i.e., about the duration of an academic year). The length and frequency of sessions were reported in 11 studies with sessions lasting from 10-min to 4 hours and occurring once to five times per week.

Type of Social Activity-Based Interventions

A common ingredient across most of the shared social activities in this review was the incorporation of interests of autistic children. Among eight studies, four used the circumscribed or preferred interests of each autistic child to form the theme of a socially appropriate club (Baker et al., 1998; L. K. Koegel, Vernon et al., 2012; R. L. Koegel et al., 2012; R. L. Koegel et al., 2013) and four selected pre-existing activities based on the shared interests of autistic children and their peers (Hu et al., 2021; Kasari et al., 2016; R. L. Koegel et al., 2005; Watkins, O'Reilly, et al., 2019). A hybrid of these methods was used in one study wherein autistic children and their peers selected an activity of their choosing from a range of options deemed interesting to the children and additional activities that complemented the circumscribed interests of autistic children were later created if participation was low (Vincent et al. 2018). Moreover, programs in six other studies incorporated one type of social activity instead of several different activities. In two studies, autistic children and their peers collaboratively built preferred models using Lego, which is a structured, predictable, systematic, and positively reinforcing play experience for many children with and without autism spectrum (Hu et al., 2018; Levy & Dunsmuir, 2020). In one study, active participation in musical experiences, such as singing tailored songs about each autistic child and playing instruments, served as the intervention context for children who had an affinity for music (Kern & Aldridge, 2006). In another study, autistic and TD children engaged together in an inclusive physical activity program that involved warm-up movements, functional exercises involving joint movements and muscle strengthening and flexibility, and collaborative activities with hoops, ropes, balls, and other equipment that target the development of fundamental movement skills. The remaining two studies evaluated a theatre-based program that used acting techniques, such as theatre games, role-play and improvisation activities, character development, and choreography, to explicitly teach social behaviours while the children worked together to put on a play performance (Corbett et al., 2016; Corbett et al., 2019). Aside from the physical activity and theatre-based interventions, studies in this review primarily targeted the interests and/or common strengths of children on the autism spectrum to naturally facilitate social learning.

The age and level of support needs of autistic children varied depending on the type of social activity employed. Overall, intervention programs that used one or several activity modalities that capitalized on the circumscribed and preferred interests of autistic children included preschool-aged children and older children (up to 16 years old) with a range of low to high support needs, depending on the study (e.g., younger children with high or medium needs in Hu et al. (2021), Kerns & Aldridge (2006), and Watkins, O'Reilly et al. (2019), and older children with low support needs in R. L. Koegel et al. (2012) and R. L Koegel et al. (2013)). Lego club interventions involved younger and older children with medium and low support needs (Hu et al., 2018; Levy & Dunsmuir, 2020), and both the physical activity and theatre interventions included older children with low support needs.

Type of Peer and Adult Involvement

As displayed in Table 1, nine studies involved the equal participation of peers in social activities (e.g., L. K. Koegel, Vernon et al., 2012; R. L. Koegel et al., 2012; R. L Koegel et al., 2013; Watkins, O'Reilly et al., 2019), whereas five studies followed a peer-mediation model by having peers lead activities and/or use social training strategies to improve the social behaviours of autistic children (e.g., Corbett et al., 2016; Corbett et al., 2019; Hu et al., 2018; Kasari et al., 2016). In addition, one study evaluated two interest-based play interventions (adopted from Watkins, O'Reilly et al., 2019), with the first intervention involving the equal participation of peers and the second intervention involving peer support strategies (Hu et al., 2021). All but one study (Vincent et al., 2018) involving the equal participation of peers included adult activity-oriented support and minimal-to-no socially-oriented support. Although two studies with equal participation of peers involved adults providing some socially-oriented support, this was limited to the initial days of the intervention (Baker et al., 1998) or to facilitate conflict resolution when necessary (Levy & Dunsmuir, 2020). Of the studies with peer-mediation, three did not stipulate the type of adult involvement (Corbett et al., 2016; Corbett et al., 2019; Kasari et al., 2016) and two included a combination of activity- and socially-oriented strategies (i.e., social instruction)

(Baker et al., 1998; Kern & Albridge, 2006). The study assessing two interest-based play interventions with and without peer support strategies had adults providing only activity-oriented support (Hu et al., 2021). Pre-intervention training for peers and adults who provided social support was reported in four studies for peers (e.g., Corbett et al., 2016, Corbett et al., 2019) and in three studies for adults (Kern & Albridge, 2006; Levy & Dunsmuir, 2020; Vincent et al., 2018). One study did not incorporate social support strategies from peers or adults into the intervention but had TD children attend educational sessions about disability and autism spectrum (Sansi et al., 2020).

Targeted Behaviours and Outcome Measures

Targeted behaviours, outcome measures, and results are displayed in Table 2. Two studies assessed the social functioning of autistic children via autism spectrum-related and adaptive behaviour questionnaires or sociometric methods (Corbett et al., 2016; Kasari et al., 2016). Two studies also assessed social cognition, such as theory of mind and face perception skills, using standardized assessments and neural responses to stimuli (Corbett et al., 2016; Corbett et al., 2019). All the studies included at least one measure of social communication. Generally, social communication was measured via observed peer engagement or interaction, defined as time spent participating in a reciprocal social activity with peers, and/or observed social (verbal and non-verbal) or verbal initiations and responses, defined as instances of behaviours used to approach or answer a peer. Only three studies included a measure that directly reflected the quality of social communication (Hu et al., 2021; Kern & Albridge, 2006; Levy & Dunsmuir, 2020). Four studies reported on non-social behaviours including child affect (Baker et al., 1998; R.L. Koegel et al., 2005), play and engagement with materials (Kern & Albridge, 2006), problem behaviours (i.e., internalizing, externalizing, and hyperactivity problems), and motor skills (Sansi et al., 2020). With respect to outcomes related to peers, two studies assessed social functioning using friendship nominations (Kasari et al., 2016) and attitudes towards autistic children (Sansi et al., 2020), and one study measured social communication by measuring social responses, social initiations, inappropriate social interactions (e.g., grabbing, lack of responses), and engagement in social play (Hu et al., 2021). Three studies examined other behaviours like child affect (Baker et al., 1998; R. L. Koegel et al., 2005) and motor skills (Sansi et al., 2020). Although two studies also reported on skills related to the execution of peer-mediation strategies, such as frequency of prompts (Hu et al., 2018) and execution of tasks by peers (Kern & Albridge, 2006), these results reflect adherence to the peer-mediation protocol as opposed to intervention outcomes and are thus not displayed in Table 2.

Results for Children on the Autism Spectrum

Beginning with single-subject design research, seven of 11 studies reported a positive result across all their measures of social communication, with one study indicating large effect sizes for engagement, initiation, and responses (*NAP* = .93-.99) (Watkin, O'Reilly et al., 2019). Three studies found a mixed finding related to one social communication measure. In the study by Hu et al., (2021), inappropriate social interactions increased for one participant and remained consistently low throughout the study for the second participant. However, compared to baseline sessions, all the participants showed improvements in their social initiation, social response, and engagement in social play with moderate to large effects across participants and intervention condition (i.e., interest-based play with and without peer support) (*TAU* = .81-96). Despite positive results for peer engagement, Vincent et al. (2018) reported a small-to-no therapeutic trend for most of the participants and R. L. Koegel et al. (2012) found increases in verbal initiations for two out of three children, which may have been influenced by the commencement of medication for one participant. Although Levy and Dunsmuir (2020) found mixed results across all of their outcome measures, these findings were impacted by one participant (out of six) who dropped out of the study after receiving six (out of 12) intervention sessions. The remaining five participants demonstrated increases in social interactions, social initiations and responses, and positive responses, with large effects of the intervention observed across participants and variables (*PAND* > .93 and *TAU* > .91). None of the single-subject design studies reported negative findings. Of the studies that included non-social outcome variables, two revealed positive findings related to expressed enjoyment during interest-based activities (Baker et al., 1998; R. L. Koegel et al., 2005) and one study produced mixed results such that active and meaningful engagement with play materials in the music center was variable across the children (Kern & Albridge, 2006).

Among group research, two of four studies generated several positive findings related to social functioning, social cognition, and social communication. Corbett et al. (2016) found large improvements in reciprocal communication and adaptive social skills, memory for faces, and theory of mind skills following participation in a theatre program compared to a waitlist comparison group (*d* = -.86-.93). Large increases in peer engagement were also reported (*d* = .93), but no significant change in solitary play was found (Corbett et al., 2016). In a larger scaled evaluation of this intervention, improvements in memory for faces and some (verbal) theory of mind skills were found as well as increases in peer engagement during group activities, but not during unsolicited (free) play (Corbett et al., 2019), with medium effect sizes associated with these findings (*d* = .45-.58). In the study by Kasari et al. (2016), there was no significant time by intervention group interaction across two measures of sociometric status (i.e. social network ratio [with $p = .974$; although an overall trend at $p = .059$ was found when combining both intervention groups] and friendship nominations [with $p = .161$ for the number of children nominated by autistic children]) and significantly smaller improvements related to time spent engaged with peers (i.e., increased duration of social interactions and decreases in solitary play) was found among children who attended a peer-mediated activity-based intervention with their peers compared to a social skills intervention without peers (with $p = .003$ for peer engagement and $p = .002$ for solitary play). Lastly, Sansi et al., (2020) found significant increases in motor skills (i.e., running: $p = .003$), but not in problem behaviours or social skills ($p_s > .05$) for autistic children who participated in the physical activity intervention compared to those in the control group. Though not displayed in Table 2, qualitative methods involving semi-structured interviews with parents and teachers were incorporated into the study design at post-intervention to complement quantitative findings and during these interviews, autistic children were described as not only being more active and having better motor skills, but also being more socially inclined and better communicators.

Generalization or Maintenance

Seven studies assessed the generalization and/or maintenance of intervention outcomes. In regard to interest-based interventions, sustained and generalized social communication gains were found about one to two months later during interest-based (Baker et al., 1998; Watkins, O'Reilly, et al., 2019) and non-interest-based activities (Baker et al., 1998). Hu et al., (2021) also collected maintenance data five-weeks following the interest-based intervention with peer support, which essentially replicated the results obtained during the intervention such that findings were mixed for inappropriate social interactions and positive for social initiation, social response, and engagement in social play. In contrast, R. L. Koegel et al. (2013) reported mixed findings across measures of maintenance and generalization; gains were reported during interest-based activities but were not sustained or generalized among adolescents who engaged in activities that were highly dissimilar to their intervention club. In one study assessing a Lego club, social communication gains for the five participants were sustained three months later during free-play Lego sessions, but the generalization of skills outside the intervention context was inconsistent between raters (parents versus teachers) and participants (Levy & Dunsmuir, 2020). The theatre program yielded sustained effects related to one of two measures of social functioning two months following its conclusion (Corbett et al., 2016). Interestingly, Kasari et al. (2016) reported that improvements in social interactions among children in the social skills training group were not sustained at the eight-week follow-up.

Results for Peers

Similar to the performance of autistic children, Hu et al., (2021) demonstrated mixed results for inappropriate social interaction, but positive results for social initiations and social responses during interest-based play with and without peer support, with moderate to large effect sizes (*TAU* = .85-.94) and gains sustained at follow up. The peer-mediated activity-based intervention by Kasari et al. (2016) did not produce a significant increase in cross-group friendships for peers. Peers demonstrated an increase in ratings of affect during two interventions (Baker et al., 1998; R. L. Koegel et al., 2005) with one study reporting sustained effects at a one- or two-month follow-up (Baker et al., 1998). Although Sansi et al. (2020) found improvements in motor skills like running, galloping, skipping, and ball skills ($p_s < .01$), clinically significant increases related to their perception of autistic children were not found ($p_s > .05$). Qualitative information not summarized in Table 2 was collected at post-intervention interviews with the TD participants and physical education teachers, which corroborated the quantitative findings related to improvements in motor skills but contrasted those found related to their perceptions of their autistic peers, such that TD participants reported positive changes in attitudes towards their autistic peers such as being more comfortable around their autistic peers and being eager to spend more time with them. Although not displayed in Table 2, the execution (peer prompts and on task behaviours) of a peer-mediation model was consistent across preschool-aged peers in the Lego play program (Hu et al. 2018), but variable for one peer in the music-based program (Kern & Albridge, 2006).

Strength of Research and Evidence of Social Validity

Strength ratings and social validity indicators are presented in Table 3. Within this review, four studies were rated as strong, eight studies were rated as adequate, and three studies were rated as weak. Among studies with weak ratings, one study showed evidence of less than two secondary quality indicators (R. L. Koegel et al., 2012), and the other two studies were assigned an unacceptable qualifier on the primary quality indicator of baseline condition (i.e., significant variability in behaviours at baseline) and/or the primary indicator of visual analysis (i.e., more than 25% of data overlap between baseline and intervention conditions) (Baker et al., 1998; Vincent et al., 2018). Of these three studies, two produced mixed results related to one social outcome measure (R. L. Koegel et al., 2012; Vincent et al., 2018).

Ten studies met the criteria outlined by Reichow et al. (2008) for social validity (i.e., the presence of at least four social validity measures). All studies were conducted in a natural context and included a socially relevant dependent measure. A clinically significant increase in social behaviour unique to the activity-based intervention was found in all but two studies (e.g., Kasari et al., 2016; Sansi et al., 2020). Six studies included comparisons between autistic and TD children (e.g., L.K. Koegel, Vernon et al., 2012; R. L. Koegel et al., 2013; Watkins, O'Reilly, et al., 2019) and seven studies used some or all intervention implementers that were familiar to the children (e.g., parents, teachers, and classmates) (e.g., Kern & Albridge, 2006; Levy & Dunsmuir, 2020). In addition, six studies retrieved satisfaction information from school staff and/or the participating children and demonstrated good feasibility of the intervention (e.g., Hu et al., 2018; Hu et al., 2021; Vincent et al., 2018; Watkins, O'Reilly, et al., 2019).

Discussion

The current systematic review aimed to evaluate the use of shared social activities for supporting the social development of children on the autism spectrum and their TD peers. Fifteen articles met the inclusion criteria and were included in this synthesis. Using two rubrics developed by Reichow (2008) for single-subject research and group research, respectively, most studies were found to be of high quality, with 12 studies achieving strong or adequate strength ratings in terms of methodological rigor and eight demonstrating sufficient social validity. Overall, the findings of this systematic review lend support for including autistic children and peers together in social activities.

Do Shared Social Activities Improve the Social Cognition, Social Communication, and/or Social Functioning of Children on the Autism Spectrum and Their TD Peers?

Improvements in social outcomes for autistic children were reported in 13 studies and included, for example, improvements in autism spectrum-related and social adaptive behaviours (Corbett et al., 2016), theory of mind, face perception (Corbett et al., 2016, Corbett et al., 2019), peer engagement, and social initiations and responses (e.g., Corbett et al., 2016; Corbett et al., 2019; Hu et al., 2018; Hu et al., 2021; Kern & Albridge, 2006; L. K. Koegel, Vernon, et al., 2012; Koegel et al., 2013; Levy & Dunsmuir, 2020; Watkin, O'Reilly, et al., 2019). One other study qualitatively demonstrated a positive change in social skills via semi-structured interviews, but no change in this area was found from the quantitative analyses (Sansi et al. 2020). The generalization and/or maintenance of intervention effects was assessed in seven of the 13 studies and appeared promising. Six out of these seven studies found that gains related to autism spectrum-specific behaviours (Corbett et al., 2016) or social communicative skills (Baker et al., 1998; Hu et al., 2021; R. L. Koegel et al., 2013; Levy & Dunsmuir, 2020; Watkins, O'Reilly et al., 2019) were generalized and sustained across autistic children who participated in a theatre, Lego, or interest-based intervention. Peer outcomes were obtained in five studies with two of these studies finding no significant change in friendship nominations (Kasari et al., 2016) or attitudes towards autistic children, though an improvement was reported qualitatively (Sansi et al., 2020). In addition, it was demonstrated in two studies that autistic children showed expressed enjoyment over the course of an interest-based intervention, which was observed to be maintained and generalized during activities that were similar and different from those used in the intervention setting (Baker et al., 1998; R. L. Koegel et al., 2005). The finding that shared social activities can be fun and enjoyable for autistic and TD children is noteworthy because positive affect is linked to intergroup outcomes like social acceptance and cross-group friendships (Allport et al., 1954). Overall, the studies reviewed found that children on the autism spectrum can benefit from participating in social activities with peers.

In some studies, information from autistic and TD children was collected as a measure of social validity following the completion of the intervention. For example, autistic children and their peers reported positive attitudes towards each other and new friendships following participation in Lego play and interest-based clubs (Hu et al., 2018; R. L. Koegel et al., 2013). Although Sansi et al. (2020) did not demonstrate a quantitative increase within the social domain for autistic children following their participation in an inclusive physical activity intervention (which the authors noted was potentially related to the small sample size of the study), semi-structured interviews following intervention revealed parent- and teacher-reported increases in social interaction and communication, as well as TD children-reported improvements in attitudes towards autistic peers, such as feeling more comfortable interacting with their autistic peers and wanting to spend time with them. Studies that were not included in this review due to failure to meet the inclusion criteria also show that shared social activities can lead to improvements in overall social competence, friendship quality, and reductions in social anxiety (Chiang et al. 2004; Kaboski et al., 2015). In a recent study, Cook et al. (2019) found that an 11-week music-making program yielded greater gains in prosocial emotions of TD children and reductions in victimization among TD children and children with autism spectrum-related behaviours who attended the program together versus separately, which suggests that musical activities can be used to combat social exclusion and bullying at school. To better capture broader social implications of shared social activities for autistic children and their peers, it would be informative for studies to include a more comprehensive battery of outcome measures that reflect not only specific social cognitive and communication skills but also broad social outcomes related to overall social functioning, such as social acceptance, social support, sociometric status, and friendship qualities, which can be obtained at various stages of the intervention (e.g. before, during, and after intervention) for all participating children. Moreover, studies in this review that assessed the generalization and/or maintenance of intervention effectiveness for children on the autism spectrum have predominately done so during activities that were similar in content or structure to those used in the intervention setting (e.g., Hu et al., 2021; Watkins, O'Reilly et al., 2019). To elucidate the extent of intervention effectiveness, it would be worthwhile for future investigations of shared social activities to assess the presence or absence of long-term gains that translate to different and undefined play areas like the playground.

Are Shared Social Activities Appropriate for Children on the Autism Spectrum of Different Ages and Support Needs?

Age and level of support needs of autistic children did not impact outcomes. That is, positive results were reported across studies that included younger and/or older children and children with various levels of autism spectrum symptomatology, cognitive, and/or language skills, which is a compelling finding for clinicians who must select interventions that accommodate children across the spectrum. However, the type of social activity used during the intervention may need to be carefully selected based on the age and skill profiles of the children. Activity-based programs that commonly service younger and older children with diverse capabilities tend to capitalize on the children's circumscribed or general interests and take various forms depending on available resources. While crafting individualized social clubs may be feasible to implement in high schools wherein the children are older and perhaps more capable of independently organizing the club with adult supervision (e.g., distributing flyers or asking peers to join) (e.g., R. L. Koegel et al., 2012; L.K. Koegel, Vernon, et al., 2012; R. L. Koegel et al., 2013), it may be more convenient in elementary schools to select one activity modality that is interactive and naturally enjoyable for everyone such as music and Lego play; both of which are known to also hone strengths commonly found among people on the autism spectrum (Hu et al., 2018; Kern & Albridge, 2006; Levy & Dunsmuir, 2020). As it stands, the effects of physical activity and theatre interventions for younger children and children with limited cognitive and language skills remain to be investigated; an older age range of children, particularly within the theatre intervention, with low support needs have been included in this work. According to the recent report by the National Professional Development Center on Autism Spectrum Disorder (2020), exercise and movement interventions like recreation sport activities, martial arts, yoga, or other movement-based activities that target physical fitness or motor development are considered an evidence-based practice for improving social communication, learning, challenging behaviours, and motor skills for children as young as 3 years of age and as old as 18 years old. Involving TD peers in this type of intervention at school or during extra-curricular activities outside of school may offer autistic and TD peers a unique opportunity to learn fundamental movement skills together while also getting to know each other and potentially building new friendships. In addition, acting may be an invaluable tool for teaching empathy, social cognitive and communicative behaviours, as well as for reducing social stress (Corbett et al., 2014; Goldstein, 2011). Thus, continued investigation on the effects of inclusive physical activity and theatre activities for younger and older children across the spectrum seems promising.

Do Children on the Autism Spectrum and Their Peers Participate Equally When Engaged in Shared Social Activities?

The findings of this review indicate that the type of peer involvement during social activities may influence social outcomes. In more than half of the included studies wherein autistic and TD children engaged similarly in activities, results were positive across participants and social outcome variables (e.g., L. K. Koegel, Vernon, et al., 2012; R. L. Koegel et al., 2013; Levy & Dunsmuir, 2020; Watkins, O'Reilly et al., 2019), except for one study that found no group difference (Sansi et al., 2020). Apart from one study (Vincent et al., 2018), adults did not intervene beyond organizing and supervising the activity, which suggests that gains were a result of the activity itself and the interaction with peers during the activity. This lends credence to the suggestion that increases in social interaction might be attributed to specific characteristics of an activity like structure and positive affect (DeKlyen & Odom, 1989; R. L. Koegel et al., 1987) and that explicit social teaching may not always be necessary. Among the studies reviewed that included peer-mediation, one study reported no change in social status and quantity of friendships and less of an improvement in interactive play when compared to a social skills training group without peers (Kasari et al., 2016). In a qualitative study using the same data as Kasari et al. (2016), micro behavioural coding revealed subtle signs that one child on the autism spectrum in the activity-based intervention experienced more social isolation and exclusion (Dean et al., 2013). Although these results may have been a byproduct of a lack of explicit social teaching, it is possible that the use of hierarchical roles to select and organize activities (i.e., peers as the leaders and autistic children as the followers) may have led to a selection of activities that were biased towards the preferences of TD peers, which may have reduced the incentive for autistic children to socialize. Among the other four studies reviewed with peer-mediation, results were mostly positive, but it remains unclear to what extent gains are related to peer-mediation or to the shared activity itself. Although Hu et al., (2021) assessed two interest-based play interventions that had one involving the equal participation of peers and the other incorporating peer support strategies, the interventions could not be directly compared given that the peer-support condition was not assessed outside of the interest-based activity and the interventions were not counterbalanced to control for potential order effects. Hu et al. (2018) indicate that Lego play on its own may provide sufficient structure and motivation to sustain and reinforce social relationships, which was later empirically supported by Levy and Dunsmuir (2020). It would be interesting for future studies in this field to conduct component analyses to examine whether or not peer-mediation protocols in the context of shared social activities yield unique social benefits for children on the autism spectrum and their peers. Doing so would help professionals decide whether or not they can implement a shared social activity on its own, which could be particularly compelling when resources are low (e.g., lack of time to train peers), or need to implement it in combination with more explicit social teaching strategies, which could be useful for children who require more support, such as children with less cognitive and language skills or children with challenging behaviours.

Are Shared Social Activities a Socially Valid Intervention?

Based on the criteria developed by Reichow et al. (2008), 10 of the 15 studies demonstrated sufficient social validity. The most common measure of social validity was executing the intervention in a natural context such as a school setting, including socially relevant dependent variables, and demonstrating a clinically significant increase in social behaviour uniquely related to an activity-based intervention, with these measures present in all of the studies in this review (except for Kasari et al., 2016 and Sansi et al., 2020 who did not find a significant increase in social behaviour unique to the activity-based intervention). In addition, seven studies included intervention implementers who were familiar to the children on the autism spectrum such as teachers, parents, and/or classmates (e.g., Levy & Dunsmuir, 2020; Kern & Albridge, 2006; R. L. Koegel et al., 2005), six studies compared social behaviours of autistic children to a normative TD sample, six demonstrated participant satisfaction following the intervention, and five demonstrated the time and cost effectiveness of the intervention (e.g., Hu et al., 2018; Hu et al., 2021; Vincent et al., 2018; Watkins, O'Reilly, et al., 2019). From these findings, it appears that shared social activities yield promising outcomes for autistic children and their peers, are well-suited for implementation in inclusive environments, and are garnering increasing attention in the literature intervention for autism spectrum with about half of the studies in this review published in the last five years. It is recommended that future studies in this line of work continue to collect measures of maintenance of behaviour, comparisons with TD children, feasibility, and satisfaction from stakeholders (i.e., school staff, parents, and students) in order to demonstrate the efficacy of this type of intervention when implemented in natural contexts such as mainstream schools. Doing so, may simultaneously increase school administrators' willingness to integrate these programs into educational curricula (Kennedy, 2002), which would be relatively simple given that many activity-based interventions use opportunities and resources that are already available at school (e.g., a music room or a play area with building blocks); a distinctive advantage over more complex multi-component intervention packages.

Future Directions

The results of the current systematic review suggest that activities including autistic children and TD peers hold promise to improve social outcomes of autistic children. These results provide guidance for clinical practice and offer several recommendations for future research. The first suggestion relates to the need for future studies to provide detailed demographic characteristics for children on the autism spectrum such as their level of cognitive and language skills in addition to autism severity in order to further distinguish the types of shared social activities that are most effective for accommodating the needs of children with heterogenous skill profiles. Second, most studies provided minimal and unstandardized information about peers, which limited our ability to explore the potential impact of peer characteristics on intervention outcomes in this review. Age, gender, selection process, similarity to autistic children, and a standardized measure confirming the absence of an autism spectrum diagnosis are examples of peer characteristics that can be helpful for understanding the mechanisms of behavioural change in intervention. Third, more group and single-case research with strong methodological rigor that assess different types of activities like music, theatre, Lego, and interest-based clubs with younger and older children across the spectrum is encouraged to draw conclusions about the types of activities that lead to optimal outcomes.

Conclusion

Given the push for inclusive practices and rise in children diagnosed with autism spectrum (see Fombonne, 2018 for a discussion of prevalence studies), autistic children are increasingly attending community and educational settings alongside TD peers. However, their effective inclusion remains a very intricate and poorly understood process (Humphrey & Lewis, 2008; Rotheram-Fuller et al., 2010). Findings of the current systematic review suggest that shared social activities lead to increases in social behaviours for autistic children such as improvements in autism spectrum-related and social adaptive behaviours, theory of mind, memory for faces, interactive play, and verbal and nonverbal initiations and responses, as well as promote positive affect between autistic children and their peers. Thus, shared social activities seem to be a powerful catalyst for therapeutic change regarding both the social behaviours and social inclusion of autistic children. In addition, many shared activities covered in this review build on the positive qualities and natural talents of children on the autism spectrum to advance social learning, which contrasts other social interventions that put emphasis on problems and deficits. This field of study holds tremendous promise for the education system as it aligns well with contemporary efforts to create a strength-based culture in the classroom for students with special educational needs (e.g., Alberta Mentoring Partnership, 2013).

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Appendix

Tables 1-3 of Manuscript 1 are presented on the next few pages.

Table 1. *Descriptive Data Related to the Research Design, Children on the Autism Spectrum, Peers, and Activity-Based Interventions.*

Author (year)	Study Design	Autistic children		Peers		Intervention characteristics		
		n, Gender, Age; DX	Support level (assessment)	*n,* Gender, Age; type of peer	Selection; similarity	Setting; duration	Social activity: brief description	Peer and adult involvement: type
Baker et al. (1998)	MB	2 females, 1 male, age: 5-8 years; autism	medium, high	NR; TD	natural participation; schoolmates	playground; 3-4 sessions	*Interest-based clubs:* individual activities created based on special interests of each autistic child	*peer*: equal participation *adult*: AO: organizing materials; SO only during initial days: prompting participation
Corbett et al. (2016)	RCT	4 females, 13 males, mean age: 11 years; ASD	low	12 (1 per autistic child), mean age: 15 years; TD	good social communication skills, general interest in interacting with autistic children; same age and gender when possible (unfamiliar peers)	summer camp; 10 x 4-hour sessions, 1 per week	*SENSE® theatre*: engaged in theatre games, role-play, improvisation, singing, and dancing, while putting on a play *Waitlist group*	*peer[TR]*: peer-mediation: in-vivo and video modeling, positive reinforcement *adult*: type NR (faded)
Corbett et al. (2019)	RCT	11 females, 33 males, mean age: 11 years; ASD	low	NR (1 per autistic child); TD	good social communication skills, general interest in interacting with autistic children; NR (unfamiliar peers)	auditorium; 10 x 4-hour sessions, 1 per week	*SENSE® theatre*: engaged in theatre games, role-play and improvisation, singing, and dancing, while putting on a play *Waitlist group*	*peer[TR]*: peer-mediation: in-vivo and video modeling, positive reinforcement *adult*: type NR (faded)
Hu et al. (2018)	MP with ABAB	3 males, age: 4-6 years; ASD	low, medium (CARS)	3 females, 10 males (2 per session with an autistic child), age: 4-6 years; TD	good social communication skills, regular school attendance, interest in interacting with autistic children; classmates, same age	classroom; 28-31 x 40-minute sessions, 2 per week	*Lego® play:* construct models via assigned roles of an engineer, supplier, or builder. Built models are rewarded ceremonially	*peer[TR]*: peer-mediation: modeling, prompting, positive reinforcement *adult*: AO: organizing, explaining activity; SO: prompting, visual schedules
Hu et al. (2021)	MP with ABAB+C	1 female, 1 male, age: 5-6 years; ASD	medium	2 females, 4 males (3 per autistic child); age: 5-6 years; TD	good social communication skills, regular school attendance, interest in interacting with autistic children; classmates, same age	classroom; 5-8 x 15-minute sessions, daily	*Interest-based play without peer support:* Pre-existing activities selected based on shared interests of each group *Interest-based play with peer support:* Same activities as above with the inclusion of peer support strategies	*peer*: equal participation *adult*: AO: instruction, modelling, response to questions related to activity *peer[TR]*: peer-mediation: prompting, positive reinforcement *adult*: AO: instruction, modeling, response to questions related to activity

Table 1. *(continued)*

Author (year)	Study Design	Autistic children: *n*, Gender, Age; DX	Autistic children: Support level (assessment)	Peers: *n,* Gender, Age; type of peer	Peers: Selection; similarity	Intervention characteristics: Setting; duration	Intervention characteristics: Social activity: brief description	Intervention characteristics: Peer and adult involvement: type
Kasari et al. (2016)[a]	RCT	19 females, 61 males, mean age: 6-11 years; ASD	low, medium	over 160 (2-3 per autistic child); TD	positive role models; classmates	classroom, playground; 16 x 30-45-minute sessions, 2 per week	*ENGAGE:* Pre-existing activities selected based on shared group interests *SKILLS*: explicit social skills training for only autistic children	*peer*: peer-mediation; general leading *adult*: type NR but as needed *peer*: not applicable *adult*: SO: explicit teaching, positive reinforcement
Kern & Aldridge (2006)	MB	4 males; age: 3-4 years; autism	medium, high (CARS)	32 including 8 assigned as a "peer buddy" (2 per autistic child), age: 2-5 years; TD and OD	peer buddies: good social communication skills, positive relationship with the autistic child, motivation to participate; schoolmates or classmates, mutual interest in music	playground; 10-31 x 10-minute sessions, five per week	*Music Hut*: music-based program with individualized songs about choice-making, turn-taking, and body contact for each autistic child	*peer*[TR]: peer-mediation; modeling, positive reinforcement *adult*[TR]: AO and SO: modeling, prompting, positive reinforcement
R. L. Koegel et al. (2005)	MB with 1 reversal	1 female, 1 male, age: 8-9 years; autism	medium	5-9 (1 per session with an autistic child); TD	responsible, good social behaviour; classmates or same-aged neighbors, mutual interests	indoor/outdoor community settings; up to 52 sessions, 1 per week	*Contextually supported play dates*: pre-existing activities selected based on shared interests of each dyad	*peer*: equal participation *adult*: AO: setting up cooperative arrangements
R. L. Koegel et al. (2012)	MB with 2 reversals for 1 child	3 males, age: 11-14 years; ASD	low	NR; TD	natural participation; schoolmates	classroom, courtyard; 6-23 sessions	*Interest-based clubs*: individualized activities created based on special interests of each autistic child	*peer*: equal participation *adult*: AO: organizing materials
L. K. Koegel, Vernon, et al. (2012)	MB with 1 reversal for 1 child	1 female, 2 males, age: 9-12 years; 1 PDD-NOS, 2 autism	low	15-60 (5-20 per club); TD	natural participation; schoolmates, generally same grade	classroom, courtyard; 8-22 x 30-45-minute sessions, 2 per week	*Interest-based clubs*: individualized activities created based on general interests of each autistic child	*peer*: equal participation *adult*: AO: organizing materials

Table 1. *(continued)*

Author (year)	Study Design	Autistic children: *n*, Gender, Age; DX	Autistic children: Support level (assessment)	Peers: *n*, Gender, Age; type of peer	Peers: Selection; similarity	Intervention characteristics: Setting; duration	Intervention characteristics: Social activity: brief description	Intervention characteristics: Peer and adult involvement: type
R. L. Koegel et al. (2013)	MB	1 female, 6 males, age: 14-16 years; ASD	low	70-135 (7-24 per club); TD	natural participation; schoolmates	classroom, courtyard; 4-10 sessions, 1 per week	*Interest-based clubs:* individualized activities created based on general interests of each autistic child	*peer*: equal participation *adult*: AO: organizing materials
Levy & Dunsmuir (2020)	MB	6 males, age: 11-14 years; ASD	medium, low	12 males (2 per autistic child); TD	volunteer sampling; schoolmates, same grade and gender	classroom; 12 x 45-minute sessions, 2 per week	*Lego® club:* construct models via assigned roles of an engineer, supplier, or builder. Built models are rewarded with certificates	*peer*: equal participation *adult*[TR]: AO: facilitating activity; SO: prompting conflict resolution as needed
Sansi et al. (2020)[a]	Mixed method group design[b]	1 female, 12 males, age: 7-10 years; ASD	low	7 females, 7 males, age: 8-9 years; TD	third or fourth graders, no history of attending inclusive physical activity, no health problems; schoolmates	school's motor activity hall; 24 x 1-hour sessions, 2 per week	*Physical activity*: group activities targeting muscle strength, flexibility, and fundamental movement skills (e.g., run, gallop, skip) *Control group*	*peer*[TR]: equal participation *adult:* AO: facilitating activity and physical contact among participants
Vincent et al. (2018)	MB	2 females, 4 males, age: 5-9 years; ASD	NR	NR; general education peers	natural participation; classmates, same gender	playground; 150-160 x 20-minute sessions, five per week	*FRIEND Playground:* pre-existing activities of general interest to autistic children and peers made available at recess.	*peer*: equal participation *adult*[TR]*:* AO: following the child's lead, setting up cooperative arrangements, sometimes embedding interests; SO: prompting, giving, and encouraging children to reward each other
Watkins, O'Reilly, et al. (2019)	MP with ABAB	1 female, 3 males, age: 4-6 years; ASD	medium, high (CARS)	4 females (1 per autistic child), age: 3-5 years; TD	good social communication skills, compliant, helpful; classmates	classroom; 9-14 x 10-minute sessions	*Interest-based play:* Pre-existing activities selected based on shared interests of each dyad	*peer*: equal participation *adult:* AO: instruction, modeling, response to questions related to activity

Note. MB/MP = multiple baselines/probes; RCT = randomized control trial; *n* = number; DX = diagnosis; ASD = autism spectrum disorder; PDD-NOS = pervasive developmental disorder not otherwise specified; CARS = Childhood Autism Rating Scale; NR = not reported; TD = typically developing; OD = other disabilities; [TR] pre-intervention training, AO: activity-oriented, SO: socially-oriented. [a] participant characteristics for only the activity-based intervention; [b] the participants were randomly assigned to the intervention or control groups and quantitative and qualitative method were used to assess behavioural changes.

Table 2. *Targeted Behaviours, Outcome Measures, and Results for Children on the Autism Spectrum and Peers*

Author	Targeted behaviour	Autistic children			Peers	
		Outcome measure	Results [ES]	Generalization (G) or Maintenance (M)	Outcome measure	Results [ES], Generalization (G) or Maintenance (M)
Baker et al. (1998)	• SCOM	Peer engagement	Positive	Positive G + M		
	• Other	Ratings of affect	Positive	Positive G + M	Ratings of affect	Positive, Positive M
Corbett et al. (2016)[a]	• SF	SRS communication	Positive [*d* = -.86]	Positive G + M [*d* = .82]		
		ABAS social	Positive [*d* = .77]	No change G + M		
	• SCOG	NEPSY TOM Contextual	Positive [*d* = .99]			
		NEPSY delayed face memory	Positive [*d* = .98]			
		NEPSY immediate face memory	Positive [*d* = .75]			
		EEG immediate face memory	Positive [*d* = .93]			
	• SCOM	Peer engagement	Positive [*d* = .93]			
		Solitary play	No change			
Corbett et al. (2019)[a]	• SCOG	NEPSY TOM Verbal	Positive [*d* = .45]			
		NEPSY TOM Contextual	No change			
		EEG immediate face memory	Positive			
	• SCOM	Peer engagement in solicited play	Positive [*d* = .58]			
		Peer engagement in free play	No change			
		Verbal interaction in solicited play	Positive [*d* = .47]			
Hu et al. (2018)	• SCOM	Social initiation	Positive			
		Social response	Positive			
Hu et al. (2021)	• SCOM	Social initiation	Positive [*TAU* = .84-.91] (interest-based play)		Social initiation	Positive [*TAU* = .85-.93] (interest-based play)
			Positive [*TAU* = .92-.93] (interest-based play with support)	Positive M		Positive [*TAU* =.92-.94], Positive M (interest-based play with support)
		Social response	Positive [*TAU* = .81-.95] (interest-based play)		Social response	Positive [*TAU* = .85-.93] (interest-based play)
			Positive [*TAU* = .92-.96] (interest-based play with support)	Positive M		Positive [*TAU* = .92-.94], Positive M (interest-based play with support
		Inappropriate social interaction	Mixed (interest-based play)		Inappropriate social interaction	Mixed (interest-based play)
			Mixed (interest-based play with support)	Mixed M		Mixed, Mixed M (interest-based play with support)
		Engagement in social play	Positive [*TAU* = .90] (interest-based play)	Positive M		
			Positive [*TAU* = .92-.96] (interest-based play with support)			

Table 2. *(continued)*

Author	Targeted behaviour	Autistic children			Peers	
		Outcome measure	Results [ES]	Generalization (G) or Maintenance (M)	Outcome measure	Results [ES]
Kasari et al. (2016)[a]	• SF	Social network ratio	No change (ENGAGE = SKILLS)			
		Friendship nominations of a peer	No change (ENGAGE = SKILLS)		Friendship nominations of an autistic child	No change (ENGAGE = SKILLS)
	• SCOM	Social interaction	Negative (ENGAGE < SKILLS[c])	No change M (ENGAGE = SKILLS)		
		Solitary play	Negative (ENGAGE < SKILLS)	No change M (ENGAGE = SKILLS)		
Kern & Aldridge (2006)	• SCOM	Positive social interaction	Positive			
	• Other	Play and engagement with equipment	Mixed			
R. L. Koegel et al. (2005)	• SCOM	Social interaction	Positive			
	• Other	Ratings of affect	Positive		Ratings of affect	Positive
R. L. Koegel et al. (2012)	• SCOM	Social interaction	Positive			
		Verbal initiation	Mixed[d]			
L. K. Koegel, Vernon, et al. (2012)	• SCOM	Social interaction	Positive			
		Verbal initiation	Positive			
R. L. Koegel et al. (2013)	• SCOM	Social interaction	Positive	Mixed G + M		
		Verbal initiation	Positive	Mixed G + M		
Levy & Dunsmuir (2020)	• SCOM	Social interaction	Mixed [*PAND* = 1.0, *TAU* = .24-1.0][e]	Positive M [*PAND* = 1.0]		
		Social initiation	Mixed [*PAND* = .80-1.0, *TAU* = .17-1.0][e]	Positive M [*PAND* = 1.0]		
		Social response	Mixed [*PAND* = .60-1.0, *TAU* = -.98-1.0][e]	Positive M [*PAND* = 1.0]		
		Positive response	Mixed [*PAND*= .40-1.0, *TAU* = 06-1.0][e]	Positive M [*PAND* = 1.0]		
		SSIS, parent form		Mixed G		
		SSIS, teacher form		Mixed G		

Table 2. *(continued)*

Author	Targeted behaviour	Autistic children			Peers	
		Outcome measure	Results [ES]	Generalization (G) and/or Maintenance (M)	Outcome measure	Results [ES]
Sansi et al. (2020)[a b]	• SF				Friendship Activity Scale	No change (physical activity = control)
					Adjustive Checklist	No change (physical activity = control)
	• SCOM	SSRS- PF social skills	No change (physical activity = control)			
	• Other	SSRS-PF problem behaviour	No change (physical activity = control)			
		TGMD-3	Positive (physical activity > control)		TGMD-3	Positive (physical activity > control)
Vincent et al. (2018)	• SCOM	Social interactions	Positive			
		Social initiations	Mixed			
Watkins, O'Reilly, et al. (2019)	• SCOM	Peer engagement	Positive	Positive G + M [*NAP* = 1.0][f]		
		Social initiation	Positive	Positive G + M [*NAP* = .93-.99][f]		
		Social response	Positive	Positive G + M [*NAP* = .98-1.0][f]		

Note. SF = social functioning; SCOG = social cognition; SCOM = social communication; SRS = Social Responsiveness Scale; ABAS = Adaptive Behavior Assessment System; NEPSY = Developmental Neuropsychological Assessment; TGMD-3=The Test of Gross Motor Development-3; TOM = theory of mind; SSIS = Social Skills Improvement System; SSRS- PF= The Social Skills Rating System-Parent Form; ES = effect size; d = Cohen's d effect size (group research); NAP = nonoverlap of pairs effect size (single-subject research); G = generalization; M = maintenance; [a]Activity-based intervention compared to a waitlist comparison group or another type of intervention. **[b]** Only quantitative results displayed.[c] Within group comparisons revealed that children on the autism spectrum across intervention groups increased in social interactions. [d] Authors reported that the commencement of medication for one participant likely contributed to this finding. [e] Findings for this study are impacted by one participant who dropped out mid-intervention (completed only 6 out of 12 intervention sessions) [f] Effect sizes for this study represent the magnitude of change at post intervention, generalization, and maintenance combined.

Table 3. *Strength of Research and Evidence of Social Validity*

Author (year)	Rigor rating	Natural context	Socially relevant outcome	Clinically significant change	Comparison data of TD children	Implementers are familiar to the children	Time and cost effective	Participant satisfaction
Baker et al. (1998)	Weak	✓	✓	✓	✕	✕	✕	✕
Corbett et al. (2016)	Strong	✓	✓	✓	✕	✕	✕	✕
Corbett et al. (2019)	Strong	✓	✓	✓	✕	✕	✕	✕
Hu et al. (2018)	Strong	✓	✓	✓	✕	Partially	✓	Teachers, children
Hu et al. (2021)	Adequate	✓	✓	✓	✓	Partially	✓	Teachers, parents
Kasari et al. (2016)	Strong	✓	✓	✕	✕	Partially	✕	✕
Kern & Albridge (2006)	Adequate	✓	✓	✓	✕	✓	✕	✕
R. L Koegel et al. (2005)	Adequate	✓	✓	✓	✕	Partially	✕	✕
R. L Koegel et al. (2012)	Weak	✓	✓	✓	✕	✕	✕	✕
L. K Koegel, Vernon et al. (2012)	Adequate	✓	✓	✓	✓	✕	✕	✕
R. L Koegel et al. (2013)	Adequate	✓	✓	✓	✓	✕	✕	Children
Levy & Dunsmuir (2020)	Adequate	✓	✓	✓	✕	✓	✓	✕
Sansi et al. (2020)	Adequate	✓	✓	✕*	✓	✓	✕	Teachers, parents, children
Vincent et al. (2018)	Weak	✓	✓	✓	✓	✕	✓	School staff
Watkins, O'Reilly, et al. (2019)	Adequate	✓	✓	✓	✓	✕	✓	Teachers

Note. ✓ = presence; ✕ = absence or unreported; TD = typically developing; *significant improvements in the motor domain only.

Bridge Between Manuscripts 1 and 2 – Chapters 3 and 4

In Manuscript 1 of Chapter 3 (Dahary et al., 2022), I evaluated the effects of shared structured social activities on the social development of autistic and neurotypical children in inclusive education and community contexts. Through a systematic review, I found that most shared social activities produced positive social outcomes for autistic children, such as increases in adaptive social behaviours (Corbett et al., 2016), theory of mind, memory for faces (Corbett et al., 2016; Corbett et al., 2019), and interactive play (e.g., Corbett et al., 2016, Corbett et al., 2019; Hu et al., 2018; Hu et al., 2021; Kern & Aldridge, 2006; Koegel, Vernon et al., 2012; Koegel et al., 2013; Levy & Dunsmuir, 2020; Watkins, O'Reilly et al., 2019), as well as increases in shared enjoyment between autistic children and their peers (Baker et al., 1998; Koegel et al., 2005). Most shared social activities that capitalized on autistic children's interests or skills in addition to their preference for structure did not require excessive peer or adult mediation and were effective for younger and older children with varying support needs (e.g., Hu et al., 2018; Koegel, Vernon et al., 2012; Koegel et al., 2013; Watkin, O'Reilly et al., 2019). With only 15 studies having met the inclusion criteria of the review, shared social activities require greater empirical support to confidently conclude that this type of intervention facilitates the social inclusion and social learning of autistic children over time and across different inclusive settings. We, as researchers, can fuel motivation around the development and implementation of shared social activities by studying autistic children's skills in specific activity modalities (e.g., music skills) to clarify the ecological validity of leveraging such skills for promoting learning and social well-being, which was the overarching aim of my following two manuscripts.

Inclusive musical experiences hold incredible promise for supporting the social development of autistic children because music is a domain of skill for many autistic children (Heaton, 2009; Quintin, 2019) and is enjoyable and motivational for all children (Campbell, 2002). Although the social benefits of shared musical activities were examined in only one study in the systematic review of Chapter 3, findings from other relevant studies that did not meet the inclusion criteria (Cook et al., 2019) or were published following the date of the literature search (Johnson & LaGasse, 2022) have demonstrated improvements in interpersonal skills when autistic and neurotypical children make music together. Moreover, music-based interventions with autistic children increase joint attention, turn-taking, and communication (Chenausky et al., 2016; Chenausky et al., 2017; Kim et al., 2008; LaGasse, 2014; Sharda et al., 2018; Srinivasan et al., 2016; Wan et al., 2011) and active musical experiences with neurotypical children increase prosocial emotions (Cook et al., 2019), cooperation (Kirschner & Tomasello, 2010; Reddish et al., 2013; Wan & Zhu, 2021b), and social bonding (Cirelli et al., 2014). Music engagement is also associated with improvements in oral and written language skills (Lima & Castro, 2011; Overy, 2003), attention control (Kasuya-Ueba et al., 2020), verbal memory (Dunning et al., 2015; Ho et al., 2003), and motor movements (Janzen et al., 2022), demonstrating that music may be an ideal activity modality for targeting developmental differences that characterize autism (i.e., social communication and interaction challenges) (APA, 2022) and that often co-occur with autism (e.g., language, speech, motor, and cognitive challenges) (Christensen et al., 2018; Kangarani-Farani et al., 2023; Zeidan et al., 2022).

The positive outcomes associated with musical participation are proposed to be a byproduct of music's salient and predictable temporal properties, including rhythm and beat (Lense & Camarata, 2020). Musical rhythm and its underlying beat accentuate the structure and predictability of non-musical rhythms (e.g., the back-and-forth in conversation and play) and, thus, make them more accessible to autistic children. More specifically, sharing beat-based musical rhythms modulates attention to non-musical sensory information, scaffolds the timing of non-musical behaviours, and drives cortical plasticity, enabling children to understand and navigate their environments more successfully (Daniel et al., 2022; Hyde et al., 2009; Lense & Camarata, 2020). The role of rhythm in learning and development is increasingly being studied among neurotypical children and children with neurodevelopmental disabilities, including dyslexia, developmental language disorder, stuttering, developmental coordination disorder, and attention deficit hyperactivity disorder (Fiveash et al., 2021; Ladányi et al., 2020). Knowledge about the musical rhythm and beat perception skills of autistic children is much more limited, even though several studies show they have well-developed pitch, melodic, and music-evoked emotion processing skills (Heaton, 2009). In addition, the few studies that have assessed musical rhythm perception have used same-different rhythm discrimination tasks, which draw on non-rhythmic skills (i.e., sequence memory) and do not fully capture the multidimensionality of rhythmic abilities (Fiveash et al., 2022). Therefore, in Manuscript 2 of Chapter 4 (Dahary et al., 2023), I examine the musical beat perception skills of autistic and neurotypical children with an adapted version of the Beat Alignment Test (BAT) because performance on the BAT is found to correlate with multiple dimensions of rhythmic abilities including beat-based rhythm perception and production (e.g., Bonacina et al., 2019; Dalla Bella et al., 2017; Fiveash et al., 2022; Tierney & Kraus, 2015). My objective was to understand whether autistic children are perceptually sensitive to the beat of the music to inform on the ecological validity of using beat-based group musical activities as a strength-based, multisystem intervention tool for autistic children to build new skills and make meaningful social connections with their neurotypical peers. Chapter 4 is an exact reproduction of the article entitled, “Musical beat perception skills of autistic and neurotypical children,” which was published in the *Journal of Autism and Development Disorders* in January 2023.

Chapter 4: Manuscript 2

This chapter is an exact reproduction of the following article published in the *Journal of Autism and Developmental Disorders*.

Musical beat perception skills of autistic and neurotypical children

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Abstract

Purpose: Many autistic children show musical interests and good musical skills including pitch and melodic memory. Autistic children may also perceive temporal regularities in music such as the primary beat underlying the rhythmic structure of music given some work showing preserved rhythm processing in the context of basic, nonverbal auditory stimuli. The temporal regularity and prediction of musical beats can potentially serve as an excellent framework for building skills in non-musical areas of growth for autistic children. We examine if autistic children are perceptually sensitive to the primary beat of music by comparing the musical beat perception skills of autistic and neurotypical children.

Methods: Twenty-three autistic children and 23 neurotypical children aged 6-13 years with no group differences in chronological age and verbal and nonverbal mental ages completed a musical beat perception task where they identified whether beeps superimposed on musical excerpts were on or off the musical beat.

Results: Overall task performance was above the theoretical chance threshold of 50% but not the statistical chance threshold of 70% across groups. On-beat (versus off-beat) accuracy was higher for the autistic group but not the neurotypical group. The autistic group was just as accurate at detecting beat alignments (on-beat) but less precise at detecting beat misalignments (off-beat) compared to the neurotypical group.

Conclusion: Perceptual sensitivity to beat alignments provides support for spared music processing among autistic children and informs on the accessibility of using musical beats and rhythm for cultivating related skills and behaviours (e.g., language and motor abilities).

Keywords: Music, beat perception, rhythm processing, autism, neurotypical, children

Introduction

Autism spectrum disorder (autism[5]) is associated with social communication skills and behaviours that diverge from the "typical" range of skills and behaviours seen in neurodevelopment (American Psychiatric Association, 2013). Much like everyone else, autistic children experience areas of strength in addition to areas of challenge and it is through the discovery of their skills that accessible external supports can be designed and implemented to help them thrive in learning environments (Sonuga-Barke & Thapar, 2021). Music is increasingly being recognized as an area of skill for autistic people (Heaton, 2009; Quintin, 2019) and a catalyst for therapeutic gain (Bharathi et al., 2019; Lense & Camarata, 2020). We examine the musical beat perception, or the ability to perceive the primary pulse underlying the rhythmic structure of music, of autistic and neurotypical children to better understand the musical skills of autistic children and to inform on the use of musical rhythm, or beat, as an accessible, strength-based tool for helping these children reach their full learning potential.

Music Processing Skills of Autistic Children

Many autistic people display an early attraction to and preference for musical stimuli (Molnar-Szakacs & Heaton, 2012), listen to a variety of musical genres on a daily basis (Bhatara et al., 2013), deliberately use music to regulate their moods and make social connections (Allen et al., 2009a, 2009b), and understand the emotional qualities of music (e.g., Heaton et al., 2008, 1999; Quintin et al., 2011; Stephenson et al., 2016). Autistic children also show typical or enhanced processing of the structural components of music (Heaton, 2009) with musical pitch and melodic processing having received the most research attention thus far. Autistic children are

[5] "autism" and "autistic" are used to reflect preferred language of many members of the autism community (Bottema-Beutel, 2021; Monk et al., 2022).

more accurate than their neurotypical peers at holding melodies in long-term memory (Stantuz et al., 2014), disembeding individual pitch tones from chords (Altgassen et al., 2005), classifying pitch contour (Heaton, 2003), and recalling, labelling, and discriminating pitches in the context of music (Heaton, 2005; Jiang et al., 2015; Mottron et al., 2000; Stanutz et al., 2014). In other studies, autistic and neurotypical children show similar ability in remembering pitch and melodies (Heaton et al., 1998; DePape et al., 2012; Jamey et al., 2019), processing harmonies (DePape et al., 2012), replicating, producing, and discriminating melodies (Heaton, 2005; Jamey et al., 2019; Quintin et al., 2013; Stanutz et al., 2014; see however, Sota et al., 2018), and attending to local and global information in melodies (Foster et al., 2016; Germain et al., 2019).

Musical Rhythm and Beat Perception

Much less is known about autistic people's perception of temporal regularities in music. Rhythm is one of the most essential structural elements of music across cultures that serves to organize information in time (Brown & Jordania, 2013; Thaut et al., 1999). Musical *rhythm* is a grouping structure created by patterns of sound events and silences that differ in length and duration to give rise to the perception of phrase boundaries (Grahn, 2012; Hannon et al., 2018). Underlying most musical rhythms is a primary and salient *beat*, or pulse that is evenly spaced in time and readily extracted from the rhythmic surface without being physically present in the stimuli (Repp & Su, 2013; Toiviainen et al., 2020). The primary beat is often multiplied or subdivided into hierarchical time scales called *meter* so that some beats are perceived as faster than others and thus, as stronger, or more accented such as the first and third of every 4 beats in music with a 4/4-time signature (**1** 2 **3** 4, where the third beat is less accented than the first, e.g. "We will rock you" by Queen) or the first of every 3 beats in music with a 3/4-time signature (**1** 2 3, e.g. "My favourite things" from The Sound of Music) (Grahn, 2012; Hannon et al., 2018).

Rhythm and its underlying beat may be useful for targeting core features of autism in addition to language, motor, and intellectual differences that are associated with autism (Christensen et al., 2018; Liu et al., 2021; Zeidan et al., 2022). Sharing musical rhythms (or the beat of music) with others, such as during music-making in group settings, elicits positive emotions (Quintin, 2019; Zentner & Eerola, 2010), cooperation (Kirschner & Tomasello, 2010; Reddish et al., 2013; Wan & Zhu, 2021), and social bonding (Cirelli et al., 2014), creating an environment conducive to learning social skills such as joint attention, imitation, and socio-emotional reciprocity (Overy & Molnar-Szakacs, 2009; Srinivasan & Bhat, 2013). Rhythm accentuates prosodic features and language structures such as syllable, word, and phrase boundaries, in literacy and speech (Fiveash et al., 2021; Tierney & Kraus, 2014) and offers structured guidance for improving the planning, coordination, and stability of limb and whole-body movements (Devlin et al., 2019; Hardy & LaGasse, 2013). Musical training is linked to better cognitive language (Moritz et al., 2013; Overy, 2003), memory (Ho et al., 2003; Kraus et al., 2012), executive functioning (Moreno et al., 2011), and general intelligence (Schellenberg, 2004), likely because music perception and production engage brain regions that overlap with non-musical function and drive cortical plasticity (Hyde et al., 2009; Patel, 2011).

Musical Beat Perception and Neurotypical Development

Most people show an early predisposition for perceiving temporal regularities in auditory stimuli with the support of internal oscillations that synchronize attentional energy to notable moments of sound signals such as the primary beat of music (Dalla Bella, 2018; Jones & Boltz, 1989; Large & Jones, 1999). Children begin to move rhythmically with musical beats within the first two years of life (Fuji et al., 2014; Zentner & Eerola, 2010) with their music-motor coordination becoming more precise as they get older (McAuley et al., 2006; Thompson et al.,

2015) and as they develop more sophisticated auditory-motor connectivity and motor control (Thompson et al., 2015). Perceptually, two-or-three-day-old infants detect beat violations in rhythmic sound sequences as evidenced by discriminative electrical brain responses produced at moments when the downbeat position of a sequence is omitted (Winkler et al., 2009) and such neural entrainment to the beat continues to be present in older infants (Cirelli et al., 2016).

Musical beat perception is directly assessed with children using beat alignment paradigms that were first catered to adult listeners. On the beat perception subtest of the Beat Alignment Test (BAT) (Iversen & Patel, 2008), for example, adult listeners are asked to judge whether beeps superimposed on musical excerpts are correctly aligned with the musical beat or not. Overlaid beeps that do not align with the musical beat have a tempo error (too slow/fast by 10% or 25%) or a phase error (onset occurs too early/late). Musically untrained adults were excellent at identifying when overlaid beeps fit with the musical beat (*mean accuracy* = 90%) and were more sensitive to beat alignments than misalignments. Although not as proficient as adults, Einarson and Trainor (2015, 2016) utilized an adapted child-friendly version of the BAT and found that 5-year-old children with no formal musical training performed above chance level when asked to identify which of two video-recorded hand puppets, presented in succession, was drumming in accordance with the primary beat of the music. Even without visual cues, children aged 5 to17 years effectively assessed the fit between the sound of a metronome and the primary beat of music (Nave-Blodgett et al., 2021). Although performance increased with age and musical training, the youngest children as well as children with no musical experience were sensitive to beat alignments and misalignments (Nave-Blodgett et al., 2021). However, the processing of hierarchical beats and the simultaneous perception of beat and meter may not reach adult-like accuracy levels until later in adolescence (Nave Blodgett et al., 2021; Nave et al., 2022).

Musical Rhythm and Beat Perception Among Autistic People

Two recent studies showed that autistic children performed similarly when asked to discriminate between simple rhythmic groupings compared to neurotypical children matched in age, cognitive ability, and musical experience/interest (Jamey et al., 2019; Sota et al., 2018). No group difference was also found in the overall categorization of meter in another study (DePape et al., 2012), though autistic adolescents showed less specialization in classifying music with simple (native) meters versus complex (foreign) meters, potentially suggesting less enculturation to metric structures (DePape et al., 2012). The discrimination tasks used in these three studies require listeners to attend to and hold in memory two successively played musical sequences to judge if they are the same or different. Such tasks do not directly assess for beat perception in the same way that beat alignment paradigms do, and thus, it is difficult to make conclusions about beat sensitivity, specifically. While autistic children with preserved musical rhythm discrimination skills may be extracting the underlying beat to monitor temporal intervals in the rhythms, it is also possible that they are relying on other musical qualities that cue differences (e.g., overall rhythmic structure) and do not need to perceive a beat (Nave et al., 2022).

Nevertheless, autistic people appear to be able to entrain their movements to temporal regularities in simple, nonverbal auditory stimuli. Autistic adults effectively press a space bar in accordance with tones presented at fixed time intervals (Edey et al., 2019) and autistic children can tap in synchrony, or on the beat of woodblock rhythmic sequences with their performance increasing with sequences inducing stronger versus weaker beats (Tryfon et al., 2017). Excellent performance on such auditory-motor rhythm synchronization tasks may indicate that temporal information like the primary beat of music is accessible to autistic people, especially considering that overt and covert synchronization skills are often positively correlated with each other in neurotypical development and may tap into similar perceptual (e.g., beat extraction) and cognitive (e.g., attention and memory) processes (Dalla Bella et al., 2017; Fuji & Schlaug, 2013; Iversen & Patel, 2008). Autistic people also successfully participate in musical activities that involve singing, playing musical instruments, and/or moving in synchrony with the beat of music (see Geretsegger et al., 2022; Marquez-Garcia et al., 2022 for reviews).

The purpose of the current study was to better understand the musical rhythm processing skills of autistic children and to inform on the accessibility of musical training, with a focus on rhythm perception (and its underlying beat) for improving non-musical areas of functioning, such as social (Lense & Camarata, 2020), speech/language (Fiveash et al., 2021), and motor development (Hardy & LaGasse, 2013) via far transfer effects associated with musical training. We directly compare the musical beat perception skills of autistic and neurotypical children using an adapted version of the beat perception subtest of the BAT (Iversen & Patel, 2008). Based on the existing literature showing intact musical rhythm perception (Jamey et al., 2019; Sota et al., 2018) and rhythm production skills of autistic children (Tryfon et al., 2017), we hypothesized that autistic and neurotypical groups would correctly judge when superimposed beeps were aligned or misaligned with the beat of the music more often than would be predicted by chance and that performance on the task would be similar between groups.

Methods

Participants

Twenty-three autistic children (16 male, 7 female) and 23 neurotypical children (11 male, 12 female) between 6 and 13 years old participated in the current study (N = 46) (see Table 1 in

Results). The 23 autistic participants were selected from a larger pool of autistic participants (N = 46) who had a wide range in chronological age and cognitive ability and were included in the analyses of a separate study by our research group examining potential predictors of musical beat perception skills (manuscript in preparation). Propensity score matching using the optmatch package (v0.9-14; Hansen & Klopfer, 2006) in RStudios (v4.1.1) was conducted to fully match autistic participants to neurotypical participants in chronological age and verbal and nonverbal mental ages in order to limit potential confounds in our results (Randolph et al., 2014). Autistic participants were recruited from elementary and high schools in Quebec that had specialized education for neurodivergent children, and the neurotypical participants were recruited from an elementary school in Quebec (Canada) as well as within the Montreal and Toronto communities (Canada). Advertisement strategies for recruitment included flyers, social media posts, and word of mouth.

Study Procedure and Measures

The children completed cognitive, hearing, and beat perception measures in a quiet space at their school, home, or at the University. All measures were administered in participants' dominant language (French or English) and took approximately 1-hour to complete. The children's parents or teachers were asked to report on the participants' hearing ability (parents), autism characteristics (parents or teachers), and musical experience (parents). Thirty-five parents and 16 teachers consented to complete questionnaires about their child/student via paper and pencil or a secure online survey platform (REDCap; Harris et al., 2009). Stickers to children and gift cards for parents and teachers were given as a token of our appreciation. Most parents and all teachers consented to participating by completing questionnaires, all parents consented to having their child participate, and the children provided assent.

Autism Characteristics

Autistic participants either attended a school specialized for children with developmental disabilities or a regular school with specialized classes for autistic children. Diagnosis of autism was confirmed using special education codes for autism, based on expert clinician report (Lazoff et al., 2010) and parent or teacher responses on the *Social Responsiveness Scale, 2nd Edition* (SRS-2) (Constantino & Gruber, 2012). Total *T*-scores on the SRS-2 were above the clinical cut off of 60 for the autistic participants. Parent or teacher responses on the SRS-2 were also collected for neurotypical participants to confirm the absence of autism. All but two neurotypical participants obtained total *T*-scores below 60. The parents of the two children who obtained total *T*-scores above 60 on the SRS-2 completed an additional screening tool for autism, the *Social Communication Questionnaire* (SCQ) (Rutter et al., 2003), which yielded total scores below the clinical cut-off of 15, and thus confirmed a non-autism profile.

Musical Experience

The following four questions from the musical training subscale of the *Goldsmiths Musical Sophistication Index* (GMSI) (Müllensiefen et al., 2013) were adapted for parent report and used to characterize participants' musical experience: 1) "How many years [*0; 0.5; 1; 2; 3-5; 6-9; 10 or more*] of formal training on a musical instrument has your child taken (including choir or voice lessons)?", 2) "How many musical instruments [*0; 1; 2; 3; 4; 5; 6 or more*] can your child play (not including voice)?" (if applicable, parents were also asked to list the musical instruments that their child played), 3) "How many hours [*0; 0.5; 1; 1.5; 2; 3-4; 5 or more*] per day has your child practiced their main musical instrument (not including voice) currently or in the past?" and 4) "How many years [*0; 0.5; 1; 2; 3; 4-6; 7 or more*] has your child been formally trained in music theory?". The four items from the GMSI were measured on a 7-point Likert scale (0 to 6) and responses across items were summed to generate a total score ranging from 0 (no experience) to 24 (most experience) to reflect overall musical experience. Information about musical experience could only be obtained for participants whose parents consented to completing questionnaires (*n* = 14 autistic children and *n* = 21 neurotypical children).

Cognitive Functioning

Selected subtests of the *Wechsler Abbreviated Scale of Intelligence, 2nd Edition* (WASI-II) (Wechsler, 2011) or the *Weschler Intelligence Scale for Children, 5th Edition* (WISC-V) (Wechsler, 2014) were administered in 30-45 minutes. The Vocabulary and Similarities subtests of the Verbal Comprehension Index measured the ability to think about and reason with verbal information and express ideas with language. The Block Design and Matrix Reasoning (WASI-II) or Visual Puzzles (WISC-V) subtests of the Visual Spatial (WISC-V)/Perceptual Reasoning (WASI-II) Index assessed the ability to examine visual details and think about and reason with visual information. Standard scores on the Verbal Comprehension and Visual Spatial/Perceptual Reasoning Indices were used to derive verbal and nonverbal mental ages by multiplying the standard scores with the participants' chronological age and dividing this number by 100.

Hearing Check

Preserved hearing was verified using a standard in-person hearing screener (https://www.legroupeforget.com) (*n* = 20 autistic children, *n* = 23 neurotypical children) or via parent report (*n* = 3 autistic children). An experimenter also confirmed with participants that they could hear the musical stimuli through their headphones during the practice session of the task.

Musical Beat Perception Task

Musical beat perception was measured using an adapted version of the beat perception subtest of the *Beat Alignment Test* (BAT) (Iversen & Patel, 2008). The musical stimuli of the beat perception task were taken from a large bank of genres including jazz, rock, and pop orchestral and consisted of 10 non-lyrical musical excerpts with simple meter (i.e., 3/4- or 4/4-time signatures), a tempo ranging from 104-185 beats per minute, and a duration of 12 to 19 seconds. Each musical excerpt contained superimposed beeps that started after 5 seconds of the music and stopped 1 second before the music ended. The 10 musical excerpts were heard twice during the task, once with superimposed beeps on musical beat and once with superimposed beeps off the musical beat. Within the ‘on-beat’ condition, the overlaid beeps were played in accordance with the tempo of the music for 10 trials, and within the ‘off-beat’ condition, the overlaid beeps were presented 10% faster in 5 trials and 10% slower in 5 trials than the music’s correct tempo. Overall, the beat perception task comprised of 10 on-beat trials and 10 off-beat trials for a total of 20 test trials that were presented in random order across the participants.

The beat perception task took approximately 8-10 minutes to complete and was administered individually with over-ear headphones on a PC laptop in the E-prime (3.0) environment at a comfortable volume. For each trial of the task, the participants listened to a musical except with superimposed beeps and were asked to indicate if the beeps were on the beat of the music. The participants documented their responses by clicking the “yes” or “no” options on the computer screen using a mouse. A short practice session was completed at the start of the task where the participants became familiar with the sound of the superimposed beeps by listening to a 30 second excerpt containing the sound of the beeps without music. The participants were then presented with one ‘on-beat’ trial and one ‘off-beat’ trial using a musical excerpt that was not used in the task and shared their responses with the experimenter, so corrective feedback could be provided. The participants went on to complete the test trials on the beat perception task irrespective of their accuracy on the practice session.

Planned Analyses

SPSS statistics (v27.0) was used for frequentist analyses with Cohen's *d* and partial eta squared (η_p^2) as measures of effect size (Cohen, 1988). JASP software (v.16.3; JASP Team, 2022) was also used to further assess the presence or absence of an effect of group on musical beat perception within a Bayesian framework (Peter Rosenfeld & Olson, 2021; van Doorn et al., 2021; van den Bergh et al., 2020) A Bayes factor (BF) hypothesis test offers a continuous measure of the strength of evidence in favor of the null hypothesis relative to the alternative (BF_{01}, or $1/BF_{10}$) and in favor of the alternative hypothesis relative to the null (BF_{10}, or $1/BF_{01}$) without necessitating a large sample size (Peter Rosenfeld & Olson, 2021). BF values were interpreted using the following classification scheme (Jeffreys, 1961; Lee & Wagenmakers, 2013, as cited in Schönbrodt & Wagenmakers, 2018): 1 = "no evidence", 1 to 3 = "anecdotal evidence", 3 to 10 = "moderate evidence", 10 to 30 = "strong evidence", 30 to 100 = "very strong evidence", and >100 "extreme evidence" (see annotated files available here)

Sample Characterization

Independent *t*-tests assessed group differences in chronological age, verbal and nonverbal mental ages, autism characteristics (SRS-2 total *T*-scores), or overall musical experience (total scores across four musical training items from the GMSI). Mann-Whitney U tests assessed group differences in years of formal training on a musical instrument, number of musical instruments played, hours of daily practice on a musical instrument, and years of formal training in music theory given that the dependent variables were measured on ordinal scales.

No extreme outliers were found across variables. Chronological, verbal, and nonverbal mental ages, and overall musical experience revealed a normal distribution of scores based on Shapiro-Wilks tests ($p_s > .05$) or absolute z-scores below 1.96 for skewness and kurtosis.

Although there was some variability in the distribution of the SRS-2 total *T*-scores for autistic and neurotypical children, convergence evidence from q-q-plots and skewness and kurtosis values indicated only minor asymmetry. The *t*-test assumption for homogeneity of variance was met for all variables via the Levene's test ($p_s > .05$), except for overall musical experience and thus, the statistics for equal variances not assumed were reported and used for interpretation.

Musical Beat Perception

To examine performance on the beat perception task, accuracy scores reflecting the average number of correct responses in percentage across and within each task condition (on-beat and off-beat) were produced. Alternative performance scores were also calculated using the algorithm by Tillman et al. (2009) to control for response bias. Response bias was defined as the general tendency to respond with "on" more often than "off" or with "off" more often than "on", which is reflected in the following formula: Hits (number of correct responses for 'on-beat' trials/number of 'on-beat' trials) minus False Alarms, FAs (number of incorrect responses for 'off-beat' trials/number of 'off-beat' trials) (Tillman et al., 2009). Hits-FAs ranged from -1 to +1. All performance analyses related to overall performance (conditions combined) were first conducted with percent accuracy scores and re-ran with the Hits-FAs, which revealed the same pattern of findings. Thus, results were only reported in terms of percent accuracy.

Binomial tests were used to determine the statistical threshold for chance performance by taking into consideration the baseline probability of guessing correctly on each trial (50%, two response options) and the total number of test trials on the task (20 trials), which resulted in a chance performance threshold of 70% (i.e., a correct response on more than 14 out of 20 trials, $p = .041$). Given that the small number of test trials on the beat perception task yielded a relatively high performance threshold (i.e., Einarson & Trainor (2016) reported a mean accuracy of 67%

for simple meters on a similar beat perception task with neurotypical children), we used a series of one-sample t-tests to compare overall accuracy of autistic and neurotypical groups to both the statistical chance threshold of 70% and the theoretical threshold of 50% (i.e., a correct response on more than half the trials, which was the same theoretical threshold used to assess chance performance in Einarson & Trainor, 2016). Chance performance within the on-beat and off-beat conditions was also examined separately for each group with the theoretical threshold of 50%. Pearson's chi-square test and Bayesian contingency table analyses were used to detect group differences in the proportion of children who performed above the chance thresholds of 70% (overall) and/or 50% (overall and within conditions).

The frequentist and Bayesian versions of a mixed design analysis of variance (ANOVA) with group (autistic and neurotypical) as the between-subjects factor and task condition (on-beat and off-beat) as the within-subjects variable and post-hoc frequentist and Bayesian versions of t-tests were used to assess our hypothesis of no group difference in performance on the musical beat perception task. The default prior with a scale parameter of .05 for fixed effects and 1 for random effects was used for the Bayesian ANOVA and the default Cauchy prior with a scale parameter of .70 was used for the Bayesian t-tests.

Assumption and Robustness Checks. Following inspection of a boxplot and studentized residuals, no significant outliers were found across all the dependent variables (overall, on-beat, and off-beat percent accuracy scores) within the autistic and neurotypical groups. Shapiro-Wilks tests ($p_s > .05$) or an examination of the kurtosis and skewness values (z-scores < 1.96) confirmed that the distribution of accuracy scores on the beat perception task across and within task conditions were symmetrical. For the ANOVA, the Levene's and Box's tests confirmed that the assumptions for homogeneity of variances and homogeneity of covariances, respectively, were met ($p_s > .05$). Robustness checks were conducted for the Bayesian ANOVA and t-tests and the results were found to be robust (unless otherwise specified) and can be reviewed here.

Results

Sample Characterization

The characteristics of the participants are presented in Table 1. No significant group differences in chronological age, verbal mental age, and nonverbal mental age were found, and the autistic group had significantly higher levels of autism characteristics than the neurotypical group. Musical experience data were available for 14 autistic children and 21 neurotypical children (N = 35). The participants had little musical experience with most having no or minimal formal training on a musical instrument, formal training in music theory, and regular practice with a musical instrument. However, neurotypical children had relatively more training than autistic children as measured by years of formal training on a musical instrument, number of musical instruments played, and number of hours spent practicing their primary musical instrument. Five autistic children and 16 neurotypical children played one or more musical instruments with percussion instruments being the most reported including the piano, xylophone, and/or drums. Some neurotypical children played the flute, clarinet, trombone, and/or the recorder and two autistic children played the trumpet or guitar.

Table 1

Chronological Age, Verbal and Nonverbal Mental Ages, Autism Characteristics, and Musical Experience for Autistic and Neurotypical Participants

Characterization of participants	Autistic group Mean (SD) Range	Neurotypical group Mean (SD) Range	Independent *t*-test *t*-statistic, *p*-value
CA (years)	10.42 (1.97) 6.75 - 13.75	9.34 (1.80) 6.00 - 12.25	1.96, .056
WISC-V/WASI: NVMA (years)	9.79 (2.98) 5.60 - 17.98	9.47 (2.28) 5.67 - 13.97	.38, .707
WISC-V/WASI-II: VMA (years)	9.11 (3.02) 4.68 - 14.34	9.26 (2.58) 5.40 - 15.07	-.19, .848
SRS-2 (*T*-scores)	69.48 (7.52) 60.00 - 87.00	49.30 (8.77) 40.00 - 76.00[a]	8.37, .000***
GMSI: Overall musical experience[b] (total scores)	1.07 (1.27) 0 - 4	4.67 (3.72) 0 - 13	-4.09, .000***
Responses on four items from the GMSI[b]	Median Range	Median Range	Mann-Whitney U test *U*-statistic, *p*-value
Years of formal training on a musical instrument	0 0 - 1	1 0 - 6-9	69.00, .008**
Number of musical instruments played	0 0 - 2	1 0 - 3	79.50, .022*
Hours of daily practice on a musical instrument[b]	0 0 - 0.5	0.5 0 - 1	77.50, .018*
Years of formal training in music theory[b]	0 0 - 1	0 0 - 4-6	92.50, .066

Note. CA = chronological age in years taking into account the proportion of months completed for current age, WISC-V = Wechsler intelligence scale for children, 5th edition, WASI-II = Wechsler Abbreviated Scale of Intelligence, 2nd edition, NVMA = nonverbal mental age (Visual Spatial Index scores from the WISC-V or Perceptual Reasoning Index scores from the WASI-II), VMA = verbal mental age (Verbal Comprehension Index scores on the WISC-V or WASI-II). SRS-2 = Social Responsiveness Scale, 2nd edition, GMSI = Goldsmiths Musical Sophistication Index. [a] *n* = 2 neurotypical participants received a *T*-score of 62 and 76, respectively, but obtained a total score below the clinical cut off on the Social Communication Questionnaire (SCQ). [b] Information about musical experience represents *n* = 14 autistic participants and *n* = 21 neurotypical participants. **p* < .05, ***p* < .01, ****p* < .001

Musical Beat Perception

Average percent accuracy scores on the beat perception task are presented in Table 2. Overall performance was not significantly better than the statistical chance threshold of 70% for the autistic group, $t(22) = -1.898$, $p = .071$, $d = -.40$, and the neurotypical group, $t(22) = -.895$, $p = .380$, $d = -.19$. Seven autistic and 10 neurotypical participants obtained overall scores above 70% and there was no significant difference in the proportion of children performing above this threshold between groups, $\chi^2(1, N = 46) = .840$, $p = .359$, $BF_{01} = 1.97$, (anecdotal evidence in favor of H_0). However, overall performance was significantly above the baseline threshold of 50% for the autistic group, $t(22) = 3.923$, $p = .001$, $d = .82$, and the neurotypical groups, $t(22) = 5.441$, $p < .001$, $d = 1.14$, with 18 participants in each group obtaining an overall score above 50% ($BF_{01} = 3.41$, moderate support for H_0).

Continuing with the threshold of 50%, performance was above chance for the on-beat condition for the autistic group, $t(22) = 6.056$, $p < .001$, $d = 1.26$, and the neurotypical group, $t(22) = 4.468$, $p < .001$, $d = .93$, with 20 autistic and 18 neurotypical participants scoring above 50% on the on-beat condition, $\chi^2(1, N = 46) = .605$, $p = .437$. Performance on the off-beat condition was also above 50% for the neurotypical group, $t(22) = 4.413$, $p < .001$, $d = .920$, but not for the autistic group, $t(22) = .401$, $p = .692$, $d = .08$, though 12 autistic and 16 neurotypical participants performed above 50%, which resulted in proportions that were not significantly different between groups, $\chi^2(1, N = 46) = 1.460$, $p = .227$. The finding of no group difference in proportions was only anecdotally supported for the on-beat condition (BF_{01} = 2.80) and the off-beat condition (BF_{01} = 1.44) indicating potential insensitivity in our data to detect a group difference (e.g., potentially more autistic than neurotypical participants performing above 50% on the on-beat condition and more neurotypical than autistic participants performing above 50% on the off-beat condition).

Table 2

Performance on the Beat Perception Task by Autistic and Neurotypical Participants

Task performance	Autistic group *n* = 23	Neurotypical group *n* = 23	Across groups *N* = 46
	Mean (SD) Range	Mean (SD) Range	Mean (SD) Range
Overall[a] (% accuracy)	63.48 (16.48) 30-100	67.17 (15.14) 45-90	65.33 (15.76) 30-100
Overall[a] (Hits-FAs)	.27 (.32) -.40-1.00	.34 (.30) -.10-.80	.31 (.31) -.40-1.00
On-beat condition (% accuracy)	75.22 (19.97) 30-100	68.70 (20.07) 30-90	71.96 (20.07) 30-100
Off-beat condition (% accuracy)	51.74 (20.81) 10-100	65.65 (17.01) 40-90	58.70 (20.07) 10-100

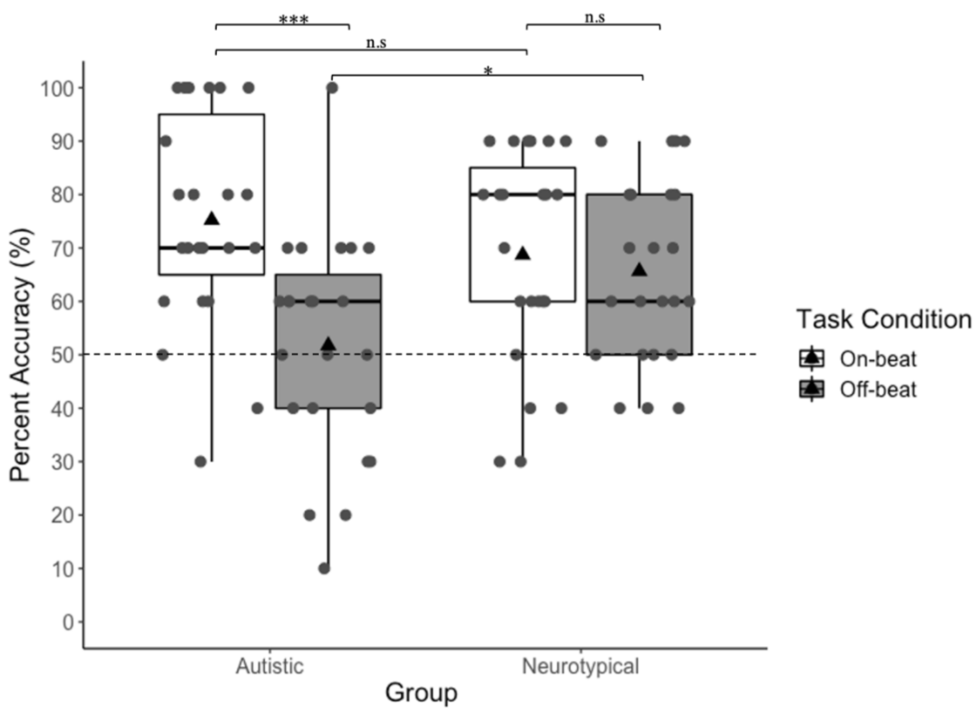
Note. [a] = on-beat and off-beat conditions combined; Hits-FAs = Hits minus False Alarms.

The ANOVA revealed no main effect of group, $F(1,44) = .628$, $p = .433$, $\eta_p^2 = .01$, but a main effect of condition, $F(1,44) = 15.469$, $p < .001$, $\eta_p^2 = .26$, and an interaction between group and condition, $F(1, 44) = 9.183$, $p = .004$, $\eta_p^2 = .17$ (see Fig. 1), with large effect sizes corresponding to both of these significant findings. Although no significant main effect of group was found, the main effects model (condition + group) was 24.10 times more favored than the null model containing no effects (BF_{01} = .04, strong evidence for H_1). In terms of the effect of group, specifically, the null model was 2.91 times more likely than the main effect of group (BF_{10} = .34), which provided only anecdotal evidence in favor of H_0 and suggested that the observed data were insensitive to detect a group effect. The main effect of condition was 67.98 times more likely than the null model (BF_{01} = .02, very strong evidence in favor of H_1) and there was extreme evidence that the main effect of condition was preferred to the main effect of group (*BF* = 67.98/0.34). In addition, the interaction model (which includes the main effects model: condition + group + condition*group) was 281.84 times more likely than the null model (BF_{01} = .00, extreme evidence in favor of H_1). The interaction model (condition + group + condition*group) was preferred to the main effects model (condition + group) (BF = 281.84/24.10) and a model including the interaction (condition*group) was more likely than a model without this interaction ($BF_{inclusion}$ = 12.07), providing strong evidence that condition and group were interacting - a result consistent with the frequentist ANOVA analysis.

Based on post-hoc analyses, the autistic group showed better performance on the on-beat condition than the off-beat condition, $t(22) = 4.682$, $p < .001$, $d = .98$, with this difference being 242.40 times more likely than the null hypothesis of no difference (BF_{01} = .00, extreme evidence in favor of H_1). The neurotypical group did not show a difference in performance between conditions, $t(22) = .675$, $p = .507$, $d = .14$, and the absence of a difference was moderately supported (BF_{01} = 3.72). The average score on the on-beat condition was qualitatively higher by approximately 7 percentage points for the autistic group (*M* = 75.22%, *SD* = 19.97%) than the neurotypical group (*M* = 68.70%, *SD* = 20.07%), and although this difference was not significant, $t(22) = 1.105$, $p = .275$, $d = .33$, the finding of no difference only obtained anecdotal evidence (BF_{01} = 2.09), indicating insensitivity in our data to detect an effect (e.g., potentially better performance on the on-beat condition by the autistic group compared to the neurotypical group). The neurotypical group performed significantly higher on the off-beat condition than the autistic group, $t(22) = -2.482$, $p = .017$, $d = .33$, with this result obtaining anecdotal to moderate evidence (default prior: BF_{10} = 3.26 and wider prior: BF_{10} = 2.95; see robustness check here) and supported by the finding of above chance performance on the off-beat condition for only the neurotypical group. Taken together, accuracy on the on-beat condition was significantly higher than that on the off-beat condition for the autistic group but not for the neurotypical group; and there was some evidence to suggest that the autistic group performed similarly on the on-beat condition, but less accurately on the off-beat condition compared to the neurotypical group.

Figure 1

Significant Interaction Between Group and Task Condition on the Musical Beat Perception Task



Note. The groups performed similarly on the on-beat trials (p = .275). The neurotypical group was more accurate than the autistic group on the off-beat trials (p = .017). The autistic group performed more accurately on the on-beat trials than on the off-beat trials (p < .001), while the neurotypical group performed similarly across task conditions (p = .507). *p < .05, **p < .01, ***p <.001, n.s > .05. Triangles denotes mean accuracy. Dashed line indicates theoretical threshold of 50%.

Follow-up Correlation Analyses with Task Performance

Given group differences in years of formal training on a musical instrument, number of musical instruments played, hours of daily practice on a musical instrument, and overall musical experience in a subgroup of participants whose musical experience was known (n = 14 autistic children, n = 21 neurotypical children) (see Table S1), Pearson's/Kendall tau-b correlation coefficients were analyzed to examine if there was a relationship between these four musical experience variables and performance on the beat perception task. None of the musical experience variables were related to beat perception within the neurotypical group and years of formal training on a musical instrument and hours of daily practice on a musical instrument were unrelated to task performances within the autistic group. Within the autistic group, a positive association was found between overall musical experience and off-beat accuracy scores (M = 54%, SD = 22%), $r = .54$, $p = .046$, and between number of musical instruments played and overall accuracy scores (M = 63%, SD = 19%), $\tau_b = .46$, $p = .048$, and on-beat accuracy scores (M = 73%, SD = 22%), $\tau_b = .70$, $p = .004$, with none of these associations passing the Bonferroni correction (i.e., $p < .002$ for 24 comparisons). It is possible that the significant associations with musical experience (before Bonferroni correction) were driven by the five autistic children who played one or more musical instruments because they mostly obtained high scores overall (50%, 65%, 80%, 85%, 100% vs. subgroup mean of 63%) and on the off-beat condition (60%, 60%, 70%, 70%, 100% vs. subgroup mean of 54%).

For exploration, we also assessed for potential relationships between chronological age and verbal and nonverbal mean ages, and overall, on-beat, and off-beat accuracy scores. No significant associations were found within the neurotypical group (n = 23). Nonverbal mental age was positively associated with overall, $r = .77$, $p = .001$, on-beat, $r = 67$, $p = .009$, and off-beat accuracy scores within the autistic group (n = 23), r = .66, p = .010, with only the correlation with overall accuracy scores passing the Bonferroni correction (i.e., p <.003 for 18 comparisons).

Discussion

We compared the musical beat perception skills of autistic and neurotypical children on an adapted version of the beat perception subtest of the Beat Alignment Test (BAT) (Iversen & Patel, 2008) with the goal of better understanding the musical skill profiles of autistic children and the use of musical rhythm as a potentially accessible, strength-based tool for supporting development of non-musical areas of functioning, such as language, social, and motor skills, via far transfer effects of musical training. The findings of this study varied depending on the chance threshold and the task condition being examined.

Overall Performance on the Musical Beat Perception Task

Overall accuracy scores (conditions combined) were not above the statistical threshold of 70% for either groups, which is the chance level that took into account both the baseline probability of guessing correctly on each trial (i.e., 50%) and the task design (i.e., 20 total test trials). However, it was above the theoretical threshold of 50% for both groups (which was supported by supplemental analyses with Hits-FAs to control for false alarm responses), coinciding with previous work showing that neurotypical children perform above the baseline probability of .50 on a similar two-alternative forced choice beat perception task (Einarson & Trainor, 2015, 2016). Although the proportion of autistic and neurotypical children performing above 50% was exactly the same and no group difference was found in overall performance, a Bayesian analysis provided insufficient evidence in favor of the null hypothesis. Instead, there was strong evidence that group and task condition were interacting.

On-beat Performance on the Musical Beat Perception Task

Autistic and neurotypical groups performed above the theoretical threshold of 50% on the on-beat condition. No group difference in the proportion of children performing above 50% and in average accuracy scores was found on the on-beat condition, yet these null findings were only anecdotally supported with Bayesian analyses. Given that average accuracy scores on the on-beat condition were qualitatively higher within the autistic group, it is unlikely that autistic children had more difficulty identifying beat alignments than neurotypical children. Instead, a larger number of participants are likely needed to increase sensitivity in our data to either confirm the null hypothesis of no effect of group or to more rigorously explore if autistic children have greater sensitivity for beat alignments than neurotypical children. Regardless, the findings of the current study related to beat alignments support those of previous studies showing that autistic children are just as proficient as their neurotypical peers at tapping in synchrony with (or on the beat of) auditory stimuli (Tryfon et al., 2017), discriminating rhythmic sequences built on a regular beat (Jamey et al., 2019; Sota et al., 2018), and processing other structures in music such as pitch and melody (e.g., DePape et al., 2012; Heaton, 2005; Jamey et al., 2019; Quintin et al., 2013), and confirms that neurotypical children can readily detect alignments in music with simple meter (Einarson & Trainor, 2016; Nave-Blodgett et. al., 2021).

Off-beat Performance on the Musical Beat Perception Task

In contrast to the on-beat condition, it was only the neurotypical group that performed above the theoretical threshold of 50% on the off-beat condition. Even though Bayesian analyses showed only some evidence for the absence of a group difference in the proportion of children detecting beat misalignments above the theoretical threshold and for the presence of a group difference in off-beat accuracy scores, the difference in performance between the on- and off-beat conditions was larger in the autistic group and overwhelmingly supported by a Bayesian analysis. While it is possible that children across groups were better at detecting beat alignments than misalignments based on an effect of condition that was strongly supported and preferred to an effect of group, this pattern of performance was much more pronounced within the autistic group with the majority of autistic participants showing lower accuracy on the off-beat condition.

The finding that beat misalignments may be more difficult to detect than beat alignments for autistic children (and perhaps for neurotypical children as well) is consistent with the pattern of performance found among neurotypical adults on the BAT (e.g., Iversen & Patel, 2008; Matthews et al., 2016). In the current study, however, this pattern was only clearly observed among autistic children, potentially indicating less sensitivity to beat misalignments among autistic children, which supports the finding of less specialization for simple metric structures (DePape et al., 2012). Although the well-developed or enhanced perceptual systems of autistic people have been proposed to give them an advantage in processing certain musical qualities like pitch, melody, and regular beat (Jamey et al., 2019; Mottron et al., 2000; Mottron et al., 2006; Sota et al., 2018) and beat alignments as in the on-beat condition, musical beat perception within the context of a beat misalignment paradigm may be a more complex process that may not only rely on good auditory perception. On the musical beat perception task, the children have to 1) listen to the music while they 2) identify the tempo of the musical beat and the tempo of the superimposed metronome (likely with the help of their internal oscillations: Jones & Boltz, 1989; Large & Jones, 1999), and then 3) compare the two tempos to make a judgment about alignment or misalignment. This last step is likely more taxing within the off-beat condition compared to the on-beat condition because the musical beat and the metronome have different timing positions and explicitly require the children to integrate multiple pieces of information together (auditory information, internal oscillations, and in some cases motor movement when tapping along to the beat), which may be especially challenging for autistic children given difficulties with multisensory integration (Stevenson et al., 2014).

It is also possible that group differences on the musical beat perception task reflected differences in musical experience. Even though the 35 of 46 participants with available musical experience data had very minimal musical training, neurotypical children (n = 21) had relatively more musical experience than autistic children (n = 14). Greater general musical experience increases perceptual sensitivity to musical beats among neurotypical children and adults (Fujii & Schlaug, 2013; Matthews et al., 2016; Nave-Blodgett et. al., 2021; Thompson et al., 2015), especially on more demanding musical tasks (Nave-Blodgett et. al., 2021; Nave et al., 2022), such as the off-beat condition on the BAT (Iversen & Patel, 2008). Off-beat performance was positively related to overall musical experience and number of musical instruments played, and the 5 of 14 autistic children who played a musical instrument obtained qualitatively higher off-beat accuracy scores compared to the group mean. With that said, these associations were not significant after correcting for multiple comparisons and there were no significant relationships with other items on the GMSI that are more commonly used for measuring musical experience (e.g., years of formal musical training), which may either be attributed to a lack of power given our sample size or indicative of musical experience not being required for extracting the primary beat of music (Nave-Blodgett et al., 2021). The role of musical experience (and even dance: e.g., Nave-Blodgett et al., 2021; Nave et al., 2022) on the musical beat perception skills of autistic children needs to be more thoroughly examined.

Moreover, our preliminary exploration into other associations with musical beat perception showed no relationship with chronological age, even though rhythm processing is positively linked with chronological age in other studies (Jamey et al., 2019; Nave-Blodgett et al., 2021; Nave et al., 2022; Tryfon et al., 2017). In harmony with previous work investigating musical pitch and melodic processing (e.g., Chowdhury et al., 2017; Jamey et al., 2019; Quintin et al., 2013), however, we did find that musical beat perception was positively related to nonverbal but not verbal mental ages within the autistic group, which may indicate that the results of this study may extend to autistic children with varying linguistic abilities. Our research group is currently examining the musical beat perception skills of a larger group of autistic children with a broader range in chronological age, autism characteristics, and verbal and nonverbal cognitive abilities to better understand the developmental trajectory of beat perception skills and increase the generalizability of findings to children across the spectrum.

Future Directions

We intentionally created a shorter version of the BAT that contained the same (or slightly more) test trials than that used in other child-friendly musical rhythm tasks (e.g., Einarson & Trainor, 2016; Jamey et al., 2019; Sota et al., 2018) to cater to the attention span of child participants and to accommodate school schedules. Including more test trials would have decreased the statistical chance threshold (70%) but may have introduced confounds related to attention and boredom, which may have made it difficult to make explicit interpretations about task performance. It may be necessary to make additional adaptations (e.g., more practice trials) to the BAT in future work in order to verify that autistic people can understand the task and complete both conditions with an appropriate level of success despite possible multisensory integration challenges (Stevenson et al., 2014).

In addition, Western neurotypical children show greater ability to perceive the musical beat of simple meter typical of Western music compared to the more complex meters (e.g., 5/4-

or 7/8-time signatures) commonly heard in Eastern music (Einarson & Trainor, 2015, 2016). Meter would need to be manipulated to directly examine if musical beat perception varies depending on metric structures, which could inform on the type of music that may be better suited as external support for autistic people.

While the use of musical excerpts in this study allowed for musical beat perception to be studied in a manner that simulated real-life musical listening, it may have tapped into other musical processes that interacted with each other and impacted beat perception (e.g., Foxton et al., 2006). It is possible, therefore, that the results of this study reflect autistic children's sensitivity to other musical elements, such as pitch, melody, and music-evoked emotions (e.g., DePape et al., 2012; Heaton, 2005; Jamey et al., 2019; Quintin et al., 2011; Quintin et al., 2013). Future work is encouraged to incorporate a combination of musical excerpts and psychophysically controlled auditory (e.g., woodblock) stimuli to disentangle musical beat perception from other musical processes that are often well-developed among autistic people. It would also be informative to include measures of both musical beat perception and production tasks as already done with neurotypical people (e.g., Dalla Bella et al., 2017; Fuji & Schlaug, 2013), to assess the potential relationship between covert and overt sychronization skills of autistic people. Doing so, could potentially provide empirical evidence that rhythm-based music interventions that require participants to perceive the beat of music and physically align their movements with that beat, such as music-making activities, are accessible for autistic children.

Implications

Proponents of the neurodivergent movement and positive psychology applications in education recommend identifying and capitalizing on children's positive characteristics (i.e., what they can do) to create optimal learning and well-being outcomes at school (Galloway, 2020; Sonuga-Barke & Thapar, 2021). Accordingly, the results of the current study shed light into the musical skills of autistic children and support the use of rhythm-based music programs for targeting learning objectives. Music-making is often a central component of rhythm-based music programs where children must perceive the beat of music and synchronize a response (e.g., singing or playing a musical instrument) in keeping with the beat. Because autistic children are perceptually sensitive to musical beat alignments, as suggested by our findings, and that they can physically entrain to the beat of their auditory environment (Tryfon et al., 2017), such pre-existing rhythmic skills may explain why autistic children successfully participate in and benefit from music therapy (Geretsegger et al., 2022; Marquez-Garcia et al., 2022). For example, the children may be using the salient beat of music to learn about the timing of less salient *social* rhythms such as the timing of verbal and nonverbal communication in conversations or play (Lense & Camarata, 2020). Although it remains unclear if children across the spectrum are sensitive to the beat of music, Fiveash et al. (2021) proposed the *processing rhythm in speech and music (PRISM)* framework to explain that rhythmic competencies including beat perception can be enhanced by directly training 1) fine-grained auditory processing, 2) precise alignment of neural oscillation to external rhythmic stimuli, and 3) auditory-motor coupling in the brain via rhythmic training opportunities. These three mechanisms underlie both musical and non-musical processing skills (e.g., phonological awareness, syntax processing, and oral-motor skills), and thus explain how music therapy and education can result in far transfer effects to non-musical domains of learning (Fiveash, 2021), all within a learning environment that is pleasurable and rewarding (Quintin, 2019).

Conclusion

Musical beat perception was examined among autistic and neurotypical children. Overall performance was above the theoretical chance threshold of 50% but not the statistical chance threshold of 70% across groups. The detection of beat alignments was similar between groups, and there was some evidence that the autistic group had more difficulty detecting beat misalignments than the neurotypical group. It was only the autistic group that showed greater success at accurately detecting beat alignments than misalignments. The findings provide a foundation for future work to continue elucidating the processing of temporal information in music as a way to better understand the skill profiles of autistic children and types of accessible tools that can be put in place to support their musical learning, which can also benefit skill development in other areas via far transfer effects.

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Supplementary Material

Musical beat perception skills of autistic and neurotypical children

Table S1

Correlation Coefficients Between Musical Experience and Average Accuracy Scores on the Beat Perception Task

Musical experience $N = 35$	Autistic group: $n = 14$			Neurotypical group: $n = 21$		
	Average accuracy scores			Average accuracy scores		
	Overall	On-beat	Off-beat	Overall	On-beat	Off-beat
Overall musical experience	$r = .47$	$r = .27$	$r = .54^{*}$	$r = .16$	$r = -.04$	$r = .34$
Years of formal training on a musical instrument	$\tau_b = .27$	$\tau_b = .39$	$\tau_b = .13$	$\tau_b = .10$	$\tau_b = .06$	$\tau_b = .18$
Number of musical instruments played	$\tau_b = .46^{*}$	$\tau_b = .30$	$\tau_b = .70^{**}$	$\tau_b = .13$	$\tau_b = -.01$	$\tau_b = .26$
Hours of daily practice on a main musical instrument	$\tau_b = -.08$	$\tau_b = -.08$	$\tau_b = .24$	$\tau_b = .12$	$\tau_b = .16$	$\tau_b = .10$

Note. r = Pearson's correlation, τ_b = Kendall tau-b; * $p < .05$, ** $p < .01$ (before applying Bonferroni correction).

Bridge Between Manuscripts 2 and 3 – Chapters 4 and 5

Manuscript 2 of Chapter 4 (Dahary et al., 2023) describes the findings of an experimental study where I assessed the musical beat perception skills of 23 autistic children relative to 23 neurotypical children aged 6-13 years using an adapted version of the BAT (Iversen & Patel, 2008). The children listened to non-lyrical musical excerpts on a computer and indicated whether beeps overlaid on the excerpts were on or off the musical beat. Performance was above the theoretical chance threshold of 50% on the task overall and on the on-beat condition across groups. However, only the neurotypical group performed above chance on the off-beat condition. Although the autistic group was less precise at detecting beat misalignments compared to the neurotypical group, I found some evidence that they were just as accurate at detecting beat alignments, which is an important skill to have when participating in musical activities that involve playing and singing per the beat of the music and in synchrony with other people. I also briefly explored factors that may be related to musical beat perception in an effort to set the stage for the next and final study of my dissertation. I found that nonverbal mental age, but not verbal mental age nor chronological age, was significantly related to the musical beat perception among autistic children, suggesting that the beat of music may be accessible to autistic children across the developmental period who often have enhanced perceptual systems (Mottron et al., 2006) and concurrent language disorders (Tager-Flusberg, 2015).

I build on the findings of Manuscript 2 in Manuscript 3 of Chapter 5 by assessing the musical beat perception skills of a larger (53 participants, including the 23 participants in Dahary et al., 2023), more representative group of autistic children who showed a wide range in age, cognitive ability, and autistic traits. In addition to measuring their musical beat perception skills on the same adapted version of the BAT used in Manuscript 2 (Dahary et al., 2023; Iversen &

Patel, 2008), I explore the potential influence of chronological age, cognitive functioning (i.e., verbal and nonverbal cognitive ability and working memory), and intensity of autistic traits on the children's musical beat perception skills. It was my intention with this last study, combined with the results of Manuscript 2, to better generalize findings about musical beat perception to autistic children of different ages who present with a wide diversity of support needs in order to clarify whether music's beat is accessible and can be honed during rhythmic musical programs for supporting children *across* the spectrum in inclusive community and education settings. Manuscript 3 of Chapter 5 is entitled "Musical beat perception skills of autistic children increase with age and nonverbal cognitive ability".

Chapter 5: Manuscript 3

Musical beat perception skills of autistic children increase with age and nonverbal cognitive ability

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Abstract

Purpose: Many autistic children can process musical structures (e.g., pitch, melody), but their sensitivity to music's beat has been minimally studied, despite evidence that beat-based musical participation has far transfer effects on non-musical domains of learning (e.g., social, language, motor) that are often underdeveloped among autistic children. Here, we aim to shed light on the perceptual accessibility of music's beat among a diverse group of autistic children to inform on the appropriateness of rhythm-based music interventions for children across the autism spectrum.

Methods: Fifty-three autistic children aged 6-16 years were asked to listen to musical excerpts on a computer and indicate whether beeps overlaid on musical excerpts were aligned or misaligned with the beat of the music.

Results: Performance was above the theoretical chance level of 50% on the task overall, with greater accuracy found when beeps were overlaid on the on-beat (versus off-beat). Performance increased with age and nonverbal cognitive ability but not with verbal cognitive ability, auditory working memory, or degree of autistic characteristics.

Conclusion: Autistic children can identify musical beat alignments, a necessary skill when playing or moving to the beat of the music. The lack of relationship between musical beat perception and the degree of autistic characteristics is consistent with the proposition that music perception may be spared across the autism spectrum. Future work is needed to clarify the accessibility of rhythm-based music interventions for autistic children who are younger, have reduced nonverbal cognitive abilities, and/or have concurrent disorders associated with atypical rhythm processing.

Keywords: musical beat perception, rhythm perception, autism, age, cognitive abilities

Introduction

Rhythm is the pattern of time intervals in a stimulus sequence that typically gives rise to a natural "feel" of a salient beat (Grahn, 2012). Most people are equipped with neural oscillators that entrain attention to salient beat-based moments in their sensory environment (e.g., when listening to music), enabling them to make predictions about what and when something will occur around them (e.g., the timing of the next musical beat) and to execute a response at the predicted times (e.g., moving to the musical beat) (Large & Jones, 1999). Rhythm (and beat) perception is not only foundational to music perception (Grahn, 2012; Hannon et al., 2018) but to general development, as it underlies several non-musical processes (e.g., Fiveash et al., 2021; Hardy & LaGasse, 2013).

Autistic children[6] often show differences in the acquisition of social (e.g., turn-taking) (American Psychiatric Association [APA], 2022), language (e.g., expressive language, reading) (Ibrahim et al., 2020; Levy et al., 2010), and motor skills (e.g., speech production, motor coordination) (Bhat, 2020) that are intrinsically rhythmic and positively correlated with beat perception in typical development (e.g., Lense et al., 2022; Sun et al., 2022; Tierney & Kraus, 2014) and other clinical populations (e.g., speech/language disorders, Parkinson's disease) (Hardy & LaGasse, 2013; Ladányi et al., 2020). However, such rhythm vulnerabilities may not extend to music; a domain built on a beat that is more salient and predictable than in other domains (e.g., Fiveash et al., 2021) and, thus, potentially more accessible (Lense & Camarata, 2020).

[6] The findings of recent work show that identity-first language may be preferred over person-first language among members of the autism community (Bottema-Beutel, 2021; Monk et al., 2022), which is why we opted to use the term "autistic" in this paper.

Many autistic people regularly engage with music (Allen et al., 2009), demonstrate musical creativity (Johnson & LaGasse, 2022), and understand musical structures, including pitch, harmony, melody, and music-evoked emotions (e.g., DePape et al., 2012; Heaton, 2009; Jamey et al., 2019; Quintin et al., 2011; Quintin et al., 2013; Sivathasan, Dahary et al., 2023; Stanutz et al., 2014). In previous (albeit limited) studies, autistic children are found to adequately discriminate between (Jamey et al., 2019; Sota et al., 2018) and tap in synchrony with beat-based musical/auditory stimuli (Tryfon et al., 2017). In our earlier study (Dahary et al., 2023), we directly investigated the perceptual accessibility of music's beat among autistic children via a beat alignment task paradigm that correlates well with other rhythmic skills, including beat production (Iversen & Patel, 2008; Fiveash et al., 2021). The autistic group was just as proficient as the age-matched neurotypical group at detecting alignments, but not misalignments, between the tempo of the musical beat and the tempo of overlaid beeps, perhaps explaining in part why autistic children successfully participate in music therapy or education involving singing or playing an instrument in synchrony with the beat of the music (Geretsegger et al., 2022; Marquez-Garcia et al., 2022).

The current study builds on our earlier study (Dahary et al., 2023) by examining the musical beat perception skills of a larger group of autistic children who vary in various characteristics (i.e., age, verbal cognitive ability, nonverbal cognitive ability, auditory working memory, and core autistic features). The intention was to characterize the rhythmic musical skills of children across the autism spectrum and to provide insight into the ecological validity of using rhythm-based music interventions for promoting far transfer effects to non-musical domains of learning, as already demonstrated with other neurodivergent children (e.g., Flaugnacco et al., 2015; Moritz et al., 2013).

Musical Rhythm Perception and Age

Rhythm and beat sensitivities mature with age in typical development (Peretz et al., 2013; Nave-Blodgett et al., 2021; Nave et al., 2022; Sun et al., 2022). On beat alignment task paradigms, five-year-old children with no previous musical training can identify musical beat alignments above what would be expected by chance (Einarson & Trainor, 2015, 2016) and their performance increases with age such that even adolescents aged 14-17 years exhibit less beat sensitivity than young adults (Nave-Blodgett et al., 2021). Autistic children may also show better musical beat perception as they grow older, given that age is positively associated with general music perception (Sota et al., 2018) and the processing of musical structures (e.g., pitch) (Jamey et al., 2019; Heaton, Allen et al., 2008). Older autistic children also show enhanced rhythm discrimination (Jamey et al., 2019) and beat synchronization skills compared to younger children (Tryfon et al., 2017). Although we found no relationship between age and musical beat perception in our earlier study (Dahary et al., 2023), the current study re-examines this potential relationship with an autistic group that has a broader range in age to better understand the developmental trajectory of musical beat perception within the context of autism.

Musical Rhythm Perception and Verbal and Nonverbal Cognitive Abilities

Autistic children often have heterogeneous cognitive profiles, with either the nonverbal or verbal cognitive domains considerably better developed than the other (Black et al., 2009; Joseph et al., 2002). Very little is known about the effect of verbal and nonverbal cognitive abilities on the musical rhythm and beat perception skills of autistic children, which is why we aimed to elucidate this in the current study.

In the few studies that exist on the subject, language is only weakly correlated with auditory rhythm processing (Knight et al., 2020) and unrelated to meter categorization among autistic and neurotypical children (DePape et al., 2012), although phonological awareness, a component of language, is associated with beat perception (Rimmer, Dahary et al., 2023). Language is also not correlated with musical rhythm discrimination (Jamey et al., 2019) and musical beat perception among neurotypical children (Einarson & Trainor, 2015, 2016). Although one study found that verbal and nonverbal cognitive abilities explained some (non-significant) variability in rhythm discrimination skills of autistic children, the specific effect associated with verbal versus non-verbal abilities was unclear (Jamey et al., 2019). However, nonverbal but not verbal mental ages were positively associated with musical beat perception in our earlier study (Dahary et al., 2023), which is consistent with the pattern of findings of most studies investigating the effect of cognitive skills on musical pitch and melodic processing (e.g., Chowdhury et al., 2017; Jamey et al., 2019; Quintin et al., 2013). Higher nonverbal cognitive ability is often linked to better recall and categorizing of musical pitches (Stanutz et al., 2014; Jamey et al., 2019; see however Germain et al., 2019), whereas verbal cognitive ability does not appear to impact pitch discrimination (Chowdhury et al., 2017; Mayer et al., 2016; Jamey et al., 2019), global-local melodic perception (Chowdhury et al., 2017), and melodic memory (Jamey et al., 2019), though may affect the recognition and perceived intensity of musical emotions (Dahary, Sivathasan et al., 2022; Heaton, Allen et al., 2008; Quintin et al., 2011).

Musical Rhythm Perception and Auditory Working Memory

Auditory working memory is another cognitive function that is believed to contribute to musical rhythm and beat perception (Brower, 1993; Snyder, 2009). The sensory (aural) experience that comes with feeling the beat of the music is first stored in echoic memory (Brower, 1993) and is then transferred to working memory where information about the beat (e.g., its time period) is maintained and manipulated (or integrated) with other elements in the music, enabling listeners to make higher level perceptual interpretations about what they hear (Brower, 1993; Synder, 2009). Auditory working memory has been positively linked with general musical structure processing among autistic children and adolescents (Quintin et al., 2013; Sota et al., 2018), but its potential effect on musical rhythm and beat perception, specifically, remains to be investigated.

Span tasks like the Digit Span task (e.g., Wechsler, 2014) are commonly used to assess auditory working memory and scores on these tasks are found to be positively correlated with rhythm discrimination skills of neurotypical children (Anvari et al., 2002; Hansen et al., 2012; Strait et al., 2011; see however Lee et al., 2020), rhythm reproduction skills of children with dyslexia (Flaugnacco et al., 2014), and auditory-motor rhythm synchronization skills of neurotypical adults (Bailey & Pehune, 2010, 2012). Greater auditory working memory is also linked to better performance on beat alignment task paradigms for neurotypical adults (Matthews et al., 2016), though this relationship is not observed in five-year-old neurotypical children (Einarson & Trainor, 2015, 2016). The results of neuroscience studies also demonstrate that the perception of beat-based rhythms activates core brain regions implicated in working memory (e.g., the striatum of the basal ganglia) (Grahn, 2009; Teki et al., 2011, 2012, 2016).

Musical Rhythm Perception and Degree of Autistic Characteristics

We also aimed to investigate whether the degree of autistic characteristics is related to musical beat perception to better understand the accessibility of rhythm-based music interventions for children across the autism spectrum. The findings of the few studies on the subject suggest that level of autistic traits is not associated with rhythm discrimination skills (Jamey et al., 2019) nor with neural responses to auditory rhythms (Knight et al., 2020). The level of autistic characteristics is also not found to influence general musical discrimination skills

(Sota et al., 2018). However, core features of autism are inversely associated with pitch discrimination among autistic adults (Mayer et al., 2016) and with pitch and time-interval discrimination among the general population (Stewart et al., 2018), suggesting that the degree of autistic characteristics may impact some but not all music perception skills.

Objectives and Hypotheses

The first objective of the current study was to assess chance performance on the musical beat perception task among an autistic group that included all the autistic children of our previous study (Dahary et al., 2023) as well as new participants. We hypothesized that overall performance would be above the theoretical chance threshold of 50%, which is consistent with what was found on the same task with the autistic and neurotypical groups in our earlier study (Dahary et al., 2023) and the findings of other studies showing intact rhythm discrimination (Jamey et al., 2019; Sota et al., 2018) and production skills of autistic children (Tryon et al., 2017). The second objective was to explore correlates (predictors) of musical beat perception. In accordance with the results of previous studies (e.g., DePape et al., 2012; Jamey et al., 2019; Quintin et al., 2013; Sota et al., 2018; Tryfon et al., 2017), we hypothesized that age, nonverbal cognitive ability, and auditory working memory, but not verbal cognitive ability and level of autistic characteristics would uniquely predict musical beat perception.

Methods

Participants

The participants of the current study were 53 autistic children (44 males, 9 females) who were 6-16 years old (see Table 1). Our sample overlapped with a separate study wherein the relationship between musical beat perception and phonological awareness was investigated (Rimmer, Dahary et al., 2023). Of the 53 participants, 23 were also included in the analyses of a previous study by our research group that compared the musical beat perception skills of autistic and neurotypical children who were matched in chronological age and verbal and nonverbal mental ages (Dahary et al., 2023). The 30 of 53 participants who were not included in Dahary et al. (2023) had collectively lower verbal (but not nonverbal) cognitive ability as well as auditory working memory and overall cognitive ability, where available (see Table S1 for characteristics of the 23 children who were included in our earlier study and of the 30 children unique to the current study). An additional 11 children were initially included in the current study ($N = 64$) but were excluded from the final sample for being significant and influential outliers across analyses ($n = 1$) or demonstrating poor understanding of the musical beat perception task, i.e., providing the same response across trials ($n = 10$). The children were recruited via paper flyers distributed at a specialized school for children with developmental disabilities or mainstream elementary or high schools in Quebec that contained specialized education for students on the autism spectrum.

Table 1

Participant Characteristics and Performance Accuracy on the Musical Beat Perception Task

Participant Characteristics	*n*	Mean (SD)	Range
Age (years)	53	11 (2)	6-16
PIQ composite scores (WISC-V/WASI)	53	88 (21)	55-144
VIQ composite scores (WISC-V/WASI)	53	75 (18)	45-111
Full-Scale composite score (WISC-V/WASI)	50	78 (17)	48-121
DS scaled scores (WISC-V)	50	6 (4)	1-18
SRS-2 Total *T*-scores	52	70 (8)	55-87[a]
Musical Experience	*n*	Median[b]	Range
Years of formal training on a musical instrument	31	0	0-3 to 5
Number of musical instruments played	31	0	0-2
Hours of daily practice on a musical instrument	31	0	0-1
Years of formal training in music theory	31	0	0-3
Overall musical experience (GMSI total scores)	31	0	0-11
Musical Beat Perception Task Performance	*n*	Mean (SD)	Range
Overall[c] (Hits-FAs)	53	.20 (0.3)	-.40-1.00
Overall[c] (% accuracy)	53	62 (17)	30-100
On-beat (% accuracy)	53	72 (22)	20-100
Off-beat (% accuracy)	53	51 (25)	0-100

Note. VIQ = Verbal Intelligence Quotient; PIQ = Performance Intelligence Quotient; DS = Digit Span; SRS-2 = Social Responsiveness Scale-2; WISC-V = Wechsler Intelligence Scale for Children-Fifth Edition; WASI = Wechsler Abbreviated Scale of Intelligence; GMSI = Goldsmiths Musical Sophistication Index; Hits-FAs = Hits minus False Alarms; [a] = 4 participants obtained *T*-scores of 55, 56, 57, and 59 (respectively) on the SRS-2, and their autism profile was confirmed with their educational code for autism as well as the Autism Diagnostic Observation Schdule-2 (n = 2, total scores of 14 and 21) or the Social Communication Questionnaire (n = 2, total scores of 16); [b] = medians were produced to describe the musical experience data given that the variables were measured on ordinal scales; [c] = on-beat and off-beat conditions combined.

Study Procedure and Measures

All parents provided their consent to have their child participate in the study and the children provided their assent. Teachers provided consent to participate in the study by filling out questionnaires about their students. The hearing, cognitive ability, and musical beat perception skills of participants were measured in their dominant language (French or English) during an approximately 1-hour session at their school. Adult informants were asked to report on the participants' hearing ability (parents), autism traits (parents or teachers), and musical experience (parents) when their consent for answering questionnaires about their child/student was obtained. Questionnaires were completed by paper and pencil or online via a secure online survey platform called RedCap (Harris et al., 2009). Children were given stickers and parents and teachers received gift cards as compensation for their time. McGill University's Research Ethics Board approved this study.

Autism Characteristics

Diagnosis of autism was confirmed using special education codes for autism given that the participants were recruited from schools (Lazoff et al., 2010). Participants' codes were based on expert clinical assessment and were supported by a Total *T*-score of 60 or above on the parent or teacher form of the Social Responsiveness Scaled-2nd edition (SRS-2) (Constantino & Gruber, 2012). When a *T*-score below 60 was obtained on the SRS-2 (*n* = 4, *T*-scores of 55, 56, 57, and 59, respectively) or could not be completed (*n* =1), diagnoses were supported by a score indicative of autism on the Autism Diagnostic Observation Schedule-2nd edition (ADOS-2) (Lord et al., 2012) (*n* = 2, total scores of 14 and 21) or the Social Communication Questionnaire (SCQ)-Lifetime form (Rutter et al., 2003) (*n* = 2, total scores of 16). Available SRS-2 Total *T*-scores ranged from 55-87 and were used in statistical analyses for exploring whether the intensity of autism traits uniquely contributes to variability in performance on the musical beat perception task.

Musical Experience

Parents who consented to complete questionnaires provided their responses to the following four questions from the musical training subscale of the Goldsmiths Musical Sophistication Index (GMSI) (*n* = 31) (Müllensiefen et al., 2014): 1) "How many years [*0; 0.5; 1; 2; 3-5; 6-9; 10 or more*] of formal training on a musical instrument has your child taken (including choir or voice lessons)?", 2) "How many musical instruments [*0; 1; 2; 3; 4; 5; 6 or more*] can your child play (not including voice)?", 3) "How many hours [*0; 0.5; 1; 1.5; 2; 3-4; 5 or more*] per day has your child practiced their main musical instrument (not including voice) currently or in the past?" and 4) "How many years [*0; 0.5; 1; 2; 3; 4-6; 7 or more*] has your child been formally trained in music theory?". Responses were measured on a 7-point Likert scale (0-6) and produced a cumulative score that ranged from 0 (no experience) to 24 (most experience). Most participants had no formal training with a musical instrument (*n* = 23) or in music theory (*n* = 26) and did not play (*n* = 20) or regularly practice a musical instrument (*n* = 25).

Cognitive Abilities

Selected subtests of the Wechsler Abbreviated Scaled of Intelligence-2nd edition (WASI-II) (Wechsler, 2011) or the Wechsler Intelligence Scale for Children-5th edition (WISC-V) (Wechsler, 2014) were administered to obtain a measure of verbal cognitive ability, or verbal intelligence quotient (VIQ), and nonverbal cognitive ability, or performance intelligent quotient (PIQ). VIQ composite scores ranged from 45-111 and reflected the ability to express ideas and make abstract connections using language as assessed via the Vocabulary and Similarities subtest scores of the Verbal Comprehension Index. PIQ composite scores ranged from 55-144 and reflected the ability to examine visual details and problem-solve with visual information as measured by the Block Design and Matrix Reasoning (WASI-II)/Visual Puzzles (WISC-V) subtest scores of the Visual-Spatial (WISC-V)/Perceptual Reasoning (WASI-II) Index. The Digit Span (DS) subtest was also administered which asked the children to remember and repeat a series of numbers in the same, backward, and sequential orders. DS scaled scores ranged from 1-18 and represented a measure of auditory working memory. General cognitive functioning was measured using participants' full-scale IQ composite scores (n = 50, range = 48-121) derived from their performance on the WASI-II/WISC-V. Three participants could not complete the DS subtest and other subtests that comprised the full-scale index due to scheduling constraints.

Hearing

Preserved hearing skills were verified with a standard in-person hearing screener (https://www.legroupeforget.com) (n = 43 autistic children), parents confirming that their child did not have a hearing loss/impairment (n = 7 autistic children), or the experimenter ensuring that the musical stimuli were heard by the children through over-ear headphones during the practice session of the experimental task (n = 3 autistic children).

Musical Beat Perception Task

Musical beat perception was measured using the same adapted musical beat perception task described in our earlier study (Dahary et al., 2023; Iversen & Patel, 2008). The task consisted of 20 trials that played 10 different non-lyrical musical excerpts selected from a bank of genres (jazz, rock, pop, and orchestral). The music stimuli were played in 3/4- or 4/4-time signatures at a tempo ranging from 104-105 beats per minute for a total of 12-19 seconds. The participants were asked to listen to each musical excerpt with overlaid beeps and to indicate if the beeps were aligned with the beat of the music by clicking "yes" or "no" on a computer screen using a mouse. The tempo of overlaid beeps was aligned with the tempo of the musical beat on 10 trials (on-beat condition) and misaligned on 10 trials (5 trials 10% faster or 5 trials 10% slower; off-beat condition). The participants completed a practice session with an experimenter who provided corrective feedback to facilitate the comprehension of the task. The sound of the superimposed beeps was introduced in a 30-second track without music after which one on-beat trial and one off-beat trial using two musical excerpts (not used in the test trials) were presented. The participants went on to complete the test trials regardless of their accuracy in the practice session. The task was completed in about 8-10 minutes on a PC laptop with over-ear headphones.

Total accuracy scores were calculated by averaging the number of correct responses in percentage overall and for the on-beat and off-beat conditions, separately. To control for response bias on the task overall (i.e., the inclination to respond "yes" more frequently than "no", or vice versa), Hits minus False Alarm (Hits-FAs) were also generated using the following formula: Hits (number of correct responses for 'on-beat' trials/number of 'on-beat' trials) minus False Alarms (number of incorrect responses for 'off-beat' trials/number of 'off-beat' trials), ranging from -1 to +1. The pattern of results was similar when analyses related to overall task performance were run with accuracy scores versus Hits-FAs. The results were only interpreted with percent accuracy scores for simplicity.

Planned Analyses

Frequentist (conventional) statistical analyses were conducted in SPSS statistics (v27.0) and supplemented with Bayesian equivalent tests using JASP software (v.16.3; JASP Team, 2022) (see Supplementary Material for Bayesian analyses details).

Performance on the Musical Beat Perception Task

The first objective of this study was explored with one sample t-tests with overall scores (conditions combined), on-beat scores, and off-beat scores interchangeably entered as the dependent variable to examine whether the participants as a group ($N = 53$) performed above the theoretical chance threshold of the task (i.e., 50%, two response options). A paired t-test was also used to compare performance accuracy on the on-beat versus off-beat conditions. Despite incomplete data on participants' musical experience, an effort was also made to interpret findings within the context of musical history given findings from previous studies showing that musical experience may positively impact beat perception skills (e.g., Nave-Blodgett et. al., 2021). One-sample and paired t-tests were re-conducted with the subgroup of participants whose musical experience was available ($n = 31$) and an independent t-test was carried out to compare their performance to that of participants whose musical experience was not available ($n = 22$). Non-parametric Kendall tau-b correlation coefficients were used to explore potential relationships between GMSI total scores, and overall, on-beat, and off-beat scores on the task.

Predictors of Musical Beat Perception Task Performance

Standard multiple regression model analyses were used to explore the second objective of this study, which was to assess whether age (years), verbal cognitive ability (VIQ composite scores), nonverbal cognitive ability (PIQ composite scores), auditory working memory (DS scaled scores), and autism characteristics (SRS-2 Total *T*-scores) uniquely predicted performance on the musical beat perception task. Regression analyses were first conducted with overall scores as the outcome variable and then re-conducted with on-beat and off-beat scores interchangeably entered as the outcome variable for exploratory purposes. The sample size for the regression analyses was $n = 49$ because three participants did not complete the DS subtest and a parent of one participant did not complete the SRS-2 (see details above).

Power and Test Assumptions. A priori power analyses were conducted with G*power (v3.1; Faul et al., 2013) for the frequentist analyses. There was 80% power at an alpha level of .05 to detect medium-to-large effect sizes for the main t-test analyses (i.e., one sample and paired t-tests) ($N = 53$) and large effect sizes for the regression analyses ($n = 49$). The assumptions for t-tests and regression analyses were met following the removal of one outlier in the initial sample. For t-tests, for example, boxplots revealed no extreme outliers and Shapiro-Wilk tests ($p_s > .05$) or skewness and kurtosis values (z-scores < 1.96) confirmed normality. Robustness checks were also conducted for the Bayesian t-tests and most results were found to be robust unless otherwise specified. For regressions, visual inspection of plots (i.e., partial regression plots, a plot of studentized residuals against the predicted values, and a Q-Q plot) confirmed the assumption of linearity, homoscedasticity, and normality. There was independence of residuals and no evidence of multicollinearity based on the Durbin-Watson statistic and tolerance values, respectively, and no influential cases based on sufficiently low studentized deleted residuals (< ± 3 SDs), standardized DFBeta (< ± 1), and Cook's distance (< 1) (Field, 2013).

Results

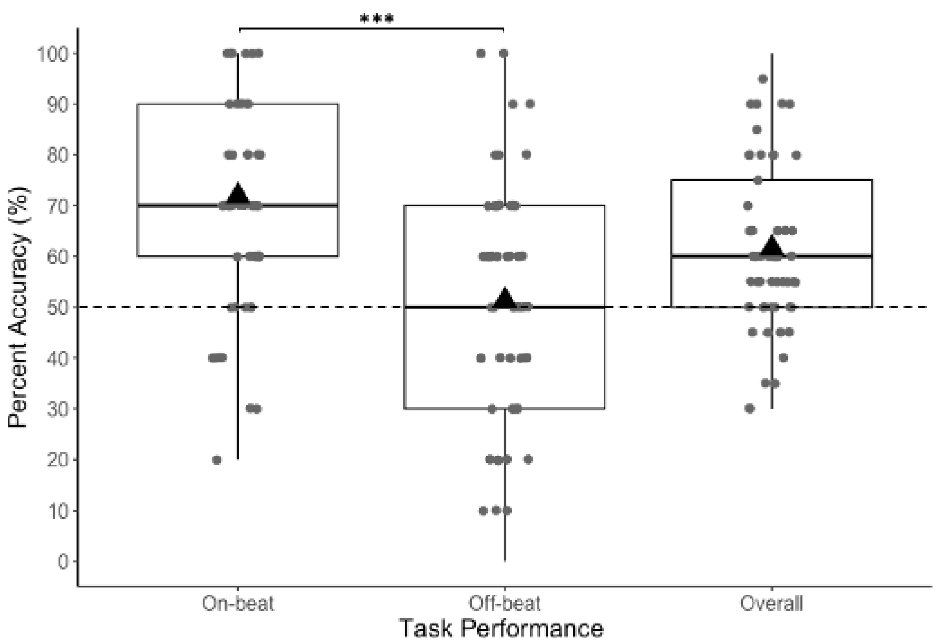
Performance on the Musical Beat Perception Task

Performance was significantly higher than the theoretical chance threshold of 50% on the task overall ($t(52) = 4.97$, $p < .001$, $d = .68$, $BF_{10} = 4\ 805.06$) on the on-beat condition ($t(52) = 7.30$, $p < .001$, $d = 1.00$, $BF_{10} = 1.36 \times 10^7$) but not on the off-beat condition ($t(52) = .39$, $p = .697$, $d = .05$, $BF_{10} = .21$) (see Figure 1). On-beat performance scores were significantly higher than off-beat performance scores at the group level ($t(52) = 4.72$, $p < .001$, $d = .65$, $BF_{10} = 1\ 090.69$) indicating that most of the participants were better at identifying beat alignments than beat misalignments. Removing the 16 of 53 participants who performed at or below the chance level on the task overall resulted in a 7-point increase in overall scores ($M = 69\%$, $SD = 14\%$ versus $M = 62\%$, $SD = 17\%$), a 9-point increase in on-beat scores ($M = 81\%$, $SD = 17\%$ versus M = 72%, SD = 22%), and a 7-point increase in off-beat scores ($M = 58\%$, $SD = 23\%$ versus $M = 51\%$, $SD = 25\%$), with performance on the on-beat condition remaining significantly higher than the off-beat condition, $t(36) = 4.67$, $p < .001$, $d = .77$, $BF_{10} = 564.76$. Compared to the participants who performed above chance level ($n = 37$), participants who performed at or below chance level ($n = 16$), did not significantly differ as a group in age ($t(51) = 1.31$, $p = .197$, $d = .39$, $BF_{10} = .59$) nor in SRS Total T-scores ($t(50) = 1.57$, $p = .123$, $d = -.48$, $BF_{10} = .80$), though only anecdotal evidence was found in support of the null. The participants who performed at or below chance level had significantly lower PIQ composite scores ($t(51) = 2.06$, $p = .044$, $d = .62$, $BF_{10} = 1.60$), VIQ composite scores ($t(51) = 2.93$, $p = .005$, $d = .88$, $BF_{10} = 8.21$), DS scaled scores ($t(48) = 3.34$, $p = .002$, $d = 1.03$, $BF_{10} = 20.47$), and FSIQ composite scores ($t(48) = 3.35$,

$p = .002$, $d = 1.03$, $BF_{10} = 20.89$), with all cognitive variables except PIQ remaining significant after Bonferroni correction for multiple comparisons was applied ($p < .008$) and obtaining at least moderate and robust evidence based on Bayes factors.

Figure 1

Musical Beat Perception Task Performance



Note. Performance was above the theoretical threshold of 50% on the task overall and on the on-beat condition (p_s < .001), but not on the off-beat condition (p =.697) at the group level. The group of participants performed significantly higher on the on-beat condition than on the off-beat condition ($p < .001$). The triangles denote mean accuracy. Dashed line indicates a theoretical threshold of 50%. ***p <.001.

Follow-up Analyses with Musical Experience

Consistent with group analyses with all 53 participants, the subgroup of participants with available musical experience data ($n = 31$) performed above the theoretical chance threshold overall ($t(30) = 3.30$, $p = .001$, $d = .59$, $BF_{10} = 29.23$), on the on-beat condition ($t(30) = 4.92$, $p < .001$, $d = .88$, $BF_{10} = 1\ 580.54$), but not on the off-beat condition ($t(30) = .07$, $p = .471$, $d = .01$,

BF_{10} = .20) (see Table S2). Similarly, scores on the on-beat condition were significantly higher than scores on the off-beat condition ($t(30) = 3.29$, $p = .003$, $d = .59$, $BF_{10} = 14.45$). There was also no significant difference in overall, on-beat, and off-beat scores between the group of participants with versus without musical experience data ($p_s > .05$), though only the finding of no difference on the off-beat condition obtained robust and more than anecdotal evidence in support of the null (see Table S2). There was also some evidence in the anecdotal-to-moderate ranges to suggest no significant associations between GMSI total scores and overall scores ($\tau_b = -.02$, $p = .881$, $BF_{10} = .23$), on-beat scores ($\tau_b = .12$, $p = .420$, $BF_{10} = .35$), and off-beat scores ($\tau_b = .05$, $p = .722$, $BF_{10} = .25$).

There was some evidence that the group of participants with versus without musical experience data significantly differed in other demographics (see Table S2). The participants with available musical experience data were significantly younger ($t(51) = -4.08$, $p < .001$, $d = -1.14$, $BF_{10} = 149.02$), had lower VIQ, ($t(51) = -2.26$, $p = .028$, $d = -.63$, $BF_{10} = 2.17$), and FSIQ composite scores ($t(48) = -2.194$, $p = .033$, $d = -.64$, $BF_{10} = 1.47$), and had higher SRS Total *T*-scores ($t(50) = 2.03$, $p = .048$, $d = .57$, $BF_{10} = 1.47$). Even though no significant group difference in PIQ composite scores ($t(51) = -1.75$, $p = .086$, $d = -.49$, $BF_{10} = .97$) and DS scaled scores ($t(48) = -1.56$, $p = .126$, $d = -.45$, $BF_{10} = .77$), little evidence was found in support of the null based on Bayes factors. Overall, age was the only variable that was significantly different between the groups after adjusting for multiple comparisons ($p < .008$) and that obtained very strong and robust evidence for this difference.

Predictors of Musical Beat Perception

Regression analyses were used to examine the influence of age, cognitive abilities (verbal, nonverbal, and auditory working memory), and degree of autistic characteristics on musical beat perception (see Table 2).

Overall Performance Scores

The initial regression model (N = 49) with age (M = 11, SD = 2), VIQ composite scores (M = 75, SD = 18), PIQ composite scores (M = 88, SD = 21), DS scaled scores (M = 6, SD = 4), and SRS-2 Total T-scores (M = 70, SD = 8) as predictors significantly predicted overall task performance (M = 62%, SD = 17%) ($p < .001$). Age ($p = .017$) and PIQ composite scores (p = .044), but not VIQ composite scores, DS scaled scores, and SRS-2 Total T-scores ($p_s > .05$), uniquely contributed to the variability in overall scores. Although DS scaled scores were not a significant predictor in the initial model, there was extreme evidence that a model including age, PIQ composite scores, and DS scaled scores was the best model compared to the null model (BF_{10} = 1 025.16). Therefore, frequentist and Bayesian regression analyses were re-run with only the three predictors of the best model. The final model (N = 50) including age, PIQ composite scores, and DS scaled scores significantly predicted overall performance ($p < .001$). Age (p = .009) and PIQ composite scores ($p = .013$) remained significant variables in the model with moderate support for their inclusion ($BF_{inclusion}$ = 4.97-5.35). Consistent with the initial model, DS scaled scores did not significantly predict overall scores ($p > .05$) and there was only anecdotal evidence for the inclusion of this predictor in the final model ($BF_{inclusion}$ = 1.75).

Table 2.

Regression Analyses Predicting Overall, On-Beat, and Off-Beat Percent Accuracy Scores on the Musical Beat Perception Task.

	Overall					**On-Beat**					**Off-Beat**				
Initial Model: Predictors *n* = 49	*B*	*SE B*	*β*	*p*	$BF_{inclusion}$	*B*	SE_B	*β*	*p*	$BF_{inclusion}$	*B*	SE_B	*β*	*p*	$BF_{inclusion}$
Age (years)	2.50	1.01	.29	.017*	4.97	2.21	1.56	.21	.163	1.08	2.78	1.49	.23	.069	1.57
PIQ (composite scores)	.25	.12	.30	.044*	5.35	.15	.19	.15	.419	.87	.35	.18	.30	.057	4.72
VIQ (composite scores)	.13	.14	.13	.357	.62	.07	.21	.05	.755	.53	.19	.20	.14	.356	.74
DS (scaled scores)	1.09	.68	.24	.112	1.48	.91	1.04	.16	.387	.76	1.28	1.00	.20	.206	1.09
SRS-2 Total (*T*-scores)	.08	.26	.04	.751	.33	.21	.41	.08	.604	.45	-.04	.39	-.02	.912	.36
Initial Model Statistics	$F(5, 43)= 6.31, p < .001$*** $R^2 = .42, R^2_{adj} = .36$					$F(5, 43) = 1.39, p = .246$ $R^2 = .14, R^2_{adj} = .04$					$F(5, 43) = 4.91, p = .001$** $R^2 = .36, R^2_{adj} = .29$				
Predictors in the Best Model	Age + PIQ + DS BF_{10} = 1 025.16					PIQ BF_{10} = 1.20					Age + PIQ + DS BF_{10} = 141.49				
Final Model: Predictors *n* = 50[a]	*B*	*SE B*	*β*	*p*	$BF_{inclusion}$	*B*	SE_B	*β*	*p*	$BF_{inclusion}$	*B*	SE_B	*β*	*p*	$BF_{inclusion}$
Age (years)	2.61	.97	.31	.009*	5.15	-	-	-	-	-	3.00	1.43	.25	.041*	1.77
PIQ (composite scores)	.29	.11	.35	.013*	7.88	-	-	-	-	-	.39	.17	.34	.023*	6.67
DS (scaled scores)	1.23	.61	.27	.051	1.75	-	-	-	-	-	1.51	.90	.24	.101	1.17
Final Model Statistics	$F(3, 46)= 11.09, p < .001$*** $R^2 = .42, R^2_{adj} = .38$					-					$F(3, 46)= 8.09, p < .001$*** $R^2 = .35, R^2_{adj} = .30$				

Note. B = unstandardized regression coefficient; SE *B* = standard error of the coefficient; β = standardized regression coefficient; R^2_{adj} = adjusted coefficient of determination; $BF_{inclusion}$ = inclusion of Bayes Factor; VIQ = Verbal Intelligence Quotient; PIQ = Performance Intelligence Quotient; DS = Digit Span; SRS-2 = Social Responsiveness Scale-2. [a] sample size increased to *n* = 50 because the one participant missing an SRS-2 was included in the final model. *$p < .05$, **$p < .01$, ***$p < .001$

On-Beat Performance Scores

The five-predictor model did not significantly explain variability in performance on the on-beat condition (*M* = 72%, *SD* =22%). There was also only anecdotal evidence for the best model compared to the null model (*BF10* = 1.20).

Off-Beat Performance Scores

The five predictors in the model collectively contributed to off-beat scores (*M* = 53%, *SD* = 24%) (p = .001) but did not significantly explain the variance on their own (p_s > .05). Based on Bayesian analyses, however, there was moderate evidence for the unique contribution of PIQ composite scores on off-beat scores ($BF_{\text{inclusion}}$ = 4.72) and extreme evidence that a model including age, PIQ composite scores, and DS scaled scores was the best model compared to the null model (BF_{10} = 141.49). Analyses were re-run with only the three predictors of the best model and this final model significantly predicted performance on the off-beat condition (p < .001). DS scaled scores remained non-significant (p > .05), but age (p = .041) and PIQ composite scores (p = .023) significantly explained variance in off-beat scores. Similar to the first model, PIQ composite scores received the most (moderate) evidence for its inclusion in the final model ($BF_{\text{inclusion}}$ = 6.67).

Discussion

We investigated the musical beat perception skills of a diverse group of autistic children and examined how these skills may differ as a function of age, cognitive abilities (i.e., nonverbal, verbal, and auditory working memory), and level of autistic characteristics using a beat alignment task paradigm (Dahary et al., 2023; Iversen & Patel, 2008). Overall, the findings suggest that the children were better at identifying musical beat alignments than misalignments and that musical beat perception was positively related to age and nonverbal cognitive ability.

Musical Beat Perception Skills

The hypothesis related to chance performance was supported such that there was extreme evidence that the autistic group performed above the theoretical chance threshold on the task overall. Performance was also examined within each task condition separately and found to be above the chance level on the on-beat condition but not on the off-beat condition. Indeed, there was overwhelming support that the children were significantly better at judging beat alignments than misalignments with a similar pattern of results found with the subgroup of children (n = 31) who had minimal (median of 0) musical experience.

The results are consistent with those of our earlier study (Dahary et al., 2023) such that above chance performance was achieved on the on-beat condition, but not the off-beat condition. In that study, we also found that the autistic group was just as accurate as the neurotypical group at detecting musical beat alignments but less precise at detecting musical beat misalignments. The addition of 30 new children in this study minimally altered performance scores on the musical beat perception task (see Table 1 versus Table S1 - overlapping participants), despite these new children having lower verbal cognitive ability, auditory working memory, and overall cognitive functioning (see Table S1). The findings of the current and earlier study combined suggest that children with higher and lower cognitive abilities are sensitive to musical beat alignments. This is consistent with the results of previous studies showing that autistic children with proficient (DePape et al., 2012; Sota et al., 2018; Tryfon et al. 2017) or varying levels of cognitive abilities have intact music perception skills (e.g., Heaton, Williams, 2008).

Musical misalignments are more difficult to detect than musical alignments among neurotypical people (e.g., Iversen & Patel, 2008; Matthews et al., 2016) and may be especially challenging for autistic children (Dahary et al., 2023), potentially due to reduced attention allocation skills and/or multisensory challenges associated with autism (Bebko et al., 2006; Magnée et al., 2011; Stevenson et al., 2014). Beat alignment task paradigms require children to simultaneously attend to multiple pieces of information (i.e., the timing of overlaid beeps, the musical beat, neural oscillations, and motor movement on beat-based production tasks) and to amalgamate this information to make judgements about alignment. The off-beat condition is likely more taxing than the on-beat condition because the different pieces of information are not in synchrony with each other and thus, need to be attended to individually and then compared to each other in multiple ways before a decision about alignment can be made.

Musical Beat Perception Increases with Age

In harmony with our hypothesis, age was a unique predictor of musical beat perception. A two-year increase in age was associated with about a 5-point increase in overall scores when holding other predictors constant. Anecdotal evidence based on Bayes factors suggested that age was possibly important for detecting beat misalignment given that older children tended to do significantly better on the off-beat condition (in the final model), which was a finding that was not found for beat alignment judgments. However, small Bayes factors associated with these results suggest potential insensitivity in our data, precluding accurate conclusions about the impact of age on the identification of beat alignments or misalignments, specifically. Nevertheless, our finding related to age and overall beat perception is in keeping with the findings of other work showing that beat sensitivity increases with age in childhood (Nave-Blodgett et al., 2021) and that age is positively related to rhythm discrimination (Jamey et al., 2019; Sota et al., 2018) and beat synchronization skills among autistic children (Tryfon et al., 2017).

Musical Beat Perception Increases with Nonverbal but not Verbal Cognitive Ability

As hypothesized, nonverbal cognitive ability, but not verbal cognitive ability, was a unique predictor of musical beat perception. We found moderate evidence that a 21-point increase in PIQ composite scores resulted in a 6 to 7-point increase in overall scores and that a 24-point increase in PIQ composite scores resulted in a 7 to 8-point increase in off-beat scores. In terms of verbal cognitive ability, children who performed below (versus above) chance performance had significantly lower VIQ composite scores, with a corresponding Bayes factor in the moderate range. However, VIQ composite scores did not significantly contribute to children's musical beat perception skills when holding other variables constant and were not included as a predictor in the best model across Bayesian regression analyses.

The findings of the present study are similar to those of other studies showing that musical rhythm discrimination skills of autistic children (DePape et al., 2012) and musical beat perception skills of autistic and neurotypical children are unrelated to language skills (Dahary et al., 2023; Einarson & Trainor, 2015, 2016), but that the perception of musical structures is linked to nonverbal cognitive ability (e.g., Chowdhury et al., 2017; Heaton, Allen et al., 2008; Jamey et al., 2019; Stanutz et al., 2014; Quintin et al., 2013). In Jamey et al. (2019), PIQ and VIQ composite scores were not significantly related to performance on a musical rhythm discrimination task; PIQ explained about 13% and VIQ explained 12-16% of task performance variance [albeit non-significant], putting the degree of specificity of the effect of nonverbal versus verbal cognitive ability into question. We address this ambiguity by showing that verbal cognitive ability unlikely accounts for variability in musical rhythm/beat perception that is not already explained by other variables like nonverbal cognitive ability and age.

Our finding that nonverbal cognitive ability is related to musical beat perception skills aligns with idea that autistic children with well-developed or enhanced perceptual systems have an advantage in processing sensory (e.g., musical/auditory) information (Mottron et al., 2000; Mottron et al., 2006). It has also been proposed that children with higher (versus lower) nonverbal cognitive ability may be more effective at allocating attentional resources to process music-related qualities (Mayer et al., 2016) and this may become more apparent on tasks that place a high demand on attention such as the off-beat condition of the musical beat perception task. Children have to integrate multiple pieces of incongruent information simultaneously to make judgements about beat misalignments and those with better developed nonverbal cognitive skills may be more equipped to do this successfully given that multisensory integration skills are linked to and modulated by attention (e.g., Magnée et al., 2011).

Auditory Working Memory May not Uniquely Contribute to Musical Beat Perception

Auditory working memory did not significantly affect musical beat perception when variability in other predictors was held constant. This ran counter to our hypothesis and the findings of other work showing that auditory working memory is positively associated with rhythm perception and reproduction skills of neurotypical children (Anvari et al., 2002; Hansen et al., 2012; Strait et al., 2011) as well as of autistic and other neurodivergent children (Flaugnacco et al., 2014; Sota et al., 2018). The relationship between auditory working memory and musical rhythmic skills of children has been predominately explored within the context of rhythm discrimination (Anvari et al., 2002; Hansen et al., 2012; Strait et al., 2011) or reproduction tasks (Flaugnacco et al., 2014) as opposed to beat alignment tasks, which may rely less heavily on working memory. While the beat alignment task requires listeners to attend to both the musical beat and overlaid beeps, it does not require the children to hold in memory one musical excerpt in order to compare it to another musical excerpt as is the case on rhythm discrimination tasks or to recreate it as is the case on rhythm reproduction tasks (Fiveash et al., 2022). In keeping with our findings, Einarson and Trainor (2015, 2016) used a beat alignment task paradigm and did not find a significant effect of auditory working memory on the performance of young neurotypical children.

Alternatively, our data may have been insufficiently sensitive to detect the unique effect of auditory working memory on task performance. Inclusion Bayes factors for DS scaled scores neared 1 across models (i.e., demonstrating inconclusive evidence) even though there was extreme evidence that the final (best) models for predicting overall and off-beat scores should include auditory working memory. Indeed, positive associations between working memory and beat perception and production skills (Bailey & Pehune, 2010, 2012; Matthews et al., 2016) as well as shared neural mechanisms underlying working memory and beat-based rhythm processing are found among neurotypical adults (Teki et al., 2011, 2012). In addition to potential insensitivity in our data, the autistic group in our study had lower than average auditory working memory abilities based on a mean DS scaled score of 6 (versus a mean scaled score of 10 in the general population). Thus, the children may not have been able to capitalize on their auditory working memory skills to support their performance on the musical beat perception task.

Degree of Autistic Characteristics do not Predict Musical Beat Perception

The degree of autistic characteristics did not significantly predict musical beat perception and was not included in the best model across Bayesian analyses. Our result suggests that musical beat perception remains intact across a broad range of autistic characteristics, which coincides with previous results showing that core features of autism are unrelated to musical/auditory rhythm processing (Jamey et al., 2019; Knight et al., 2020; Sota et al., 2018), and to other musical skills including melodic and pitch perception (Jamey et al., 2019; Sota et al. 2018). Our finding of no relationship is also consistent with the lack of group difference found between neurotypical and autism diagnostic groups when they make same-different judgments about beat-based rhythms (Jamey et al., 2019; Sota et al., 2018), perceive beat alignments (Dahary et al., 2023) or physically synchronize with the beat of the music (Tryfon et al., 2017).

Future Directions

The current study offers several avenues for future research to continue clarifying the perceptual accessibility of music's rhythm/beat for children across the autism spectrum. To start, the suitability of the beat alignment task paradigm for children with co-occurring intellectual difficulties needs to be further explored. Ten children with low VIQ composite scores were excluded from analyses in this study for seemingly not having understood the task and 16 children with low scores across most cognitive variables at the group level did not achieve performance above the chance level on the task overall, suggesting that the task was very difficult for children with limited cognitive abilities. It may be helpful to add more practice trials and visuals that correspond to the timing of the overlaid beeps to facilitate task comprehension and delineate more clearly beat alignments and misalignments (e.g., a video of a puppet drumming in accordance with the overlaid beeps as done by Einarson and Trainor, 2015, 2016).

More research is needed to clarify predictors of musical beat perception. Several non-significant results obtained Bayes factors close to 1 (e.g., associations with on-beat scores and the effect of auditory working memory on overall and off-beat scores), suggesting data insensitivity (i.e., more participants might be needed) as opposed to a true lack of relationship between predictor and outcome variables (Quintana & Williams, 2018). In addition to using a larger sample size in future studies, the potential relationship between auditory working memory and musical beat perception should be examined with autistic children who collectively show at least average auditory working memory and with neurophysiological measures that may better suited for capturing this relationship (e.g., Grahn, 2009; Teki et al., 2011, 2012, 2016).

Moreover, although verbal cognitive ability and level of autistic characteristics were not unique predictors of musical beat perception, these findings do not preclude the potential for impaired musical beat perception among autistic children with concurrent disorders. Developmental speech and language disorders are associated with atypical rhythm/beat processing (Ladányi et al., 2020) and our research group found evidence of a positive relationship between musical beat perception and phonological awareness among autistic children (Rimmer, Dahary et al., 2023). Future work may consider comparing musical beat perception between different groups of children (e.g., a neurotypical group versus autistic groups with and without co-occurring language-based disability) and/or assessing the relationship between musical beat perception and language using more comprehensive measures of language to elucidate the potential impact of language on musical rhythmic skills.

Lastly, while we found some evidence that musical experience was not associated with task performance, musical experience data was only available and very minimal (i.e., little variability) for a subgroup of children. Future investigations may consider exploring how autistic children with and without musical training may differ in musical beat perception and how their level of musicianship may interact with other predictors in light of work showing improved musical beat sensitivity (Nave-Blodgett et al., 2021) and cognitive functions (e.g., attention, multisensory, working memory skills) in musically trained children (e.g., Kausel et al., 2020).

Implications

The current study provides a better characterization of the rhythmic musical skills of autistic children and supports music programs as an ecologically valid non-verbal intervention, contrasting other intervention programs for autistic children and adolescents that rely heavily on preserved verbal cognitive abilities (e.g., Rodda & Estra, 2018). Autistic children appear perceptually sensitive to musical beat alignments, which is an important skill when participating in musical activities that involve playing and singing in synchrony with the beat of the music and with other people. Musical beat perception is likely spared across a broad range of autistic characteristics and verbal cognitive abilities, demonstrating that beat sensitivity may be independent of variability in these areas. While being younger, having nonverbal cognitive difficulties, and/or having concurrent disorders may negatively impact one's sensitivity to the beat of the music, musical beat perception can be directly reinforced via formal musical training (i.e., music lessons) (Fiveash, 2021; Patel, 2011). Following formal musical training (if needed), the timing of music's beat during interactive musical activities (e.g., playing music as a group) can be used to learn about the timing of less accessible rhythms in non-musical areas of learning (Daniel et al., 2022; Lense & Camarata, 2020) and may lead to other far transfer effects associated with music participation benefiting domains such as speech/language (e.g., Chenausky et al., 2016; Chenausky et al., 2017), socialization (e.g., LaGasse, 2014; Sharda et al., 2018), and cognition (e.g., Kausel et al., 2020). The results of this study and the therapeutic potential of regularly engaging with music illustrate why musical experiences should be prioritized instead of deprioritized in education (e.g., Canadian Union of Public Employees, 2019).

Conclusions

We examined the musical beat perception skills of a diverse group of autistic children and the unique effect of age, cognitive abilities, and autistic characteristics on these skills. Overall musical beat perception was above the theoretical chance level of 50%. The children showed greater accuracy scores on the on-beat condition compared to the off-beat condition, suggesting adequate perceptual sensitivity to musical beat alignments; an important skill to have when singing or playing an instrument in synchrony with the beat of the music and with other people. Musical beat perception increased with age and nonverbal cognitive ability, but not with verbal cognitive ability, auditory working memory, and degree of autistic characteristics. The findings provide some evidence that the beat of the music is perceptually accessible across the autism spectrum and motivates future work to clarify the appropriateness of rhythm-based music interventions for autistic children with concurrent disorders that have been associated with atypical rhythm processing (e.g., developmental speech and language disorders).

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Supplementary Material

Musical beat perception skills of autistic children increase with age and nonverbal cognitive ability

Bayesian Analyses

Bayesian versions of frequentist t-test, correlations, and regression analyses were conducted to provide more quantifiable evidence in support of the null versus the alternative hypotheses. Unlike tests of significance, Bayesian inferences do not necessarily require a large sample size to find reliable evidence for retaining or rejecting the null hypothesis (Peter Rosenfeld & Olson, 2021). A Bayes factor (*BF*) is a continuous measure of the evidence that assesses the probability of obtaining the data under the alternative hypothesis (H_1) compared to the probability of obtaining the data under the null hypothesis (H_0). A BF_{10} of 6.0, for instance, suggests that the data observed is 6 times more likely under the alternative hypothesis than under the null hypothesis, and is equivalent to a $BF_{01} = 1/6 = 0.17$. *BF* values were interpreted using an acceptable classification scheme (Jeffreys, 1961; Lee & Wagenmakers, 2013, as cited in Schönbrodt & Wagenmakers, 2018): 1 = "no evidence", 1 to 3 = "anecdotal evidence", 3 to 10 = "moderate evidence", 10 to 30 = "strong evidence", 30 to 100 = "very strong evidence", and >100 "extreme evidence". All Bayesian analyses were conducted with the default uninformative priors in JASP given that well-established prior knowledge regarding the hypotheses was not available (Quintana & Williams, 2018), and for Bayesian regression analyses, the "uniform" option was selected as the prior distribution of the models to assign equal probabilities for each possible model (Goss-Sampson et al., 2020).

Table S1

Participant Characteristics and Performance Accuracy on the Musical Beat Perception Task for Overlapping versus Nonoverlapping Autistic Participants with Dahary et al. (2023)

	Overlapping Participants		Nonoverlappin g Participants		Group Differences		
Participant Characteristics	*n*	*Mean (SD)*	*n*	*Mean (SD)*	*t*	*p*	BF_{10}
Age (years)	23	10 (2)	30	12 (2)	-1.91	.062	1.22
PIQ composite scores (WISC-V/WASI)	23	94 (19)	30	83 (22)	1.80	.078	1.04
VIQ composite scores (WISC-V/WASI)	23	86 (16)	30	67 (16)	4.22	<.001	220.18
Full-Scale composite scores (WISC-V/WASI)	21	86 (14)	29	73 (16)	3.15	.003	13.28
DS scaled scores (WISC-V)	21	7 (4)	29	5 (3)	2.85	.006	6.90
SRS-2 Total *T*-scores	23	69 (8)	29	70 (9)	-.37	.710	.30
Musical Beat Perception Task Performance	*n*	*Mean (SD)*	*n*	*Mean (SD)*	*t*	*p*	BF_{10}
Overall (Hits-FAs)	23	0.3 (0.3)	30	.2 (.4)	.75	.345	.35
Overall (% accuracy)	23	63 (16)	30	60 (18)	.70	.375	.34
On-beat (% accuracy)	23	75 (20)	30	69 (23)	.97	.321	.41
Off-beat (% accuracy)	23	52 (21)	30	51 (27)	.11	.729	.28

Note. VIQ = Verbal Intelligence Quotient; PIQ = Performance Intelligence Quotient; DS = Digit Span; SRS-2 = Social Responsiveness Scale-2; WISC-V = Wechsler Intelligence Scale for Children-Fifth Edition; WASI = Wechsler Abbreviated Scale of Intelligence; GMSI = Goldsmiths Musical Sophistication Index; Hits-FAs = Hits minus False Alarms; *BF* = Bayes Factor ($BF_{01} = 1/BF_{10}$).

Table S2

Participant Characteristics and Performance Accuracy on the Musical Beat Perception Task among Children with (n = 31) and without (n = 22) Available Musical Experience Data

	Musical Experience Data		No Musical Experience Data		Group Differences	
Participant Characteristics	*n*	*Mean (SD)*	*n*	*Mean (SD)*	*p*	BF_{10}
Age (years)	31	10 (2)	22	12 (2)	< .001	149.02
PIQ composite scores (WISC-V/WASI)	31	84 (17)	22	94 (25)	.086	.97
VIQ composite scores (WISC-V/WASI)	31	71 (16)	22	82 (19)	.028	2.17
Full-Scale composite scores (WISC-V/WASI)	31	74 (15)	19	85 (18)	.033	1.47
DS scaled scores (WISC-V)	31	5 (4)	19	7 (4)	.126	.77
SRS-2 Total *T*-scores	31	72 (8)	21	67 (8)	.048	1.47
Musical Beat Perception Task Performance	*n*	*Mean (SD)*	*n*	*Mean (SD)*	*p*	BF_{10}
Overall (Hits-FAs)	31	0.2 (0.3)	22	.3 (.3)	.345	.41
Overall (% accuracy)	31	60 (17)	22	64 (18)	.375	.39
On-beat (% accuracy)	31	69 (22)	22	75 (22)	.321	.42
Off-beat (% accuracy)	31	50 (24)	22	53 (25)	.729	.29

Note. VIQ = Verbal Intelligence Quotient; PIQ = Performance Intelligence Quotient; DS = Digit Span; SRS-2 = Social Responsiveness Scale-2; WISC-V = Wechsler Intelligence Scale for Children-Fifth Edition; WASI = Wechsler Abbreviated Scale of Intelligence; GMSI = Goldsmiths Musical Sophistication Index; Hits-FAs = Hits minus False Alarms; *BF* = Bayes Factor ($BF_{01} = 1/BF_{10}$).

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Chapter 6: General Discussion

Our current understanding of autism is primarily based on research focused on its areas of deficit and challenge (Pellicano & den Houting, 2021). However, we know that autistic children are like all children, such that they have areas of interest and skill (Clark & Adams, 2020). The discovery of autistic children's positive attributes and methods that hone these qualities enable clinicians, teachers, and other professionals to create and implement accessible supports in the physical environment that allow all children with and without autism to learn, play, and develop together (Sonuga-Barke & Thapar, 2021). Achieving genuine inclusion in our communities and schools does not require executing costly and time-consuming interventions. Instead, feasible and sustainable supports that embrace all children's general interests and skills are needed to enable them to attend and participate at their level, using their potential while still addressing their growth areas (Clark & Adams, 2020). My dissertation aimed to inform on the ecological validity of using shared social activities that leverage the skills of autistic children with different developmental abilities, such as musical skills during group music-making, for producing optimal outcomes in inclusive social and learning settings. The general findings and contributions of my dissertation and future directions for research and implications for clinical and educational practices are elaborated below.

Objectives and Discussion of Manuscript 1

In the systematic review presented in Manuscript 1 of Chapter 3 (Dahary et al., 2022), I evaluated the effectiveness of shared social activity-based interventions that leverage autistic children's preference for structure and predictability for promoting socialization. I explored the appropriateness of these interventions for autistic children with different developmental profiles and the role that neurotypical children assume during the various activities (i.e., an equal play partner versus a coach/helper). More specifically, I wondered whether structured social activity-based interventions 1) generated positive gains in the areas of social cognition, social communication, and/or social functioning for autistic and neurotypical children, 2) were suitable for autistic children of different ages and with different support needs, 3) allowed autistic and neurotypical children to participate in activities as equal play partners, and 4) had sufficient empirical evidence supporting their social validity.

The results of 15 studies (12 studies with strong or adequate methodological rigour) were interpreted and synthesized in Manuscript 1. Thirteen studies documented significant improvements in social cognition (e.g., theory of mind, memory for faces), social communication (e.g., social initiation and responses, interactive play), and, in some cases, social functioning (i.e., overall social competence) for autistic children immediately after participating in musical, Lego, theatre, or general interest-based activities (e.g., Corbett et al., 2019; Hu et al., 2018; Kern & Albridge, 2006; Koegel et al., 2005; Koegel et al., 2013) with six (out of seven) studies also demonstrating the maintenance (e.g., Baker et al., 1998; Corbett et al., 2016; Hu et al., 2021; Levy & Dunsmuir, 2020; Watkins, O'Reilly et al., 2019) and a few studies showing the generalization of these positive gains (Baker et al., 1998; Corbett et al., 2016; Watkins et al., 2019b). Although social functioning and peer outcomes were rarely measured pre to post intervention, the potential for shared social activities to promote the social well-being of autistic children and their peers was occasionally captured via post-measures of social validity. In some studies, autistic children and their peers reported positive attitudes toward each other and new friendships following the intervention (e.g., Hu et al., 2018; Koegel et al., 2013; Sansi et al., 2020). Findings of other studies that were not included in this review due to failure to meet the inclusion criteria also show that shared structured social activities, such as group music-making

(Cook et al., 2019), robotics (Kaboski et al., 2015), and videogame activities (Chiang et al., 2004), improve the quality of friendships and prosocial emotions, and decrease rates of victimization and social anxiety, which contribute to children's overall social adjustment and inclusion (Symes & Humphrey, 2010). In addition, the findings of two studies in the systematic review demonstrated that autistic children expressed positive affect towards their peers during and following interest-based activities (Baker et al., 1998; Koegel et al., 2005), which is noteworthy because shared enjoyment is associated with favourable intergroup outcomes including social acceptance and cross-group friendships (Allport,1954) and is a critical target in evidence-based naturalistic developmental and behavioural interventions (e.g., Social ABCs) (Brian et al., 2022).

Furthermore, positive results were reported in studies that included children as young as three years of age (Kern & Albridge, 2006) and as old as 16 years of age (Koegel et al., 2013) and in studies that included children with varying levels of autistic traits or cognitive and language skills (low support needs: e.g., Hu et al., 2018; Koegel et al., 2013; medium to high support needs: e.g., Baker et al., 1998; Kern & Albridge, 2006; Watkins et al., 2019b; Hu et al., 2021). Although the social effects of inclusive physical activity- and theatre-based interventions for younger children and children with high support needs remain to be investigated, the findings of the systematic review revealed that autistic children with diverse characteristics could successfully engage and benefit from structured social activities that incorporate their natural skills and interests (e.g., an affinity for model building, music, and other hobbies) for nurturing social growth (e.g., Hu et al., 2018; Hu et al., 2021; Kern & Albridge, 2006; Koegel et al., 2005; Koegel et al., 2013; Watkins et al., 2019).

Most shared social activities, particularly those that were built deliberately on children's skills and interests in addition to their natural preference for structure, allowed autistic children and their peers to participate equally in activities and share common goals (e.g., Baker et al., 1998; Hu et al., 2021; Koegel et al., 2005; Koegel et al., 2013; Watkins, O'Reilly et al., 2019), suggesting that the inclusive activity experience itself (e.g., being structured, enjoyable, and strengths-focused) was sufficient for supporting socialization and did not require the addition of peer-or adult-mediation strategies. Positive intergroup outcomes are not only more likely to occur during activities that promote positive emotion sharing but also during activities that elicit a sense of equality among the children by having them collaborate on common goals (e.g., making a musical piece, building a model) using the same means of effort (Allport, 1954), which contrast peer-mediation interventions that encourage peers to take the lead in social interactions in order to model and teach social skills to autistic children. With that said, peer-mediation interventions improve social outcomes for autistic children with diverse characteristics (e.g., Chang & Locke, 2016; Gunning et al., 2018; Watkins et al., 2015). In fact, a few structured shared social activities in this systematic review included peer-mediation strategies and produced positive results (e.g., Corbett et al., 2016; Corbett et al., 2019; Hu et al., 2018; Hu et al., 2021). However, the extent to which positive social outcomes are uniquely related to the peer-mediation strategies versus the shared activity experience is unclear. The peer-mediation component of structured social activity-based interventions needs to be experimentally manipulated to understand better whether it uniquely contributes to social effects and adds value for all or some (e.g., those with higher support needs) autistic children. Indeed, it has been proposed that peer-mediation strategies may not always be needed when sufficiently structured and naturally reinforcing activities are employed (Hu et al., 2018; Hu et al., 2021).

Social validity was demonstrated in 10 of the 15 studies reviewed based on the criteria developed by Reichow et al. (2008). All the studies executed shared social activities in a natural context, measured socially relevant variables, and demonstrated clinically significant social gains from pre- to post-intervention (except Kasari et al. 2016 and Sansi et al. 2020, who did not find significant increases in social variables). Some social activities were also led by adults familiar to the children, were feasible to implement, and generated a rewarding experience for the children, displaying that shared social activity-based interventions can be socially valid and beneficial.

Contributions of Manuscript 1

Manuscript 1 contributed to autism research as the first systematic review to evaluate and demonstrate the beneficial impact of structured social activity-based interventions on the social development of autistic children and their peers. Aggregate findings across 15 studies showed that shared social activities that are sufficiently structured and build on the children's interests and skills produce encouraging results in the social domain for autistic children with diverse characteristics, allow the children to engage in activities in an equal manner, and have accumulated empirical support for their social validity. These findings contribute to the growing body of work showing that autistic children's interest and talent for highly structured and predictable hobbies, such as technology, gaming, physical activity, and musical participation (Clark & Adams, 2020), can serve as accessible platforms for autistic and non-autistic children to share their strengths and learn how to socialize with each other on an equal playing field. This is timely with the results of the CAHS' recent autism assessment to inform a National Autism Strategy wherein service providers reported wanting "to see more availability of autistic spaces and programs for Autistic individuals that don't address therapy goals or skill-building directly but are instead based on creating community and providing accessible opportunities to explore shared interests and leisure activities." (CAHS, 2022, p.119), a perspective also endorsed by autistic adults. Koenig and Williams (2017) found that 96% of surveyed autistic adults felt strongly that teachers should leverage children's preferred interests as strengths to support their learning and mastery of skills in a self-determined way (that is, in a manner that evokes a sense of competence, connection with others, and autonomy) (Deci & Ryan, 2000). Fortunately, I found that shared interest-based activities can be feasible to implement in contexts that have minimal resources to spare because they often utilize materials that are already available (e.g., gym equipment and music rooms in schools), are not overwhelmingly time-consuming (e.g., reasonably short and do not always necessitate the training of peers or adults as social coaches) and are suitable for children with different abilities.

Manuscript 1 also contributed to the field by emphasizing the need for future work to continue exploring the efficacy of shared structured social activities for children across the spectrum and their peers, given that only 15 studies met the inclusion criteria and fewer than 15 demonstrated positive gains that were maintained and generalized to other settings and applicable to autistic children with different abilities (e.g., cognitive difficulties and minimally or non-verbal). One way to clarify the ecological validity of shared structured social activities through research is by studying autistic children's skills in specific activity modalities (e.g., music) to demonstrate precisely how certain social activities are accessible and can be utilized as a strengths-based approach to supporting social inclusion and building valued skills across the spectrum, which was a recommendation that inspired Manuscripts 2 and 3.

In Manuscript 1, I found *one* well-controlled experimental study that examined and demonstrated the social benefits of a shared music-based intervention (Kern & Albridge, 2006), signifying a paucity of work in this area even though listening to and creating music with others can serve as a powerful non-threatening platform for practicing interpersonal skills (Hallam, 2010). Music is familiar and naturally motivating for many neurotypical and neurodivergent children (Campbell, 2002; Molnar-Szakacs et al., 2009; Rabinowitch et al., 2013) because it activates neural circuits of reward and induces a pleasant desire to move (Matthews et al., 2019; Quintin, 2019). Distinct from other activity modalities, music is built on a highly salient and predictable beat (Grahn, 2012) and offers a nonverbal framework for entraining attention cross-modally to learn about the timing of less salient non-musical rhythms (Daniel et al., 2022; Lense & Camarata, 2020; Lense et al., 2022) and for driving cortical plasticity in brain areas implicated in musical and non-musical processing (Hyde et al., 2009; Peretz & Zatore, 2005). Interactive musical activities that involve singing and playing instruments on the beat of the music are associated with positive far-transfer effects to several domains of learning (Flaugnacco et al., 2015; Moritz et al., 2013; Vidal et al., 2020) that are often underdeveloped among autistic children (Christensen et al., 2018; Zeidan et al., 2022) and further interfere with their overall social functioning (e.g., see Bhat et al., 2011 for how motor difficulties can impact social functioning). Music is also increasingly being considered an area of relative strength for autistic people, with findings of most studies showing proficient musical pitch perception, musical memory, and identification of music-evoked emotions (e.g., DePape et a., 2012; Heaton, 2009; Jamey et al., 2019; Quintin et al., 2011; Quintin et al., 2013; Stanutz et al., 2014). However, little is known about autistic children's ability to perceptually synchronize with the salient beat of the music, a precursor skill for successfully creating and sharing the beat with others and benefiting from its therapeutic potential (Lense & Camarata, 2020). In the few studies that have examined the musical rhythm or beat perception skills of autistic children (DePape et al., 2012; Jamey et al., 2019; Sota et al., 2018), same-different rhythm discrimination tasks (also known as sequence-memory-based rhythm/meter perception tasks) were used that likely rely on non-rhythmic skills (e.g., memory), and do not capture the multidimensionality of beat-based abilities very well (Fiveash et al., 2022; Tranchant et al., 2021).

Objectives and Discussion of Manuscripts 2 and 3

Consequently, I examined the musical beat perception skills (i.e., the ability to perceive the salient primary beat of the music) of 23 autistic children aged 6-13 years in Manuscript 2 of Chapter 4 (Dahary et al., 2023) and 53 autistic children aged 6-16 years in Manuscript 3 of Chapter 5 (including the $n = 23$ participants from Manuscript 2) with an adapted version of the beat perception task of the Beat Alignment Test (BAT) (Iversen & Patel, 2008), which is appropriate for non-musicians and correlates well with multiple dimensions of rhythmic abilities including beat-based rhythm perception and production among neurotypical children and adults (Bonacina et al., 2019; Dalla Bella et al., 2017; Fiveash et al., 2022; Tierney & Kraus, 2015). On the adapted beat perception task, children were asked to identify whether beeps overlaid on musical excerpts were on or off the musical beat. The ultimate objective of Manuscripts 2 and 3 was to understand if beat sensitivity can be included in the repertoire of musical skills of autistic children and, in turn, can be leveraged during group music-making activities to support autistic children in reaching their full learning potential. In addition, I included all autistic children in Manuscript 3, regardless of their cognitive abilities (i.e., children with cognitive scores below a standard score of 70 were included as long as task instructions were understood) to ensure that the group of children reflected the heterogeneity that is inherent to autism and to offset the selection bias against children with intellectual difficulties in autism research (Russell et al., 2019).

In Manuscript 2, I assessed the musical beat perception skills of an autistic group matched in chronological age and verbal and nonverbal mental age to a neurotypical group. Autistic and neurotypical groups performed above the theoretical chance threshold of 50% on the task overall and on the on-beat condition. I found some evidence that the two groups of children were equally accurate at detecting beat alignments on the task (that is, at perceiving synchronization between the beat of the music and overlaid beeps), which complements the findings of previous studies demonstrating that autistic and neurotypical children comparably discriminate between beat-based rhythms (Jamey et al., 2019; Sota et al., 2018) and tap on the beat of auditory, non-verbal stimuli (Tryfon et al., 2017). The findings of above chance performance on the task overall and on the on-beat condition were replicated in Manuscript 3 with a larger group of autistic children with a broad range of cognitive abilities, providing evidence that children with higher and lower cognitive capabilities may be sensitive to musical beat alignments. This is consistent with the findings of previous work showing that musical structure processing may be independent of intelligence (e.g., Heaton, Williams et al., 2008), which is highly compelling given that more than one-third of autistic children have intellectual difficulties (Christensen et al., 2018; Zeidan et al., 2022).

In Manuscripts 2 and 3, I found that the autistic group did not perform above the theoretical threshold of 50% on the off-beat condition, and some evidence in Manuscript 2 that the neurotypical group was better at finding musical beat misalignments (that is, at perceptually noticing asynchronization between the beat of the music and overlaid beeps) than the autistic group. Although this could potentially indicate less beat sensitivity for children on the autism spectrum, supporting a previous observation of less specialization of simple metric structures (DePape et al., 2012), musical beat misalignments are naturally more difficult to detect than musical beat alignments, which is the pattern of performance observed on the beat perception subtest of the BAT among neurotypical people who have well-developed beat sensitivity (Iversen & Patel, 2008; Matthews et al., 2016). This may be because the off-beat condition of the task more heavily depends on the application of other skills, such as attention allocation and multi-sensory integration skills (i.e., auditory sequential, auditory simultaneous, and auditory-motor integration) (Reesor, 2017), which increases the cognitive demand of the task for everyone and perhaps more substantially for autistic people who often show differences in these cognitive functions (Bebko et al., 2006; Magnée et al., 2011; Stevenson et al., 2014) or have a global intellectual delay.

To understand the developmental trajectory of musical beat perception and increase the generalizability of findings to autistic children with diverse characteristics, I also looked into preliminary associations in Manuscript 2 and predictors in Manuscript 3 of musical beat perception. Although I did not find any associations between chronological age and musical beat perception in Manuscript 2, I found that it uniquely predicted overall musical beat perception in Manuscript 3 within the context of a larger sample size (i.e., more power) and a regression model controlling for variability in other variables (i.e., cognitive abilities and degree of autistic characteristics), which is in keeping with evidence that beat (or rhythm) perception and production skills increase with age in childhood (Jamey et al., 2019; Nave-Blodgett et al., 2021; Sota et al., 2018; Tryfon et al., 2017). I also found that overall musical beat perception was associated with nonverbal but not verbal mental age in Manuscript 2 and that nonverbal but not verbal cognitive ability was a unique predictor of overall musical beat perception and musical beat misalignments in Manuscript 3, coinciding with the findings of previous studies reporting associations between nonverbal cognitive skills and musical pitch and melodic processing (e.g., Chowdhury et al., 2017; Jamey et al., 2019; Quintin et al., 2013). In Manuscript 3, I also found some evidence that musical beat perception was not significantly affected by children's level of auditory working memory, which ran counter to the findings of previous work showing that auditory working memory is positively associated with rhythm perception and production in neurotypical (Anvari et al., 2002; Hansen et al., 2012; Strait et al., 2011) and neurodivergent development (Flaugnacco et al., 2014; Sota et al., 2018). Explanations for the discrepancy in findings include, for example, insensitivity in our data to detect an actual effect of auditory working memory, limited auditory working memory abilities of the autistic group (i.e., an average Digit Span scaled score of 6 versus an average scaled score of 10 in the general population), and the use of a beat alignment task that places less reliance on memory skills compared to sequence memory-based rhythm perception and reproduction tasks (Fiveash et al., 2022). In addition, I found no evidence supporting a relationship between musical beat perception and the degree of autistic characteristics, suggesting that beat sensitivity is a unique skill that likely remains intact across a broad range of autistic traits. The lack of relationship with autistic characteristics is in keeping with previous results showing that core features of autism are unrelated to the processing of specific musical structures (e.g., Jamey et al., 2019; Knight et al., 2020) and musical perception more generally (Sota et al., 2018).

Contributions of Manuscripts 2 and 3

Manuscripts 2 and 3 contributed to autism research by extending our understanding of the musical skills of autistic children. Given that researchers have traditionally focused on the differences and challenges that characterize autism, the general strengths of autistic people and how to utilize interventions designed to hone their strengths to enhance their social well-being and general development have been understudied. Based on neurodiversity and positive psychology views, it is a better understanding of what children *can do* (rather than what they cannot do) that enables interventionists to help all children interact and learn alongside others in a meaningful and valued manner (Galloway, 2020; Sonuga-Barke & Thapar, 2021). In harmony with this mindset, a well-powered study recently showed that autistic and neurotypical people endorsed similar strengths, including but not limited to musical ability and that autistic people who reported using their strengths frequently (versus less frequently) experienced better quality of life, well-being, and mental health (Taylor et al., 2023). In addition to being capable of processing pitch, melody, and emotions in music, I demonstrated in Manuscript 2 that autistic children are sensitive to temporal structures of music in that they are just as able as neurotypical children at identifying synchronization between the beat of the music and beeps superimposed on it using a task that more directly assesses rhythmic abilities than other more commonly used perception tasks (Fiveash et al., 2022; Tranchant et al., 2021). The results suggest that group music-making involving synchronizing with the beat of the music perceptually is likely an accessible shared social activity for autistic children and their peers. Such beat sensitivity may also explain the mechanism of change underlying music-based programs for autistic children in that they may be accessing the beat of the music to learn about the timing of less accessible rhythms underlying linguistic, social, and motor processes (Daniel et al., 2022; Lense & Camarata, 2020).

Manuscript 3 contributed to the field by studying the musical beat perception skills of autistic children *with a breadth of characteristics*. Studying autistic children with different developmental profiles was a research recommendation put forward by CAHS following the autism assessment in order to better cater to the complexity of needs of autistic children (CAHS, 2022). In Manuscript 3, I found that musical beat perception may be spared across a broad range of autistic characteristics and verbal cognitive abilities, revealing that the beat of the music may be perceived successfully regardless of variability in these areas. While autistic children who are older or have more proficient nonverbal cognitive abilities may show an advantage at extracting and synchronizing with the beat of the music, young children and children with less developed nonverbal cognitive abilities could participate in formal musical training (Fiveash, 2021; Patel, 2011) wherein the goal is to expand a person's knowledge about music theory and musical performance skills (in this case, beat sensitivity). Following this training, the rhythm of the music can be used more therapeutically to address their non-musical learning and social-emotional objectives (Pellitteri, 2000; Salvador & Psiali, 2017).

Future Directions

The following future directions extend those that were outlined in the three manuscripts:

Continued investigations into the effect of different types of shared social activities on the social development and inclusion of autistic people and their peers

With only 15 studies having met the inclusion criteria of the systematic review presented in Manuscript 1, there is a need for the execution of well-designed group or single-case research studies that examine the use of shared social activities as a potential evidence-based and strengths-focused approach for eliciting social outcomes that autistic people prioritize. Autistic people have voiced a desire to "fit in" socially and to form friendships with their peers (Clark & Adams, 2020; Cresswell et al., 2019; Mitchell et al., 2021). Yet, few social intervention studies, such as shared social activity-based intervention studies, for autistic people have included measures that capture improvements in the number and quality of friendships, perceived social support, or social satisfaction/quality of life more generally (Rodda & Estes, 2018). To address this gap in our knowledge, my initial dissertation plan was *proposed and defended successfully* *at my proposal defence* to evaluate the effects of two rhythm-based music interventions on the social communication skills *and* the social inclusion (i.e., peer acceptance, perceived social support from peers and teachers, and the number of friendships via multi-informant and direct behavioural observation approaches) of autistic children who attended the programs either separately (non-inclusive groups) or alongside their non-autistic peers (i.e., inclusive groups) in mainstream and specialized school settings. This large project was conducted in partnership with ÉducaTED Foundation, a non-profit organization of community-based musicians with more than 15 years of experience conducting rhythm-based music intervention programs for neurodivergent people (Approsh) in schools and community centres across Quebec (https://www.fondationeducated.com/methode-approsh). However, due to covid-19 related school closures in March 2020, the data collection I was spearheading alongside my supervisor, colleagues, and Approsh was terminated before post-measures could be collected, which unfortunately precluded any conclusions to be made about the effectiveness of these shared musical experiences. Nevertheless, findings of ongoing music intervention work in our research group have shown that inclusive music-making activities have a positive effect on the self-esteem of adolescents on the autism spectrum, do not negatively interfere with the social support and social acceptance that they experience from their peers, and increase student-teacher closeness (Kaedbey et al., 2022; Kaedbey et al., 2023).

Although musical activities are often found to be enjoyable and motivating for all children and present a unique platform for supporting social development and learning, there may very well be autistic and neurotypical children who do not endorse an affinity for music or musical strengths and, thus, may not wish to participate nor benefit from shared music-making activities. Children who are asked to participate in formal musical training or therapeutic rhythm-based musical intervention but dislike engaging with music and are not attentive to the music are unlikely to benefit from these experiences (e.g., Patel, 2011). Instead, they may prefer engaging in other shared social activities that are more reflective of their interests and skills. Continued investigations of the non-musical skills and favourite activities of autistic children (as done by Clark & Adams, 2020 and Taylor et al., 2023) and the effect of other shared social activities (e.g., Lego, theatre, gaming systems) that leverage their interests and skills are needed to better cater to the diversity of interests and needs of the autism community. The types of shared social activities that are most suitable for autistic people of different ages (including adults) with co-occurring cognitive, language, and motor difficulties are needed to ensure that the needs of all autistic people across the lifespan are being supported in a manner that aligns with a neurodiversity framework (Leadbitter et al., 2021).

Continued investigation into the musical beat processing skills of autistic children

The findings of Manuscripts 2 and 3 reveal that the adapted version of the beat alignment task developed initially by Iversen and Patel (2008) was very challenging for the children to complete successfully, with the musical beat misalignment condition being the most difficult. The musical beat perception skills of autistic children could be re-explored with adjustments to the BAT to render it more accessible for autistic children with different cognitive profiles in order to dissociate reduced musical beat perception from potentially limited sensory integration and attention allocation difficulties. In addition to including more than two practice trials and adding visual cues that emphasize more clearly the differences between beat alignments and misalignments (see Einarson & Trainor, 2015, 2016), researchers may consider including musical stimuli with a slower tempo or lowering the frequency of the metronome superimposed on the music to reduce the load on integration skills and increase comprehension and accuracy on the task. According to Auditory Scene Analysis and Sequential Integration (Bregman, 1990) principles, the current frequency of the metronome is set to 1000Hz, which may be too high compared to the beat of the music or the tempo of the music (and the accompanying metronome) may be too fast. As such, the music and superimposed beeps (metronome) may be perceived as separate auditory streams that need to be integrated, thus, not purely measuring beat perception as the developers of the task intended.

Other aspects of beat perception must be explored in future work to draw more comprehensive conclusions about beat sensitivity among autistic children. Although autistic children are likely able to find the beat of the music (i.e., beat induction) to entrain and synchronize to it based on the findings outlined in Manuscripts 2 and 3, are they able to sustain it in the absence of sensory cues for the beat (i.e., beat maintenance)? The ability to autonomously sustain the beat of the music improves well into adolescence and is predictive of non-musical skills, including phonology, in typical development (Nave et al., 2022). However, the developmental trajectory of sustained beat perception skills and their impact on non-musical learning and music-making participation is unknown among autistic people. It can be investigated using an adapted version of the Beat-Drop Alignment Test initially developed for adults (Cinelyte et al., 2022) or an existing child-friendly Sustained Beat Task (Nave et al., 2022). It will be necessary for future research examining sustained beat perception to carefully control for the potential effects of age, musical experience, and working memory, as beat maintenance is considered a more advanced skill than beat induction and, thus, may be experience-dependent and draw on cognitive abilities (Cinelyte et al., 2022).

Moreover, beat processing should be examined within the context of different tempos and metrically structured music to inform on optimal features of music that induce the most accessible beat for autistic children. Morris et al. (2021) found that out of 113 surveyed registered dance and movement therapists, 64% reported using music in 4/4 time signature, and 45% reported using moderato tempo because these were said to be more enjoyable and to elicit a strong regular rhythmic structure, which in turn, allowed participants to readily extract the beat and physically synchronize their movements with it. An experimental study that manipulates tempo and meter during beat perception tasks would confirm whether these features are, in fact, associated with optimal beat processing skills and should be integrated into music-based interventions to increase the therapeutic potential of music-based interventions.

Follow-up investigations on the musical rhythm or beat processing skills of autistic people should also include the incorporation of physiological and neuroimaging techniques together with behavioural measures of beat and meter perception and production (while controlling for differences in motor abilities for production tasks) to understand if neural oscillators and neural networks that likely support the processing of beat and meter in neurotypical development apply to autistic people (Large & Snyder, 2009; Large et al., 2015), and whether music interventions can impact brain plasticity of autistic people.

Importantly, the heterogeneity inherent to autism should be reflected in the study samples of future studies to continue generalizing findings to children across the autism spectrum. While musical rhythm and beat processing may be spared across a broad range of autistic characteristics, these skills need to be studied within the context of disabilities associated with autism, including (but not limited to) intellectual developmental disability, developmental speech and language disorders, attention-deficit/hyperactivity disorder, and developmental coordination disorder, especially given evidence that many of these co-occurring disabilities are associated with atypical rhythm and beat processing skills among non-autistic children (Ladányi et al., 2020). Although such an undertaking will likely necessitate the development of new beat processing measurements that are user-friendly for children with different abilities, the creation of such methods will be vital for understanding whether inclusive beat-based musical experiences can support children across the spectrum.

Strengths-based Clinical and Educational Applications

I have dedicated my doctoral research to focusing on the positive attributes of autistic children to counteract the deficit perspective that is typically associated with autism and create a more balanced view of autism as a developmental profile that comes with strengths in addition to challenges. It is through such strengths-focused research that professionals become better educated on how to support autistic people in discovering their personal qualities and competencies so that they can develop a positive sense of self, which is important for building resilience (McCrimmon & Montgomery, 2014) and protecting against adverse mental health outcomes that too often co-occur with autism (Fombonne et al., 2020; Lai et al., 2019; Rydzewska et al., 2019). Through strength-focused research, professionals also learn how they can capitalize on the positive attributes of autistic people in inclusive education and community settings to enhance their ability to participate in activities that give them meaning and vitality (Sonuga-Barke & Thapar, 2021).

Despite several different types of shared social activities that can be implemented based on children's interests and skills to support the social development of autistic children and their peers, as demonstrated in Manuscript 1 (e.g., Lego, lunch clubs, structured games, theatre), music is unique in its ability to be an engaging and accessible modality that can successfully target musical and non-musical skills simultaneously for most (if not all) autistic children. Precursor skills for creating and sharing musical rhythms with others include the ability to *perceptually* and *physically* align with the beat of the music, which appear to be spared across the autism spectrum based on the findings of Manuscripts 2 and 3 coupled with the findings of previous studies showing intact beat synchronization skills (Edey et al., 2019; Tryfon et al., 2017) and positive associations between beat perception and production skills in typical development (Dalla Bella et al., 2017; Fiveash et al., 2022; Fuji & Schlaug, 2013; Iversen & Patel, 2008). Rhythm-based music interventions are postulated as a strength-based approach for promoting far transfer effects to non-musical areas of functioning such as social (Daniel et al., 2022; Lense & Camarata, 2020), speech/language (Fiveash et al., 2021), and motor movement (Hardy & LaGasse, 2023) with the beat of the music assumed to account (at least partially) for these improvements given its ability to modulate attention to less salient beat-based information (e.g., Lense et al., 2022), scaffold the timing of behaviours (e.g., Dalla Bella, 2018), and promote brain plasticity (e.g., Hyde et al., 2009). Although some preliminary evidence previously suggested that autistic children can successfully participate in and benefit from interactive beat-based musical activities (Geretsegger et al., 2022; Marquez-Garcia et al., 2022), this dissertation empirically demonstrates that beat sensitivity is present among autistic children, which in turn, directly supports the implementation of proposed musical frameworks including *Press-Play* for younger children (Lense & Camarata, 2020) and *Rhythm Relating* for children and adults (Daniel et al., 2022) that capitalize on beat sensitivity to extract more fully music's therapeutic potential. In keeping with a push for inclusive practices in Canada, such musical experiences should be delivered in an inclusive format involving neurotypical and other neurodivergent children. Drum circles (i.e., wherein children are seated in a circle playing drums and/or other percussion instruments) are known to increase emotional control, self-esteem, and leadership, and foster a sense of group unity among neurotypical children as it involves the participants to work together to coordinate their rhythmic sounds and explore group dynamics effortlessly (Mikenas, 2003; Wood et al., 2012). During group music-making, children have contact with other children whom they can comfortably interact and cooperate with, coordinate their actions, and participate in “co-pathy” (the social function of empathy) simultaneously (Koelsch, 2013; Overy, 2012; Overy & Molnar-Szakacs, 2009; Pellitteri, 2000), which can increase normative social cognitive skills (Ulfarsdottir & Erwin, 1999) and serve as a normalizing activity for reducing social exclusion and bullying incidences (Cook et al., 2019) by addressing the double-empathy problem that is potentially underlying communication breakdowns between autistic children and their peers (Mitchell et al., 2021). Engagement in musical activities is also associated with the transference of skills to non-musical areas for neurodivergent children including children with Williams syndrome (Dunning et al., 2015), dyslexia and other language-based disorders (Ladányi et al., 2020), and motor movement disorders (Hardy & LaGasse, 2013), demonstrating the beneficial effect of music participation beyond the context of neurotypical development and autism.

Overall, the findings of my dissertation suggest that shared structured social activities, such as leisure group music-making (and perhaps even, orchestras and field trips involving musical participation), hold tremendous potential for facilitating the inclusion of neurodiverse children and future work around how to effectively develop and implement such neuro-affirming experiences should be prioritized to create a Canada that is more accessible to the autism community.

Chapter 7: Final Conclusion and Summary

The objectives of my dissertation were to investigate the musical skills of autistic children and how strengths-based approaches, including (but not limited) to shared music-making activities, may allow autistic children with different abilities to engage in their areas of interest and skill alongside their peers while still addressing their various learning goals. I met these objectives via one systematic review and two empirical studies.

In Manuscript 1, I conducted an original systematic review that evaluated whether shared structured social activity-based interventions (e.g., music, interest-based clubs, Lego, and theatre) effectively supported the social development of autistic children with different developmental profiles and their peers. Most shared structured social activities were associated with improvements in social cognition, social communication, social functioning, and/or shared enjoyment and were considered socially valid. Shared social activities that built on the genuine interests and skills of autistic children, in addition to their preference for structure, appeared particularly well-suited for autistic children with different developmental profiles and for encouraging children to be equal play partners in activities.

In Manuscripts 2 and 3, I assessed the musical beat perception skills of children on the autism spectrum to advance our knowledge about the musical abilities (i.e., beat sensitivity) of autistic children and inform on the ecological validity of using shared beat-based musical activities as an accessible, strength-based social activity for supporting the general learning and development of children on the autism spectrum. In Manuscript 2, I found that autistic children were just as successful as neurotypical children at identifying musical beat alignments, which is an essential skill to have when singing, dancing, and playing instruments with the beat of the music and with other people. In Manuscript 3, I also found evidence of beat alignment sensitivity among a larger group of autistic children and that age and nonverbal cognitive ability positively contributed to musical beat perception. In Manuscript 3, musical beat perception was unrelated to degree of autistic characteristics and verbal cognitive ability, demonstrating that musical beat perception may be spared regardless of variability in these areas. I stress that more research is needed to clarify how auditory working memory and the presence of concurrent disabilities (e.g., developmental speech and language disorders) may impact musical beat perception.

As detailed in Chapter 6, the findings of the studies in my dissertation contributed to strengths-focused autism literature by highlighting that autistic children have general interests and skills that can be leveraged to create strengths-based approaches that hone skills to promote growth in various learning domains. I particularly emphasized the novelty of using shared beat-based musical activities as an accessible, multi-purpose intervention tool, given that engaging with the beat of music is an enjoyable area of skill for children across the autism spectrum and their peers (with beat sensitivity being the focus of this dissertation) that is associated with far-transfer effects to various non-musical areas of learning and development (e.g., Chenausky et al., 2017; Fauziah et al., 2022; Sharda et al., 2018; Srinivasan et al., 2015). Overall, my dissertation contributed to our understanding of the skills of autistic children and how specific skills can be capitalized on to support autistic and non-autistic people in flourishing together in inclusive learning and social environments.

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