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Assessing the Impact of Music Therapy on Sensory Gating and Attention in Children With Autism: A Pilot and Feasibility Study

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Children with autism spectrum disorder (ASD) frequently demonstrate atypical processing of sensory information and deficits in attentional abilities. These deficits may impact social and academic functioning. Although music therapy has been used to address sensory and attentional needs, there are no studies including physiologic indicators
of sensory processing to determine the impact of music therapy. The objective of this study was to determine the feasibility of conducting study protocols, determine the adequacy of electroencephalography (EEG) and behavioral measures in identifying attentional differences in children with ASD compared with typically developing (TD) children, and to gather preliminary evidence of intervention effects on brain responses and attention outcomes. Seven children with high functioning ASD ages 5 –12 and seven age- and gender-matched TD completed procedures measuring brain responses (EEG) and behaviors (the Test of Everyday Attention for Children). Children with ASD then completed a 35-min individual music therapy attention protocol delivered by a board-certified music therapist ten times over 5 weeks. Children with ASD completed measures of brain responses and behavior post-intervention to determine pre- to post-test differences. Consent and completion rates were 100% for children who met the study criteria. Feasibility measures indicated that measures of brain responsivity could be used to determine attentional differences between children with ASD and typical children. Initial outcome data for brain responses and behavior indicated positive trends for the impact of music therapy on selective attention skills.

Keywords: autism spectrum disorder, attention, electroencephalography, music therapy, sensory processing

Sensory processing is integral to an individual’s ability to attend and respond to the environment. Many children with autism spectrum disorder (ASD) exhibit differences in sensory processing and attentional skills that impact daily functioning (Bundy, Shia, Long, & Miller, 2007; Christakou et al., 2013; Corbett, Constantine, Hendren, Rocke, & Ozonoff, 2009; Miller, Lane, Cermak, Osten, & Anzalone, 2005). The diagnostic criteria for ASD include differences in sensory processing, in particular hyper- or hypo-reactivity to sensory input (American Psychiatric Association, 2013). As early as 1943, researchers indicated that children with ASD have different reactions to sensory stimuli when compared to typically developing peers (Baker et al., 2008; Iarocci & McDonald, 2006; Tomchek et al., 2015). Unusual reactions to sensory input are among the earliest recognizable features of ASD and often are witnessed before a child has received an official diagnosis of ASD (Iarocci & McDonald, 2006). Sensory processing and attention
abilities often interact, directly impacting a child’s ability to sustain engagement in play, social, and academic activities (Liss, Saulnier, Fein, & Kinsbourne, 2006; Tomchek et al., 2015; Waterhouse, Fein, & Modahl, 1996). The purpose of this study was to establish feasibility and preliminary efficacy of an individualized music therapy attention protocol to improve sensory processing and attention skills in children with ASD.

Sensory processing may be defined as the adaptive responses (i.e., behaviors) to sensory experiences, i.e., visual, auditory, proprioceptive, or vestibular stimuli (Baker, Lane, Anglely, & Young, 2008). As a result, sensory processing difficulties may manifest as adaptive behaviors that interfere with daily living activities and communication (Tomchek et al., 2015). Liss et al. (2006) used cluster analysis to examine the function of sensory processing. The researchers found that hyper-responsivity to sensory stimuli was correlated with perseverative behavior, over-focused attention, and exceptional memory; whereas hypo-responsivity was correlated with poor social skills and communication impairments. These differences in sensory processing, including both hypo- and hyper-reactive responses, were related to the symptomology of ASD.

When considered from a neural processing lens, sensory processing may be defined as changes in the activity of neurons in the brain when receiving input from sensory receptors. Researchers have used electroencephalographic (EEG) brain imaging techniques to study sensory processing in the cortex. Various tasks or paradigms are used to examine sensory processing. The particular EEG paradigm of interest for this study, the sensory gating paradigm, measures a neural mechanism of sensory processing that determines one’s ability to filter irrelevant sensory information (Davies, Chang, & Gavin, 2009; Freeman et al., 1987; Rosburg et al., 2009). The sensory gating paradigm measures a passive response to repeated or irrelevant stimuli that is both neurophysiological and protective, allowing the brain to allocate vital processing resources to attend to stimuli that are more important (Davies et al., 2009). When responses to sensory gating are impaired, the brain may be processing irrelevant or redundant stimuli while failing to capture sensory input that should be more salient. This processing difference may lead to perceptual or attentional deficits.
Sensory gating may be considered a mechanism of attention, in that one must selectively attend to specific stimuli while ignoring irrelevant information (Freedman et al., 1987). If one is unable to organize sensory input, or filter irrelevant information, attending to the task at hand becomes difficult (Ayres, 1972). Conversely, if one is to be able to attend appropriately to a task, one must be able to adapt to the demands of the environment. This environmental adaptation requires the ability to regulate one’s states of arousal, which can be hindered if an individual is hypo- or hyper-responsive to sensory stimuli. The concept of arousal, or alertness, is one system that plays a role in attention (Peterson & Posner, 2012). Researchers have shown that individuals with ASD have specific difficulties with these aspects of attention, including orienting attention, selective attention, and filtering out irrelevant sensory stimuli (Pasiali, LaGasse, & Penn, 2014; Ravizza, Solomon, Ivry, & Carter, 2013). These attention difficulties, measured using behavioral assessments, impact a child’s ability to play, interact with others, and learn in the classroom where there may be competing stimuli within the environment. Thus, future studies using EEG to measure sensory gating abilities may elucidate neural mechanisms underlying the behavioral manifestation of poor attention.

In previous studies comparing the EEG of children with sensory processing difficulties and children with ASD to typically developing (TD) children, researchers have found reduced sensory gating abilities in children with ASD, specifically in their ability to filter out redundant auditory information (Crasta, LaGasse, Davies, & Gavin, 2016; Davies et al., 2009). Furthermore, significant correlations were found between sensory gating event-related potentials (ERP, a brain response to an event, in this case an auditory stimulus measured by EEG) and parent report of child sensory processing behaviors (Crasta et al., 2016; Davies et al., 2009). Conversely, Kemner, Oranje, Verbaten, and van Engeland (2002) compared gating in 12 children with ASD to 11 TD children and discovered no significant differences between groups for sensory gating. Orekhova et al. (2008) found different results in sensory gating based on the level of ASD, where severely impacted children demonstrated significantly reduced gating compared with TD peers. These findings indicate mixed results regarding whether children with ASD have deficits in sensory gating compared with TD children. However, if sensory gating in children with and
without ASD were to be demonstrated as different, then this neurophysiological process may have the potential to be an indicator of treatment impact.

Researchers have demonstrated that music is engaging to children with ASD (Kim, Wigram, & Gold, 2009), with the suggestion that active music-making can help build attentional skills (Pasiali et al., 2014). Pasiali et al. (2014) found that children with neurodevelopmental disorders, including ASD, improved selective attention, and attentional control after 6 weeks of group music therapy intervention. Although initial evidence supports the use of music therapy for improving attentional skills in children with ASD, there are no known studies investigating the impact of an individualized music therapy protocol on sensory gating and attentional abilities in children with ASD. Therefore, the purpose of this study was to establish feasibility and preliminary efficacy of an individualized music therapy attention protocol to improve sensory gating and attentional skills in children with ASD. The aims for this study were to (a) determine the feasibility of conducting study protocols including measures of sensory gating, attention behaviors, and a 5-week music therapy intervention, (b) determine the adequacy of brain and behavioral measures in identifying attentional differences in children with ASD, and (c) gather preliminary evidence of intervention effects on sensory gating and attention outcomes. We further sought to develop recommendations for future research. Research questions related to feasibility were:

1. What percentage of participants will complete EEG and behavioral evaluation sessions?
2. What percentage of planned music therapy intervention sessions will children with ASD complete?
3. Will EEG and behavioral tests demonstrate adequate differences in baseline measures of attention in children with ASD compared with TD children to warrant future studies?
4. Will there be a relationship between EEG components and the Test of Everyday Attention for Children (TEA-Ch) scores?

Research questions related to potential benefits were:

1. Do sensory gating abilities in children with ASD change after 5 weeks of the music therapy attention protocol?
2. Will attention abilities in children with ASD change after 5 weeks of the music therapy attention protocol?
Method

Participants

We recruited eight children with a clinical diagnosis of high functioning ASD for this study. One child did not meet the inclusion criteria and was excluded from the study. Of the seven children who met the inclusion criteria, ages ranged from 5 to 12 (M = 8.42; SD = 2.93; 6 males and 1 female). Participants were required to have normal or corrected vision and hearing and speak English as a primary language. Diagnoses that excluded individuals from participating in this study were: Down syndrome; cerebral palsy; history of significant brain injury; epilepsy; schizophrenia; bipolar disorder; and depression. Individuals with these disorders were excluded in order to decrease the potential of different neurological processing due to another disability. Furthermore, we included data from seven age- and gender-matched TD children, using frequency matching where the distributions of age and sex were similar in the two groups. The TD children completed baseline measures to be used as a comparison group (M = 8.28; SD = 1.74; 6 males and 1 female). The TD children were a subset of a larger study that examined maturation of sensory gating (Davies et al., 2009). We included TD children in order to test research feasibility question 3 regarding differences between TD children and children with ASD. We offered compensation in the form of a commemorative T-shirt or mug, an option for a $15 cash gift and $25 cash to offset travel costs. We obtained Institutional Review Board (IRB) approval of procedures from the Colorado State University IRB.

Procedure

We conducted a single-group pretest–posttest design to collect initial data on the music therapy intervention for children with ASD. Pretest and posttest measures included neural sensory processing measures (EEG) and behavioral responses (TEA-Ch). The behavioral and EEG testing procedures were completed by faculty and research assistants in the Brainwaves Research Lab, from the Occupational Therapy Department and Molecular, Cellular and Integrative Neurosciences Program at Colorado State University departments at Colorado State University (fourth and fifth authors). Participants were involved in two pre-intervention
(i.e., baseline condition) and two post-intervention testing visits, each lasting approximately 2 h. During these visits the child (1) participated in a passive listening activity while the EEG sensory gating data were collected and (2) completed behavioral testing.

Following parental consent and child assent procedures, we briefed the participant about the EEG recording process and research assistants applied the EEG stretch cap with metal sensors that record EEG through a water-based gel that conducts brain signals from the scalp to the sensors. After appropriate conductance levels were achieved, we provided strategies to the children to minimize movements and eye-blinks that may cause artifacts in the recordings. Research assistants fitted the child with in-ear headphones. The hearing threshold was assessed with a 3-ms click stimulus. During the EEG recording session, the child watched Wallace and Gromit, a silent Claymation video, to maintain a calm, quiet demeanor while passively listening to two auditory paradigms, each lasting about 20 min separated by a 3-min break. During the second visit, the participant completed another EEG recording session and then completed the TEA-Ch. We used two parallel versions of the TEA-Ch for the test/retest to avoid practice effects.

Within 2 weeks of the baseline data collection, each participant with ASD returned to participate in 10 bi-weekly individual music therapy sessions that occurred over 5 consecutive weeks. Each music therapy session lasted for 35 min and focused on a music therapy attention protocol designed and implemented by the first author. Music therapy sessions were held in the Colorado State University music therapy clinic. Parents were present in all music therapy sessions, although they were not participatory. One graduate research assistant provided support in each music therapy session. Upon completion of 10 music therapy sessions, the participant returned to the Brainwaves Research Lab for two additional testing sessions using the same paradigms as the initial two visits.

Measures

Feasibility. Process assessment data collected included the number of participants who consented/assented to study procedures and ability of participants to complete evaluation and intervention sessions and reasons for refusal or incompletion. We recorded anecdotal data regarding the appropriateness of inclusion/exclusion criteria for the measures (fifth author) and the music
therapy intervention (first author). We also kept anecdotal data regarding participant understanding of research protocols.

**Sensory gating paradigm used during EEG recording.** The sensory gating paradigm used in this study measures a neural mechanism that determines the brain’s ability to filter (i.e., gate out) repeated auditory stimuli (Boutros & Belger, 1999; Davies, Chang, & Gavin, 2009; Davies & Gavin, 2007). During the sensory gating paradigm, participants heard 100 pairs of click stimuli separated by a short period, an interstimulus interval of 500 ms, with the pairs separated by a long 8-s intertrial interval. The first click represents the conditioning click, while the second click represents the test click. The second click is presenting redundant auditory information; therefore, a brain with satisfactory sensory gating abilities should devote fewer resources to this stimulus demonstrated by smaller brain responses. Each click was 3 ms in duration, presented at 85 dB SPL (decibels sound pressure level) administered in both ears through the ER-3A inserted earphones (Etymotic Research) using E-Prime Software (Psychological Software Tools, Pittsburgh, PA, USA).

**EEG data acquisition.** The fourth and fifth authors obtained EEG recordings using a BioSemi ActiveTwo EEG Acquisition system. EEG was recorded from 32 Ag–AgCl sintered electrodes based on the American Electroencephalographic Society nomenclature guidelines (1994) with two electrodes, namely the common mode sense (CMS) and the driven right leg (DRL), used to generate a common reference voltage (http://www.biosemi.com/faq/cms&drl.htm). Electrodes were also placed on left and right earlobes, left and right outer canthus of the eye, and the left supraorbital and infraorbital regions in order to collect electrooculograms (EOGs). EOGs recorded eye movements, eye blinks, and facial muscle movement artifacts that were later removed from the data. Data were sampled at a rate of 1024 Hz.

**Scoring event-related potential (ERP) components.** The EEG data were segmented into stimulus-locked segments and averaged to create an ERP separately for conditioning click (first click) and test click (second click). The most relevant components of the ERP to sensory gating are the P50 and N100 peaks (Rosburg et al., 2009). The P50 component is the first major peak in the auditory evoked ERP, referring to the most positive amplitude that occurs around 50 ms, within a window of 40–90 ms, after stimulus onset.
(Freedman et al., 1987). The N100 component refers to the most negative amplitude that occurs around 100 ms, within a window of 90–120 ms, after stimulus onset. The P50 component is thought to be correlated to stimulus filtering, whereas the N100 component is thought to be linked to passive attention switching (Davies et al., 2009; Kisley, Noecker, & Guinther, 2004).

Attenuation of the amplitude of the test click compared with the conditioning click represents sensory gating. Sensory gating was evaluated using a difference score obtained by calculating the difference between peak-to-peak amplitude components between the first click and the second click for both the P50 and the N100. For the P50, a positive peak, a larger positive difference score indicates successful gating, whereas a smaller difference score indicates impaired gating. For the N100, a negative deflection, a larger negative score indicates successful gating, whereas a smaller negative score indicates impaired gating.

**TEA-Ch.** The TEA-Ch is an assessment tool with nine subtests that assess selective attention, sustained attention, and attentional control/switching through the use of game-like tasks that present auditory and visual demands (Manly, Robertson, Anderson, & Nimmo-Smith, 1999). The TEA-Ch is a standardized test with acceptable reliability and validity (Manly et al., 1999; Manly et al., 2001) that has been used successfully to study attention in children with autism (e.g., Pasiali et al., 2014). This assessment requires approximately 1 h to complete and has two versions to allow for accurate test–retest for each individual. The test–retest reliability coefficients for the subtests range from 0.57 to 0.87.

Subtests of the TEA-Ch that measure sustained attention include (1) Score!: A 10-item measure that presents 9–15 identical tones separated by intervals of variable duration. Children are asked to count the tones without counting on fingers. (2) Score DT: This measure is similar to Score!, presenting tones and requiring children to count in the same manner. However, this measure includes a distractor of a taped news broadcast, with the additional demand that the child must identify an animal mentioned during the broadcast. (3) Code Transmission: This task requires children to listen to a string of digits, presented with 2-s intervals, identify the occurrence of a target sequence, and then report the digit that immediately preceded the target sequence. This task is considered an auditory vigilance task. (4) Walk Don’t Walk: This subtest presents
“go” and “no-go” tones that correspond with a visual game board with a 14-square path. When a “go” tone is heard, the child must mark a square on the path of the game board. When the child hears a “no-go” tone, no play may be made. (5) Sky Search DT: This subtest requires children to complete Sky Search while simultaneously counting the tones presented as an auditory counting task.

Selective attention is measured by the TEA-Ch through two subtests, including (1) Sky Search: This task requires children to identify target items when presented with a laminated sheet depicting rows of paired images of spacecraft. There are 20 target images among 108 distractor images. Children are scored on both speed and accuracy. A motor control version of the task is also administered, presenting only target items with no distractor items, in order to determine the baseline of motor control for the participant. (2) Map Mission: This subtest presents children with a city map that contains eighty visual target images among various distractor images. Children must accurately circle the target images.

TEA-Ch subtests that measure switching/attentional control include (1) Creature Counting: Children are given a stimulus booklet that depicts creatures in their burrows, with arrows interspersed between the creatures. Children are required to count the creatures from the top-down, then to use these directional arrows as cues to change the direction of their count. (2) Opposite Worlds: This subtest uses two types of game boards that feature paths consisting of numerals 1 and 2. In the “same world” game board, the child is instructed to verbally state 1’s and 2’s as they appear on the game board. On the “opposite world” game board, the child is instructed to verbally say “2” when a “1” is encountered, and verbally say “1” when a “2” is encountered.

Music Therapy Intervention

The first author of this study, a board-certified music therapist, designed and implemented all the music therapy attention (MTA) protocol. The MTA protocol involved ten 35-min individual sessions over a period of 5 weeks. The music therapist developed the protocol from a neurodevelopmental framework, with the intention of targeting neural networks involved in attention processes. During the sessions, the music therapist used music-based activities targeting the development of attention skills, with a focus on selective and switching/attentional control. Selective attention
exercises included playing instruments while ignoring distractor stimuli and producing a specific rhythm in response to an embedded musical sequence. Switching/attention control exercises included playing instruments to different melodic and rhythmic themes and switching instruments or movements to different melodic stimuli, maintaining playing while monitoring additional stimuli (i.e., playing a sequence part on a xylophone while monitoring other parts played by the music therapist), and switching the rules of a task (i.e., matching a high or low drums played by the interventionist, then playing the tone opposite to the one played by the music therapist). Detailed examples of musical activities are shown in Table 1.

The music therapist used music appropriate for the child’s age and cognitive level to maintain active engagement and focus throughout the MTA protocol. The MTA protocol started with basic exercises in each area of attention and gradually became more difficult as the children progressed. Although the same exercises were used across all children, the difficulty level and instrumentation were adjusted in order to ensure engagement and a right-fit challenge.

**Data Analysis**

**Feasibility Measures.** The authors of this study reviewed all anecdotal notes regarding consent rate, attendance, and participation in the EEG testing, behavioral testing, and music therapy intervention sessions. Furthermore, the authors recorded potential barriers to delivering the testing and the intervention. The completion rate was considered by calculating the number of persons who attended sessions fully, without removal or refusing to engage and/or follow instructions. This number was converted to a percentage by dividing the number of children who completed all sessions by the number of total participants, then multiplying by 100.

Feasibility regarding whether attention differences in children with high functioning ASD would be evidenced on the EEG sensory gating protocols and the TEA-Ch was assessed using data from the children with ASD and a comparison group of age- and gender-matched TD children. Scores recorded in the EEG paradigms were compared with scores on the TEA-Ch for children with ASD and TD children to determine whether there was a relationship between sensory gating and behavioral attention scores.
### Table 1.

**Example Music Therapy Exercises for Selective and Switching Attention**

<table>
<thead>
<tr>
<th>Music Therapy Exercise</th>
<th>Example 1</th>
<th>Example 2</th>
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<tbody>
<tr>
<td>Selective attention</td>
<td>The music therapy assistant (MTA) played simple rhythms on a drum, changing rhythms every eight counts. The child was asked to match the rhythms while playing on an identical drum. Once the child was successful, a competing stimulus was introduced by the music therapist. The competing stimulus would begin with a distractor instrument (such as a wood block) played at drastically different rhythms. As the child gained success ignoring the distractor, the MT would increase difficulty with instruments that were similar in timbre to the drum or by playing rhythms closer to what the child was playing.</td>
<td>The MT played a melody on the piano and instructed the child to play a xylophone. When the MT played a particular cue embedded in the melody (for example, dotted eight, eighth, eighth on do me do), the child would play a drum each time they heard the cue. The MT would initially play the cue in a different range; however, it would increase the difficulty by playing the cue in the same range as the rest of the melody or by playing the cue with less emphasis.</td>
</tr>
<tr>
<td>Executive control/Switching Attention</td>
<td>The MT would play different musical melodies or cues on a piano, pairing each with a different instrument that was placed in front of the child. For example, the MT would play a 5-note melody in a major key with staccato notes, upon which the child would play a wood block. The MT would then switch to a lower register on the keyboard, playing minor melody with legato notes, to which the child would play the finger cymbals. Once the child showed the ability to pair 4–5 musical sequences to instruments, the MT would begin switching between the different melodies in different orders and the child will change their instrument to match the melodic pattern. The music therapist increased the difficulty of the exercise by using melodic patterns that were more similar in nature or in the same range.</td>
<td>The MT and the child were seated facing one another each with a high-pitched tubano and low-pitched tubano. The child copied the rhythms and the pitch of the drum played by the MT. Once the child demonstrated success, the MTA would play a cue upon which the child would play the “opposite” pitched instrument than the instrument played by the MT (playing the higher pitched tubano when the music therapist played the lower pitched tubano). Upon hearing the cue again, the child would switch back to playing the same pitch as the music therapist. Upon success, the MTA would hold a blocking board between the child and the MT, preventing them from using their vision in the exercise.</td>
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Preliminary Efficacy

EEG Reduction and Analysis. Raw data collected from the EEG recording session was processed using Brain Vision Analyzer (second, third, and fourth authors), with data analysis focusing on recordings from the Cz electrode site located at the crown of the head at the center of the midline. While electrical noise was minimized by recording EEG data in a sound attenuated, electromagnetically shielded booth, some electrical noise can still appear and must be addressed before ERPs are averaged. This noise was removed from the EEG data by referencing channels generated from an average of the two earlobe sensors that monitor the electrical noise in the environment. Averaged ERP waveforms for each of the two click stimuli were then obtained as follows. Segments were created according to when auditory stimuli are presented. In preparing for scoring the P50 data, the EEG signal was filtered with a bandpass setting of 10–200 Hz (24 dB/octave) and then segmented into epochs representing either the conditioning or test click with a duration of 100 ms pre-stimulus onset to 200 ms post-stimulus onset. Next, artifacts and electrical noise were removed from the data by deleting segments with deviations greater than ±100 μV on any of the EEG channels or the bipolar EOG channels. Researchers commonly delete segments of data that contain artifacts in order to prevent contamination of EEG data that reflects actual evoked brain potential in response to the presented stimulus. The nonrejected segments were baseline corrected and then averaged to create averaged ERP waveforms for both the conditioning and test clicks in order to measure the P50 component for each participant. Data related to the N100 component were processed similarly to the P50 component with the following exceptions: (a) EEG signals were digitally filtered using a 0.23–30 Hz bandpass and (b) EEG signals were segmented into epochs with durations consisting of 200 ms before the click stimulus onset through 500 ms post-stimulus.

The averaged ERP data were then imported into a computer program for automated peak picking. This software has been designed specifically for the Brainwaves Research Lab. P50 and N100 peaks were determined by the computer program, and then visual inspection was used to confirm that correct peaks were selected based on the morphology of the waveform. The P50 component
was measured as the most positive amplitude between 40 and 80 ms. The N100 component was measured as the maximum negativity between 70 and 150 ms from stimulus onset. Peak-to-peak amplitude for the P50 component was determined by calculating the difference between the P50 amplitude and the preceding negativity. Peak-to-peak amplitude for the N100 component was determined by calculating the difference between the N100 amplitude and the preceding positivity. The P50 and N100 peak-to-peak amplitudes were used to calculate the sensory gating difference score.

**Statistical Analysis**

Statistical analysis was conducted using the Statistical Package for Social Sciences (SPSS). Parametric statistics are reported for this small sample (ASD: n = 7, TD: n = 7) because all data were normally distributed (using Shapiro–Wilk test) and displayed homogeneity of variance (using Levene statistic). To determine whether brain and behavioral measures were sensitive enough to demonstrate differences in sensory processing and attention between children with and without ASD with a low probability of occurrence due to chance, an independent *t*-test (two-tailed) was performed comparing the different components of attention in EEG (P50 and N100) and TEA-Ch scores. To determine whether there was a relationship between brain and behavioral scores, a Pearson’s correlational analysis was used to compare the difference scores of P50 and N100 components to scores on the TEA-Ch for children with ASD (preintervention) and TD children to determine whether there is a relationship between these variables for either group. A Pearson’s *r* was also used to determine the correlation between difference scores of the P50 and N100 components and TEA-Ch postintervention scores of children with ASD.

To determine whether there was a promising difference in sensory gating abilities pre- and postintervention, a paired *t*-test (two-tailed) was performed comparing P50 difference scores and N100 difference scores for pre- and post-intervention data. To determine whether there was a difference in behavioral testing pre- and post-intervention, paired *t*-tests were performed comparing total TEA-Ch scores and domains scores from children with ASD pre- and post-intervention. To examine the TEA-Ch scores in the ASD group pre- and post-intervention, we were interested in change
in performance; thus we used raw scores, which are more appropriate than scaled scores, to show change over time (Davies & Gavin, 1999).

In analyzing results using small sample sizes, significance testing may not be reliable and $p$ values may be misleading. Effect sizes allow calculating the effect of the independent variable on the dependent variable. Effect sizes for $t$-tests were determined by calculating Cohen’s $d$. Cohen (1988) defines $d = 0.2$ as a small effect, $d = 0.5$ as a medium effect, $d = 0.8$ as a large effect, and $d = 1.30$ as a very large effect size.

**Results**

**Feasibility**

**Completion Rate and Barriers.** We screened eight children for eligibility; of which, one was excluded due to a lack of expressive language abilities. We obtained parental and child consent for seven individuals who met eligibility requirements. All seven individuals completed all testing and music therapy intervention sessions, for a completion rate of 100%. Potential barriers to completion included long testing times (eight total hours) and a commitment to 5 weeks of twice-weekly therapy sessions. To decrease the potential for attrition in testing due to long testing times, we provided breaks, ensured there was one research assistant consistently attending to the child’s needs (while others managed research equipment), and made efforts to provide clear explanations of all procedures. Furthermore, the individuals testing the children on the brain and behavioral measures were highly experienced in such assessments for children with ASD. Potential barriers to music therapy intervention sessions were primarily scheduling. To meet the needs of the families, evening and weekend sessions were offered. Children were overall highly participatory in the music therapy sessions; however, several of the children expressed a preference for certain activities over others. The music therapist used the order of session activities and a right-fit challenge to help maintain interest and completion of the MTA protocol.

**Measures of Sensory Gating at Baseline Comparisons.** Descriptive statistics are reported for the P50 and N100 amplitudes for children with ASD and TD children at baseline (Table 2).
When compared with the grand-averaged ERP of the TD group (Figure 1a), the grand-averaged ERP of the ASD group (Figure 1b) had smaller amplitudes for the P50 and N100 components for the conditioning click, suggesting less robust neural responses. For the test click (where smaller amplitudes are expected), children with ASD had a smaller amplitude for the P50 component compared with TD children; however, larger mean amplitude compared with their own conditioning click. Children with ASD had larger amplitudes on the test click for the N100 component compared with typical children, and larger amplitudes compared with their own conditioning click, suggesting less robust sensory gating.

An independent-samples t-test was conducted to compare P50 and N100 difference scores in children with ASD pre-music therapy and TD peers (Table 3). Means and standard deviations (SD) of the P50 difference scores for both the groups are shown in Table 3. There was no significant group difference in P50 difference scores (t(12) = 1.76, p = .10, d = −0.94). Group means suggest that children with ASD have less robust gating than the TD group. There was a significant group difference in N100 scores (t(12) = −4.47, p = .001, d = 2.39), suggesting that children with ASD have significantly less robust gating at the N100 component compared with TD peers.

**Measures of Attention at Baseline Comparisons.** Independent t-tests were conducted to compare scaled TEA-Ch scores between these groups (Table 3). Typically developing children demonstrated higher mean scores for each domain of attention (Table 3), with significant differences between groups in selective attention (t(12) = 3.21, p = .008, d = −1.69) and total attention (t(12) = 2.45,
Figure 1.
Plots of the Grand-averaged ERPs: (a) TD Children at Baseline; (b) Children with ASD at Baseline Period Before the Intervention; and (c) Children with ASD Post-intervention. The Solid Line Depicts Brain Response to the Conditioning Click (Click 1) and the Dashed Line Depicts Brain Response to the Test Click (Click 2).
No significant group differences were found in switch/control ($t(12) = 1.75, p = .12, d = −0.93$) or sustained attention ($t(12) = 2.01, p = .67, d = −1.36$). Large effect sizes (ranging from $d = −0.93$ to $d = −1.69$) suggest high practical significance (Cohen, 1988).

**Relationship Between Brain and Behavior Measures.** Pearson’s correlation was conducted to assess the relationships between sensory gating difference scores of the P50 and N100 components and TEA-Ch scores in children with ASD and TD children (Table 4). There was a significant negative correlation between N100 difference scores and selective attention ($p = .040$) for children with ASD, while for TD children there was a significant negative correlation between N100 and sustained attention abilities ($p = .020$) and a significant negative correlation between N100 and overall attentional abilities ($p = .046$). This suggests that better attention abilities (higher attention scores) are associated with better sensory gating (larger negative difference scores) at the N100 component. There were no other significant correlations between N100 difference scores and TEA-Ch scores. A significant positive correlation between P50 difference scores and the sustained attention scores was found for the ASD group postintervention ($p = .042$); however, there were no other significant correlations between P50

<table>
<thead>
<tr>
<th>Brain measures</th>
<th>Differences scores</th>
<th>Children with ASD ($n = 7$)</th>
<th>TD Children ($n = 7$)</th>
<th>Results of $t$-Tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>P50</td>
<td>−0.11 (1.67)</td>
<td>1.05 (0.52)</td>
<td>1.76</td>
<td>12</td>
</tr>
<tr>
<td>N100</td>
<td>0.53 (1.58)</td>
<td>−2.98 (1.35)</td>
<td>−4.47</td>
<td>12</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Behavioral measures</th>
<th>TEA-Ch scaled scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selective</td>
<td>13.71 (3.68)</td>
</tr>
<tr>
<td>Switch/control</td>
<td>13.57 (6.24)</td>
</tr>
<tr>
<td>Sustained</td>
<td>30.14 (13.07)</td>
</tr>
<tr>
<td>Total attention</td>
<td>57.43 (25.18)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Children with ASD ($n = 7$)</th>
<th>TD Children ($n = 7$)</th>
<th>Results of $t$-Tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>M (SD)</td>
<td>M (SD)</td>
<td>$t$ value</td>
</tr>
<tr>
<td>P50 −0.11 (1.67)</td>
<td>1.05 (0.52)</td>
<td>1.76</td>
</tr>
<tr>
<td>N100 0.53 (1.58)</td>
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<td>−4.47</td>
</tr>
</tbody>
</table>

Note. M = mean; SD = standard deviation; $d$ = effect size.

$*p < 0.05. **p < 0.01.$
difference scores and TEA-Ch scores for TD children or children with ASD.

**Preliminary Efficacy: Comparing Pre- and Postintervention in ASD**

**Sensory Gating.** The grand-averaged ERP of the ASD group after an intervention (Figure 1c) shows more organized brain activity compared with their brain activity before intervention (Figure 1b). Paired-samples t-tests were conducted to compare P50 and N100 difference scores in children with ASD pre- and postintervention. There was no significant difference in the P50 difference scores for children with ASD pre- and postintervention ($t_{(6)} = 0.52$, $p = .62$, $d = .26$) (Table 5).

Two participants did not have identifiable N100 peaks when postmusic therapy ERP components were analyzed; therefore, their data were excluded ($n = 5$). There was no significant difference in the N100 difference scores for children with ASD premusic therapy and postmusic therapy ($t_{(4)} = 1.86$, $p = 0.13$, $d = 1.17$). The large effect size ($d = 1.17$) suggests that larger sample sizes may result in statistically significant differences.

**Attention.** Paired-samples t-tests were conducted to compare TEA-Ch scores in children with ASD pre- and postintervention.
In analyzing raw TEA-Ch scores, postintervention mean scores were higher in selective, sustained, and total attention (Table 5), and there was a significant difference in selective attention ($t_{(6)} = -2.96$, $p = .025$, $d = -0.97$). A large effect size ($d = -0.97$) suggests high practical significance. This difference suggests that children with autism had significantly better selective attention abilities after music therapy intervention.

There were no significant differences in switch/control ($t_{(6)} = 0.25$, $p = .81$, $d = .06$), sustained ($t_{(6)} = -1.21$, $p = .27$, $d = -0.58$), or overall attentional abilities ($t_{(6)} = -1.71$, $p = .14$, $d = -0.69$). Furthermore, there was a small decrease in mean scores for switch/control postintervention. Moderate effect sizes for sustained ($d = -0.58$) and overall ($d = -0.69$) indicate that larger sample sizes may result in statistically significant differences.

**Discussion**

The purpose of this study was to establish feasibility and preliminary efficacy of an individualized music therapy attention protocol to improve sensory gating and attention skills in children with ASD. The aims for this pilot study were to (a) determine the feasibility of conducting study protocols including measures of sensory gating,
attention behaviors, and a 5-week music therapy intervention, (b) determine the sensitivity of brain and behavioral measures in identifying attentional differences in children with ASD compared to TD children, and (c) gather preliminary evidence of intervention effects on sensory gating and attention outcomes. We further sought to use this pilot study to develop recommendations for procedures in future research.

Feasibility of the Protocol

Feasibility data indicate that children with high functioning ASD tolerated both brain and behavioral testing measures, inclusive of a total of 8 h of testing. Children were provided with breaks, and we ensured that one research assistant was fully attentive to the child’s needs, engaging the child in conversation, explaining all protocols, and offering toys/fidgets during set-up. Children were also shown a silent movie during the EEG testing, in order to provide a focus for their attention. The EEG system used in this study requires a gel-like substance to be used for conductivity between the scalp and electrodes and all children tolerated the gel. The TEA-Ch assessment takes over an hour to complete and children were engaged in these “games” by a research team member. It should be noted that we specifically targeted children with high functioning ASD and the study procedures may not be acceptable for some individuals who have more severe symptoms.

All children completed the music therapy intervention, indicating that study protocols were acceptable to individuals who met the inclusion criteria. Although some children indicated a clear preference for some of the music therapy activities over others, the nature of an individualized protocol allowed the interventionist to ensure engagement and a right-fit challenge. The youngest child in the study (5 years old) initially demonstrated difficulty with completing all activities, asking for breaks between each activity and for a written schedule. A visual schedule was incorporated for this child (listing the activities that would be completed) and short breaks where he raced the interventionist down the hall and back. Furthermore, all participants were provided with short periods of time to explore instruments or play in any way they desired as a break from the attention tasks. Future research on attention protocols should provide breaks within the protocol and allow for the individuals to explore musically, in order to maintain engagement.
One additional aspect of the attention protocol that should be considered was the use of a board-certified music therapist and a graduate music therapy student assistant. Assistants in this study provided musical cues under the direction of the music therapist. This ranged from a distractor stimulus to musical cues on a competing instrument (e.g., piano or guitar). Although the protocol could be completed by one person alone, technology or an assistant would be needed to provide musical cues or distractor stimuli.

**Adequacy of Brain and Behavior Measures**

**EEG.** The results of this study indicated mixed results for using EEG to identify differences in sensory gating and attention between children with ASD and TD children. The results indicated that children with ASD had significantly less robust sensory gating than TD children at the N100 component, supporting research by Crasta, LaGasse, Davies, and Gavin (2016), even with the small sample size in this study. However, our analyses failed to find a significant difference between groups for the P50. The nonsignificant finding for the P50 is consistent with findings from Kemner et al. (2002), who failed to show a difference in P50 for children with ASD. Interestingly, children with ASD had smaller responses to the P50 conditioning click than to the test click both pre- and postintervention (opposite of what is expected). This discrepancy could indicate a difference in early attention processes in children with ASD or could indicate that the sensory gating had not yet matured in these children; however, more studies are needed to confirm these results before conclusive decisions can be made about the importance of using this specific measure in future studies.

**Behavioral Measures.** When comparing attention abilities of children with ASD and TD peers, we found that the TD children demonstrated greater abilities in every domain measured by the TEA-Ch, with significantly greater selective and overall attentional abilities. This result suggests that children with ASD may have deficits in selective and overall attentional abilities; however, further research is needed due to the small sample size and effect size. Although these results are limited, the TEA-Ch identified group differences in this study and could be used in a future study.

**Relationship Between Measures.** In exploring potential correlations between baseline attention abilities and sensory gating in
TD children, we found significant correlations between sustained and overall attentional abilities and gating at the N100 component in TD children. This result suggests that stronger attention abilities may be related to more robust sensory gating. Children with ASD had a significant correlation between N100 scores and preintervention selective attention scores, suggesting that children with ASD that have better gating of the N100 component demonstrate better selective attention abilities. These results should be interpreted cautiously due to the small sample size and a large number of correlations run on few variables.

We also explored potential correlations between attention abilities and sensory gating postintervention for the ASD group. We found a significant positive correlation between sustained attentional abilities and gating at the P50 component for this group postmusic therapy intervention. This is an interesting finding, as P50 gating is thought by some authors to be pre-attentive, while others have shown that sensory gating at P50 is reduced when individuals are instructed to actively attend to auditory stimuli in paradigm (White & Yee, 1997). Furthermore, children with ASD showed an atypical gating response in the P50 component, with increased responses to the test click over the conditioning click. These results should be interpreted with caution due to the small sample size and lack of control group. However, researchers could use this information to inform both brain and behavioral measures of sensory gating in future studies with larger sample sizes.

**Impact of Music Therapy on Sensory Gating**

In this study, children with ASD had greater difference scores at the N100 components postmusic therapy, suggesting improved sensory gating following the intervention. However, these improvements were not statistically significant. Since there was no control group, we cannot conclusively state that improvements in the raw scores are related to music therapy intervention. However, larger effect sizes and differences within groups were found in relation to N100 gating.

Analysis of differences scores at the P50 component before and after music therapy revealed a small effect size. It could be that P50 gating, as a pre-attentive component of sensory processing, occurs too early in neural gating to be impacted by music therapy.
interventions. Another possible explanation is that because the P50 component has a much smaller amplitude than N100 peak amplitudes, the P50 has a smaller signal-to-noise ratio. Therefore, we need either more participants to increase statistical power or more trials per subject to potentially lower measurement error.

There is limited research explicitly linking music to changes in brain processes. There is a precedence in the literature that music induces neural plasticity that can be measured through changes in EEG topography (Habibi et al., 2016; Thaut et al., 2014) and ERP responses (Putkinen et al., 2014). To our knowledge, this is the first study to explore the impact of music therapy on sensory processing using EEG.

Impact of Music Therapy on Behavioral Measures of Attention

Our study showed that children with ASD had significant improvements in selective attention following music therapy with a large effect size (i.e., $d = .97$) suggesting clinical meaningful results. Our results also indicated that the improved scores on sustained attention with a medium effect size (i.e., $d = .58$). This suggests that music therapy intervention has the potential to improve attentional abilities, especially selective attention, in children with ASD. Interestingly, switch/control attentional abilities slightly decreased following music therapy, although the difference was not statistically significant, and the effect size was very small. This could inform future studies, indicating that intervention protocol emphasis should be on selective attention and sustained attention, when compared with attention switch/control. Another interpretation is that selective attention is more severely impacted in children with ASD and the protocol may be more impactful for selective attention abilities.

Our findings support findings by Pasiali et al. (2014), where nine adolescent children with ASD who participated in eight sessions of group music therapy interventions demonstrated significant improvements on tasks related to selective attention. Pasiali et al. also showed significant differences in attentional control/switch; however, they conducted group interventions. It could be possible that certain components of attention would be better targeted in different intervention settings where there would be more interaction with environmental factors such as distractions. Additional
research would be needed to determine the impact of different intervention types (individual or group) on attentional abilities in children with ASD.

Limitations

As this pilot study utilized small sample sizes, there were only a few statistical tests that were significant. The small sample size was due to limited funds and timeframe for this project funded through an internal grant. Although some of the statistical tests were not significant, most of the effect sizes were large. However, due to the sample size, the results must be interpreted with caution and are only intended to inform future studies (see Kraemer et al., 2006). Another limitation of this study was the age range. Participants in this study ranged from 5 to 12 years, which represents a large range of skills and abilities in attention skills. Although an age- and gender-matched control group was used as a comparison for baseline measures, age could have impacted the results of this study.

A primary purpose for conducting this feasibility study was to provide initial data and suggest recommendations for improving methodology. These findings on their own cannot be generalized to larger populations. The most appropriate use of these findings would be to generate hypotheses for a more robust study that utilizes a larger sample size.

Conclusion

This feasibility and pilot study was the first study using physiological and behavioral measures of sensory gating and attention in children with ASD. Although researchers have suggested that music affects attentional networks through the perception of dynamic patterns in music (LaGasse & Thaut, 2013), there is limited research demonstrating the efficacy of music therapy for attention control and none for brain measures of sensory gating. The results of this study demonstrate that the testing and intervention protocols were feasible and demonstrated differences between children with ASD and TD children for the measures selected for this pilot study. However, the N100 component appeared to be more sensitive to differences than the P50 component. The initial data for the music therapy attention protocol demonstrated...
an impact on selective attention scores. No significant differences were found for sustained attention and switch/control attentional abilities. However, the effect size for sustained attention was large and could be an important measure in future studies along with selective attention. These results can inform future studies with larger sample sizes.

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