

Full-Length Article

Listening to Music Improves Language Skills in Children Prenatally Exposed to CocaineStephen W. Porges^{1,2,3}, Katherine E. Bono⁴, Mary Anne Ullery⁵, Olga Bazhenova³, Andreina Castillo⁵, Elgiz Bal³, Keith Scott⁵¹Indiana University Bloomington, Indiana, United States of America²University of North Carolina at Chapel Hill, North Carolina, United States of America³University of Illinois at Chicago, United States of America⁴California State University, Fullerton, United States of America⁵University of Miami, Florida, United States of America**Abstract**

The effectiveness of listening to music, as an intervention to improve language skills, was tested with young children prenatally exposed to cocaine. In addition to the prenatal exposure to cocaine, these children often share family experiences such as substance abuse, poverty, and mental illness that are prevalent in chronically stressed families in which abuse and trauma are likely to occur. In the current study 62 children, between the ages of 17 and 30 months, who were receiving a center-based intervention program, participated in a 16-week music-based trial. The trial consisted of listening to music 5 days a week for 16 weeks. During the first week music listening sessions were 50-minutes and during the subsequent 15 weeks the daily listening sessions were 10 minutes. Participants were randomly assigned to three groups: a filtered music group that listened to vocal music filtered to emphasize frequencies within the bandwidth of spontaneous human speech, an unfiltered music group that listened to the same vocal music in its original unaltered form, and a control group that only received the standard early intervention services provided by the preschool. Outcomes were evaluated with assessments for expressive and receptive language skills. Results document that children, who listened to either the filtered or unaltered music, showed greater gains on language skills than the control group. The findings suggest that providing scheduled times to listen to vocal music similar to a mother singing a lullaby would provide a simple cost-effective language intervention.

Keywords: *language skills; music therapy; prenatal cocaine exposure; children; Polyvagal Theory.*

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Children, who are prenatally exposed to cocaine, are at risk for language delays [1]. Initially researchers inferred that these delays were due to cocaine exposure (e.g., [2]). However, more recent studies suggest that the teratogenic effects of cocaine are mild, if they exist at all, and that the greatest risk to these children comes from associated pre- and post-natal environmental factors (e.g., [3,4]). However, children who are prenatally exposed to cocaine frequently come from at-risk environments that, in part due to poverty and physical danger, lead to physical and mental illness, developmental delays, and

behavioral problems. Although there are reports that early behavioral interventions improve several behavioral and cognitive functions, more than 50% of children prenatally exposed to cocaine, who completed an early intervention program, scored in the “below normal” range on measures of language ability [5]. Thus, with this risk population, there is a need to explore other intervention modalities that may selectively improve language skills.

Listening to music has been proposed as a potential intervention modality to improve language skills [6,7]. Hypothetically, the Polyvagal Theory [8,9,10,11], proposes that listening to music functions as a ‘neural exercise’ requiring the listener to attend and process acoustic signals within a frequency bandwidth similar to human voice. In the case of vocal music, there is an overlap with the frequencies of human speech. When compared with normal spontaneous speech, the enhanced modulation of intonations in vocal music can be conceptualized as exaggerated prosody. Thus, the demand of processing the words and phrases embedded in vocal music would conform to an exercise model in which the dynamically changing frequencies (i.e., intonation) and

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amplitudes (i.e., loudness) provide changing demands on the nervous system.

Listening may be conceptualized as an intervening process between the sensory processes involved in hearing and cognitive processes related to interpretation and extraction of meaning from voice. Thus, effective listening is necessary for both receptive and expressive language and deficits in listening could be related to the reported deficits in language skills in children prenatally exposed to cocaine.

Individuals, who have difficulties in listening, are often diagnosed as having auditory processing disorders or deficits (e.g., [12]). Although the mechanisms for these deficits are not totally understood, the deficits can be objectively and reliably measured through a variety of procedures evaluating performance including tasks requiring the participant to identify the different words being simultaneously presented to both ears (i.e., competing word) or extracting words embedded in background sounds with standardized assessments (e.g., [13]).

Polyvagal Theory [8,9,10,11] provides a model to explain how listening to music might have a positive impact on children with language delays, listening impairments, and/or auditory hypersensitivities. The theory suggests that atypical neural regulation of middle ear structures may underlie this cluster of symptoms by altering the middle ear transfer function. An atypical middle ear transfer function could contribute to symptoms associated with difficulties in extracting the frequencies in speech that convey meaning, while potentially amplifying the distracting and masking influence of low frequency background sounds (e.g., [7,14]).

Changes in the middle ear transfer function may either enhance or disrupt the anti-masking functions of middle ear structures [7] and functionally influence the processing of human speech [15]. Typically, the anti-masking functions of middle ear structures are context sensitive and are not recruited when physiological state shifts to support defense. When a person becomes hypervigilant in an attempt to detect potential dangers or threats in the environment, there is an adaptive retuning of the middle ear structures that shifts the bias in the middle ear transfer function to detect low frequency sounds. When tone to the middle ear muscles is increased, the transfer function of middle ear structures changes to enhance the detection and intelligibility of speech and dampens the amplitude of low frequency sounds [15]. Thus, optimizing the processing of speech via shifts in the transfer function of middle ear structures comes with a cost. The transfer function that optimizes speech processing decreases sensitivity to the low frequency sounds that are associated with predator and catastrophic natural disasters such as earthquakes, volcanoes, and severe storms.

Difficulties in recruiting the anti-masking functions of middle ear structures may be a functional cause of the difficulties that children, prenatally exposed to cocaine and/or living in high-risk environments, may have while processing

human voice. These children may be in a physiological state that supports hypervigilance and other functions related to defensive strategies (e.g., fight or flight) or in a state that supports dissociation including daydreaming. Based on the neuroanatomy and neurophysiology of the middle ear structures, increasing the neural tone to the middle ear muscles hypothetically would dampen the acoustic energy of low frequency background sounds reaching the inner ear and being transmitted to the brain structures processing language. This sequence of neurophysiological processes would optimize the extraction of the acoustic features conveying meaning in human speech.

Music as an Intervention: In our previous research, music has been used with children on the autistic spectrum as an intervention hypothesized to improve vagal regulation of the heart, auditory processing, listening, hearing sensitivity, spontaneous speech, and emotional control [16,17]. In these studies two types of music programs were used as interventions, in one program prosodic vocal music (e.g., soundtracks from Disney movies) was applied and in the other program the same music was altered to functionally amplify the prosodic features (e.g., rhythmic modulations of intonation) and dampen the amplitude of potential distracting frequencies outside the primary frequency band involved in social communication. In a preliminary clinical trial (see [17]), in which both forms of music were used, parents reported that only the altered music reduced auditory hypersensitivities and improved emotional control. However, relevant to the current study, both forms of music enhanced spontaneous speech and listening. The altered music methodology evolved to become a standardized intervention known as the Safe and Sound Protocol®, which is currently available to professionals through Integrated Listening Systems [18].

Based on the Polyvagal Theory, both music interventions (i.e., vocal music and music processed to increase frequency variations in the range of human voice) are assumed to function as a neural exercise that would optimize the extraction of speech by shifting the bias of the middle ear transfer function to pass the frequencies associated with human speech, while attenuating the loudness of low frequency background sounds. Researchers have defined the frequencies that are optimized by middle ear muscle tone to process species-specific vocalizations as the ‘band of perceptual advantage’ [7]. In humans, this frequency band is similar to the index of articulation [19] and the speech intelligibility index [20]. The band of perceptual advantage is based on the physics of the middle ear structures. Estimates of this band for a mammalian species can be calculated from the resonance frequency of the middle ear (see [14]).

The purpose of this study was to assess the effect of listening to music on an early intervention program for young children who were prenatally exposed to cocaine.

Theoretically, the music programs were administered to “prime” the auditory system to optimize the processing of human voice and were hypothesized to improve language skills. Thus, based on Polyvagal Theory, listening to vocal music, which involves the modulation of intonation within a frequency band in which comprehension of human speech is optimized, should by enhancing neural regulation of middle ear structures improve language skills.

Material and Methods

Participants. The participants (n=62; 51.6% female) were children enrolled in the center-based component of the Linda Ray Intervention Program at the University of Miami (Miami, FL). This Intervention Program functioned as a preschool and had ongoing approval by the University of Miami’s Institutional Review Board. Parents or legal guardians of the participants signed consent forms for the children upon enrollment into the program and then each year on an annual basis. Several cohorts of children were enrolled in this study to achieve an adequate sample size. Eligibility requirements were constant across cohorts. At pre-test, children ranged from 17-30 months (M =20.9 months; SD = 3.7) and at post-test, children ranged from 21-36 months (M =28.8 months; SD = 4.6). Most children were African-American (66.1%), 21.0% were Hispanic, and 12.9% were of mixed or other ethnicity. All children enrolled had mild to moderate general developmental delays and none had major handicapping conditions. Cocaine exposure was obtained as a maternal self-report at enrollment or through meconium drug testing at birth, however the amount of cocaine use for this population was unknown due to the method of reporting. All children were either exposed to cocaine prenatally or were living in high-risk environment in which drug use was common. All children had Individualized Family Support Plan with the eligibility determination of *Developmentally Delayed* and received Part C early intervention services at this center. Group data are illustrated in Table 1.

only assessments. One group (n=18) listened to the filtered music program, while another group listened to the same music without being filtered (n=20) (see Interventions section below). For the two intervention groups, the staff was blind to each child’s group assignment. The third group (n=24) served as a control and received the same assessments without a music intervention. All groups received the identical center-based intervention and were assessed at same pre/post intervals.

Interventions: Music Selection. Two types of music programs were used as interventions, in one program prosodic vocal music (e.g., soundtracks from Disney movies) was applied and in the other program the same music was altered to functionally amplify the prosodic features (e.g., rhythmic modulations of intonation) and dampen the amplitude of potential distracting frequencies outside the primary frequency band involved in social communication. Vocal music extracted from five soundtracks of Disney movies: The Little Mermaid (Under the Sea, Kiss the Girl, Part of the World, For A Moment), Pocahontas (Just Around the River Bend, Colors of the Wind), the Lion King (Hakuna Matata, I Just Can’t Wait to be King, Circle of Life), Beauty and the Beast (Tale as Old as Time, Belle, I Got a Dream, Be Our Guest, How Does A Moment Last Forever, Gaston, Something There, Human Again), and Aladdin (A Whole New World, A Friend like Me, One Jump Ahead, Prince Ali, Out of Thin Air).The extracted music was used to generate 250 minutes of intervention music, which provided 50-minute music sequences for each of the five sequential days of the initial music intervention. For the 15-week post intervention daily 10-minute booster sessions, the same 250 minute sequential music program used (i.e., 50 minutes a week). The 75 booster sessions (i.e., 5 each week for 15 weeks) required 3 repeats of the 250-minute program.

Interventions: Processing of the Music. The two music groups differed on the degree and pattern of dynamic intonation changes in the music. In the unfiltered music condition, the modulation of intonation was driven solely by the music composition expressed through instruments and voice. In the filtered music condition, in addition to the normal modulation of intonation that characterizes the selected music, an additional modulation was superimposed on the music through an algorithm that ‘filters’ the music by dynamic shifts in bandwidth. Thus, the interventions differed in degree that intonation is modulated. Hypothetically the ‘filtered’ music would demand greater dynamic adjustment of the neural tone regulating the middle ear structures.

The frequency characteristics of the music selected and the additional acoustic processing of the music applied to produce the filtered music were theoretically selected based on the documented frequency band associated with the index of articulation [19] and speech intelligibility index [20]. These

Demographics (n)	Assessment Only	Filtered	Unfiltered
Gender			
Male	13	7	9
Female	11	11	10
Race/ethnicity			
African-American	16	13	12
Hispanic	6	3	4
Mixed or other	2	2	4
Total n	24	18	20

Table 1. Demographics by Group Membership

Group Assignment. Within each cohort, children were randomly assigned to one of three groups. Two groups received music as an intervention and a third group received

indices emphasize the relative importance of specific frequencies in conveying the information embedded in human speech. In the normal ear, the primary frequencies of these indices are not attenuated as they pass through the middle ear structures to the inner ear. During normal listening, via central mechanisms, the middle ear muscles contract and stiffen the ossicular chain. This process functionally changes the middle ear transfer function to dampen the “masking” low frequency background sounds from the acoustic environment and to allow human voice to be more effectively processed by higher brain structures.

The music interventions consisted of presenting vocal music or dynamically filtered vocal music via headphones. Songs from Disney movie soundtracks were selected for the interventions, because the acoustic properties of these soundtracks are melodic, convey and elicit positive affective states, minimize low frequencies, and emphasize the dynamic range of a female voice. The “filtering” process functionally exaggerates prosody through algorithms that: 1) restrict the bandpass of the acoustic features of the music solely to the range of human voice by functionally removing frequencies lower and higher than the predominant frequencies of a female voice; and, 2) modulate the frequency band within this restricted bandpass to exaggerate the dynamic changes in acoustic frequencies. The unfiltered vocal music maintained the original acoustic features of the songs. Acoustic stimuli with these characteristics were hypothesized to modulate the neural regulation of the middle ear muscles and to functionally improve the signal-to-noise ratio (i.e., voice to background noise) in processing language (see [7,14]). The procedures incorporated in the filtered music conditions are patented [21].

Procedures.

During the first week of the trial, each child listened to the music program via headphones for approximately 50 minutes each day for 5 consecutive days (i.e., Monday through Friday) using headphones and MP3 players. For the next 15 weeks, each child received 10-minute sessions the 5 days each week. The MP3 players were inserted into a soft plastic sleeve with a clip and attached to the back of the child’s shirt. One group received filtered music during the intervention and booster sessions, while the other group received unfiltered music during the intervention and booster sessions. Researchers and staff were present at the 5-day 50- minute and daily 10-minute booster sessions. All children were compliant and there were no problems in delivering the music.

Assessments were conducted one month prior to the intervention and one month after the intervention was finished to determine changes in language and communication. The assessment only group was tested at a similar interval to evaluate anticipated changes over time in the absence of the music intervention. The assessments included the Reynell Developmental Language Scales (RDLS)

[22], which measures both receptive and expressive language and the Bayley Scales of Infant Development Mental Scale (Bayley-II) [23] to measure general cognitive ability before and after the trial. Trained research associates administered assessments pre- and post-intervention.

After the pre-test, the participants in the two music groups received the 16-week (i.e., including 15 weeks of 10-minute daily booster sessions) intervention during school days (i.e., Monday through Friday). Before the first intervention week, children wore the headphones without music to become familiar with the sensation of wearing them.

During the 50 minute sessions staff engaged, often on a one-on-one basis, the children to keep them calm and engaged. To facilitate compliance and to help maintain the child in a calm state, additional activities were planned to keep the children sufficiently involved to avoid a focusing of interest on and a removal of the headphones. These activities included playing with sand, cotton balls, smaller manipulative toys, coloring, and painting. In consultation with the center’s staff, a schedule was set to deliver the music intervention early in the morning in order to prevent having the children listen to the music during outdoor playtime, when children from other classes were also present. Staff rarely had difficulty with children keeping headphones on, although two children felt uncomfortable with the procedures and were excused from participating. All participants described in this study received the primary 5-day intervention during 5-sequential days.

After completing the initial intervention week, the booster sessions were administered requiring children to wear the headphones for 10 minutes a day for 15 weeks. After consultation with staff, booster sessions were implemented during breakfast, while children were distracted and busy with their food. During this time, all children sat at the table, making it easier to keep other children from playing with their classmate’s MP3 players. Conducting the intervention during this time also allowed the children to listen to the music quietly without be disrupted by their classmates. This schedule enabled the booster sessions to be delivered during a time that would not conflict with daily activities including opportunities to participate in the usual curricular schedule. During all phases of the intervention a research associate, a teacher, and the classroom assistants were present. If the child removed the headphones, a staff member quietly placed them back on the child and did not engage the child in conversation. Prior to each listening session, the output volume of each MP3 player was calibrated to a peak loudness of 70 db.

Measures

Standardized assessments were administered by a trained researcher and used to measure cognitive and language ability. Assessments were conducted, one child at a time, in a quiet room. Most children were able to complete each of the assessments in one session, while others required multiple visits on different days to complete them.

Receptive and Expressive Language. Language was assessed using the Reynell Developmental Language Scales (RDLS) [22]. The RDLS is frequently used for assessing the language skills of very young or developmentally delayed children. The battery consists of 134 items, divided into two 67-item scales: Verbal Comprehension and Expressive Language. The Verbal Comprehension scale tests a child’s receptive language skills and the Expressive Language scale incorporates three sets of items: structure, vocabulary and content. Each scale yields a total and a standard score with reliability coefficients for children ranging from .80 to .93. In designing the RDLS, all aspects of validity (construct, content, concurrent, predictive) were established. Standard scores are calculated from total correct scores for each child.

Cognitive Development. The Bayley Scales of Infant Development Mental Scale (Bayley-II) [23] was used to measure cognitive development. The Bayley II was used assess cognitive function for the early intervention program when it began and was not updated to a newer version in order to maintain consistency across cohorts. This commonly used

developmental assessment for children ages 1 to 42 months yields a mental age score and a standardized score, or Mental Development Index (MDI) ($M=100$; $SD=15$). The Bayley-II, test-retest reliability is .91 for 24- and 36-month old children and Cronbach Alpha ranges from .79 to .93.

Results

Descriptive statistics for the outcome variables (expressive language, receptive language, and mental development index) are listed by group assignment (filtered vocal music, unfiltered music, and assessment only) in Table 2. In contrast to the minimal changes observed in the assessment only group, both music intervention groups had noticeable gains on the language outcome assessments. Since preliminary analyses indicated that two intervention groups (filtered and unfiltered music) did not differ on the outcome measures, the two intervention groups were then combined and contrasted with the control group.

Table 2. Descriptive Statistics by Group

	Pre-Test M(SD)			Post-Test M(SD)		
	Filtered	Unfiltered	Assessment	Filtered	Unfiltered	Assessment
Expressive Language	79.13 (13.00)	74.82 (10.96)	75.14 (16.44)	83.06 (15.05)	84.83 (12.30)	75.70 (12.68)
Receptive Language	70.63 (8.36)	75.88 (13.38)	72.33 (15.41)	76.11 (11.35)	81.11 (12.60)	72.30 (12.00)
MDI	84.06 (12.49)	89.40 (6.78)	81.86 (14.50)	89.61 (13.22)	95.28 (10.65)	84.64 (14.53)

Performance levels during the pre-intervention condition were significantly related to the observed changes in the language measures and the pre/post changes were significantly correlated among all outcome variables (see Table 3). Since the correlations indicated a dependency of the language outcome scores on pre-intervention levels, the influence of group assignment on the outcome variables was evaluated in a stepwise regression model in which pre-intervention levels were entered into the model before group assignment. This statistical strategy removed the influence of initial pre-intervention levels from the evaluation of group influence. The regression analyses identified a significant improvement in the model when group assignment was entered for expressive language ($F(1,47) = 4.59, p = 0.037$) and a trend with receptive language ($F(1,48) = 3.36, p = .073$). The groups did not differ on the Mental Development Index of the Bayley Scales.

Table 3. Correlations among Pre-Tests and Change Scores

Variables	1	2	3	4	5
1. Pre-Expressive	-				
2. Pre-Receptive	.52**				
3. Pre-MDI	.68**	.59**			
4. Expressive Change	-.53**	-.22	-.13		
5. Receptive Change	-.20	-.45**	-.05	.60**	
6. MDI Change	-.21	-.19	-.22	.45**	.52**

Note: ** $p < .01$

The sample consisted of young children with heterogeneous features due, in part, to differences in age, developmental history, classroom cohort, and developmental status at the start of the study. Given the heterogeneity of the samples, we supplemented the above parametric analyses with nonparametric Mann-Whitney U tests. The Mann-Whitney U tests evaluated the distribution of unstandardized residual change scores from pre to post intervention for each group. The unstandardized residual change scores removed the influence of pre-levels and maintained the metric of the original variable. These analyses, consistent with the regression analyses described above, indicated that the combined “Listening Group” exhibited a significant improvement in expressive language ($U= 401.5, p = .044, r = .284$) and a trend toward more improvement in receptive language ($U= 396.5, p = .095, r = .234$).

The contribution of group assignment to the distribution of residualized change scores can be observed in the box-and-whisker plots illustrated in Figures 1 and 2. The box is defined by lower and upper quartiles and the horizontal line represents the median. As illustrated in both figures, greater improvements are more frequently observed in the combined music intervention group relative to the assessment only control group.

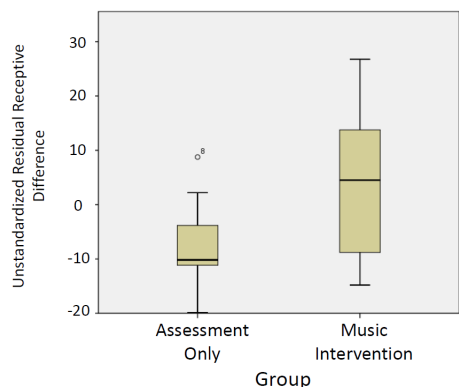


Figure 1. *Box-and-Whisker Plot of Residualized Change Scores in Receptive Language*

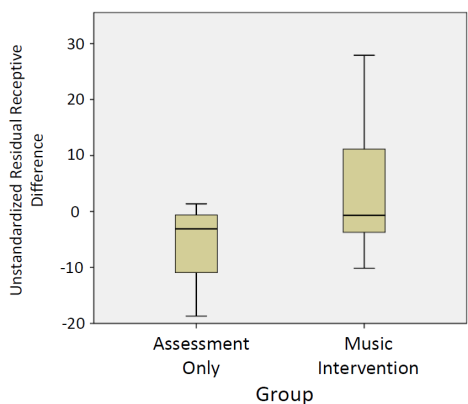


Figure 2. *Box-and-Whisker Plot of Residualized Change Scores in Expressive Language*

Discussion

Although various early interventions have been effective in stimulating the mental development of children prenatally exposed to cocaine (e.g.,[24]), these interventions have been relatively ineffective in normalizing language skills [25]. The study was conducted to test the hypothesis that listening to music within a frequency consistent with the intonation of a mother’s lullaby would improve language skills. The hypothesis was supported. Specifically, children who listened to the music programs showed greater gains in language skills than children in the control group that had only assessments.

The statistical effect of the intervention was stronger on expressive language than on receptive language. This seems counterintuitive, since the goal of the intervention was to help children be able to listen and process the human voice more effectively. It is possible that expressive language delays are more apparent at younger ages. Previous research has documented that a higher percentage of children in this population experienced delays in expressive language than in receptive language [1]. Additional research is needed to understand the differential effects of listening interventions on expressive and receptive language in this population of children.

Neural model: The results suggest that listening to vocal music, as a neural exercise involving middle ear structures, may improve the ability of at-risk young children to express and to comprehend language. Listening to music could influence language skills by recruiting the anti-masking functions of the middle ear structures, which filter out low frequency sounds from the environment, to allow the person to more effectively process the human voice [7, 15]. Although these anti-masking functions improve the fidelity of the frequencies associated with human speech, there is a cost to the fidelity of low frequency sounds. When the anti-masking functions are not recruited, the transmission of low frequency sounds through the middle ear is optimized resulting in a lower threshold to detect the low frequency sounds frequently associated with predator or environmental threats. Thus, a nervous system optimally ‘tuned’ to detect low frequencies would result in compromised speech processing (i.e., receptive language skills) and developmental delays in expressive language skills, while a nervous system ‘tuned’ to the frequencies associated with human speech would optimize the development of language skills at the expense of detecting risk.

In addition to the teratogenic effects of prenatal exposure to cocaine, the children in this study were also we exposed to several environmental risk factors. In the current study most the children were living in homes that had been affected by substance abuse, poverty, and mental health problems. Many experienced multiple custody changes. Many had severe stress reactions in response to family violence. These environmental factors may have contributed to observations of general defensiveness, which was manifest in chronic hypervigilance

even when the children were physically safe in the center. Consistent with these observations other researchers suggest a similar hypervigilance in children of depressed mothers [26]. Potentially, this hypervigilance could require a neurophysiological state to optimize the fidelity of the low frequency sounds associated with predator by changing the transfer function of middle ear structures, which would reduce the intelligibility of speech by dampening sounds within the frequency band of human voice. Thus, the biobehavioral state that promotes hypervigilance would limit the availability of the relevant sounds from human voice necessary to develop efficient language skills. If this were true, then hypervigilance and the hypothetical dysregulation of the middle ear structures would add to additional risk factors for poor language development faced by this population of at-risk children.

Unfiltered versus filtered music: Although the two interventions differed in the degree that intonation was modulated, both forms of music (i.e., filtered and unfiltered) had similar positive influences on language skills. Below three plausible explanations for this finding are proposed.

First, the protocol differed in duration from previous clinical trials (see [16,17]). In the previous studies only a 5-day, one-hour a day protocol was used. In the current study, a similar 5-day intervention was used, however, it was supplemented with 15 weeks of an additional 10 minutes a day of listening during the preschool schedule (i.e., Monday through Friday). It is possible that the added exposure to music in both music interventions minimized condition differences.

Second, the current study targeted a population with different clinical features. In previous studies, the participants were older children or adolescents with autism spectrum disorders with a prevalence of auditory hypersensitivities and auditory processing deficits [16,17], processes that were not assessed in the current study. Thus, it is possible that a delay in language skills prevalent in children prenatally exposed to cocaine may not be accompanied by auditory hypersensitivities or auditory processing deficits. There is a possibility that the mechanisms underlying language development may be dependent on a neural substrate that is different than the mechanisms involved in down-regulating auditory hypersensitivities and enhancing auditory processing. For example, the down-regulation of auditory hypersensitivities and the enhancement of auditory processing may be a prerequisite substrate for language development and these processes may not be as challenged in toddlers exposed prenatally to cocaine as they are in older children and adolescents with autism spectrum disorders. Consistent with this explanation, the participants of this study had mild to moderate delays and did not have any major neurological or developmental disorders.

Third, there is a possibility that the acoustic features embedded in both interventions were sufficient to recruit the

neural mechanisms involved in processing speech. In the unfiltered music condition, the modulation of intonation was driven solely by the music composition expressed through instruments and voice. In the filtered music condition, in addition to the normal modulation of intonation that characterizes the selected music, an additional modulation was superimposed on the music through an algorithm that ‘filters’ the music by dynamic shifts in bandwidth. Thus, the music interventions differed in degree that intonation is modulated. Hypothetically the ‘filtered’ music would demand greater dynamic adjustment of the neural tone regulating the middle ear structures. However, both music interventions, by employing vocal music, were predominantly represented by an acoustic frequency band similar to a mother’s lullaby in range and intonation. Therefore, unfiltered vocal music might have provided the participants with sufficient modulations of intonation to ‘retune’ the hypothesized mechanisms involving neural regulation of middle ear structures.

Future research will need to confirm that listening to music enhances the neural regulation of middle ear muscles and functionally changes the middle ear transfer function. Unfortunately, assessment instruments necessary to confirm this plausible hypothesis are not currently available for clinical research. However, research does support that, similar to this study, listening to filtered music for a 5-day, one hour a day intervention [16] improved processes dependent on a shifting of the middle ear transfer function to emphasize speech as measured with the filtered words and competing words subscales of the SCAN [13]. While in another study [17], when contrasted with unfiltered music, filtered music selectively reduced auditory hypersensitivities and improved emotional control, while both interventions resulted in a similar positive effect of parental reports of improved listening and language skills. The latter findings are consistent with the results of the current study.

Contrasts with auditory intervention therapies

The music interventions used in this study share features with other auditory intervention therapies (i.e., AIT). AIT was originally developed by otolaryngologists Guy Berard [27] and Alfred Tomatis [28]. Although AIT was developed specifically for the treatment of auditory and language difficulties (see [29]), it has been applied to a wide range of disorders, including autism, learning disabilities, depression, migraine headaches, and epilepsy [30]. Due, in part, to the lack of standardization, development of underlying neurophysiological theory, and documented scientific efficacy, AIT has not been a preferred evidence-based treatment [31, 32].

Some studies evaluating the effectiveness of the AIT report improvements [33,34] and others do not [29, 35, 36, 37, 38]. Gilmore [39] conducted a meta-analysis based on several studies conducted with the Tomatis Method involving 231 children. When outcome measures were clustered into

behavioral domains, a small effect, consistent with the current study, was identified for linguistic processes.

Conclusion

The music interventions delivered in this study differ from AIT and other forms of listening therapies in method and theory. The interventions were theory-based (i.e., Polyvagal Theory) and reflect a strategic attempt to engage neural regulation of middle ear structures.

Several limitations should be considered when interpreting this study's findings. First, the sample size was relatively small and future studies should evaluate larger samples and investigate intervening variables that may mediate or moderate the effectiveness of the interventions. Second, the sample was heterogeneous in age, developmental status, and developmental history. These features could contribute to potential violations of distributional assumptions when using parametric statistics. Lastly, we lacked individual measures of regulation of the middle ear muscles and auditory processing, both of which could influence the effectiveness of listening to music as an intervention that would improve language skills.

Efficient interventions to enhance language skills are in great need given the disparity between typically developing children and at-risk children in language development and the strong association between language ability and other outcomes such as school readiness and school achievement (e.g., [40,41]). If the future studies replicate the positive effect of listening to music on language skills, then the administration of a music intervention incorporating acoustic features similar to a mother singing a lullaby would be a simple and cost-effective language intervention.

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