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Technology-enhanced multisensory music education for children with autism: Effects on sensory integration and learning behaviors

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Abstract

This study explores the integration of FigureNotes–a color-coded music notation system–and the Musical Jumping Pad–a multisensory music technology–within the holistic music educational approach for young children (HMEAYC) improve sensory processing and learning behaviors in preschool children with autism spectrum disorder (ASD). A quasi-experimental design was implemented with 33 participants (17 with ASD and 16 typically developing children), randomly assigned to either an intervention group receiving HMEAYC-based multisensory music instruction or a control group following a standard curriculum. Pre- and post-intervention assessments were conducted using the sensory profile (SP) and the teacher rating scale of the social behavior assessment system for preschool (SBASP), focusing on auditory, visual, and tactile processing, along with learning habits and performance. Results indicated significant improvements in the intervention group across all SP and SBASP subscales, with especially strong gains in tactile processing and learning performance. These findings underscore the efficacy of synchronized multisensory music interventions in supporting sensory integration and behavioral engagement in young neurodiverse learners. The study contributes to the field of inclusive early childhood education by demonstrating how technology-enhanced music education can be both culturally adaptive and developmentally responsive. Future studies should examine the long-term impacts and cross-setting applicability of such interventions.

Keywords: autism spectrum disorder, FigureNotes, Musical Jumping Pad, sensory processing, learning behaviors

INTRODUCTION

Autism spectrum disorder (ASD) is defined in the diagnostic and statistical manual of mental disorders, fifth edition, text revision a as a neurodevelopmental condition characterized by persistent deficits in social communication and interaction, along with restricted, repetitive patterns of behavior, interests, or activities (American Psychiatric Association, 2022; Ketcheson et al., 2021; Lord, 2010; Supekar et al., 2018). One of the most pervasive concerns among children with ASD involves sensory processing difficulties–such as hyper- or hypo-responsiveness–that significantly affect motor coordination, attention, and social participation (Crasta et al., 2020; Harrison & Hare, 2004; Hazen et al., 2014; Hochhauser & Engel-Yeger, 2010). These challenges are especially critical in early childhood, when foundational cognitive and behavioral competencies are rapidly developing (Liss et al., 2006; Suarez, 2012; Takahashi et al., 2018).

Music has been increasingly recognized as an effective, multisensory medium for promoting attention, social-emotional engagement, and sensorimotor regulation in children with ASD (Heaton, 2009; Heaton et al., 2008; LaGasse et al., 2024; Molnar-Szakacs & Overy, 2006). Notably, rhythmic and interactive music activities can scaffold behavioral engagement and enhance communication and learning in inclusive educational contexts. In Taiwan, the growing prevalence of ASD (Autism Foundation Taiwan, 2023) highlights the urgent need for developmentally appropriate and culturally responsive intervention strategies that

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Contribution to the literature

- The study's significant contribution to the literature is the integration of FigureNotes and the Musical Jumping Pad in the holistic music educational approach for young children (HMEAYC) for children with ASD.
- This innovative approach conducted in Taiwan, demonstrates the transformative impact of music technology on sensory learning and learning behaviors for children with ASD.
- The study's results highlight the potential for music technology to revolutionize special education practices, emphasizing the importance of multi-sensory experiences in addressing the unique needs of young learners with ASD.

address sensory and behavioral diversity in preschool classrooms.

In response to these needs, this study integrates FigureNotes and the Musical Jumping Pad into the HMEAYC to evaluate its impact on sensory processing and learning behaviors among preschoolers with ASD. Unlike prior studies that focused on isolated sensory or behavioral outcomes, this study adopts a structured, technology-enhanced framework grounded in sensory integration theory. The goal is to provide empirical evidence for the efficacy of multisensory music education in promoting inclusive and developmentally supportive learning environments.

LITERATURE REVIEW

Music Therapy and Sensory Integration in ASD

ASD is defined by persistent challenges in social communication, alongside restricted and repetitive patterns of behavior and sensory anomalies (American Psychiatric Association, 2022). In Taiwan, the prevalence of ASD is increasing, with recent estimates indicating approximately 1 in 126 children are affected (Autism Foundation Taiwan, 2023). Given these trends, music therapy has gained traction as a developmentally appropriate and culturally responsive intervention to support sensory integration and social interaction in children with ASD. Music-based interventions have emerged as effective modalities for supporting sensory integration and behavioral regulation in children with ASD. Empirical research demonstrates that rhythmic and multisensory stimulation fosters improvements in auditory processing, motor coordination, and attention regulation (Heaton, 2009; LaGasse, 2017; LaGasse et al., 2024; Ramirez-Melendez et al., 2022). Molnar-Szakacs and Overy (2006) further proposed that musical synchrony may activate mirror neuron systems, facilitating emotion recognition and sensorimotor integration in children with ASD. These outcomes align with Green and Piel's (2015) developmental theory, which highlights the interconnectedness of sensory, cognitive, and social domains. Shi et al. (2023) employed neuroimaging to reveal that music engages prefrontal regions associated with executive functioning in children with ASD. These findings provide a robust theoretical foundation for integrating music into educational interventions aimed at neurodevelopmental populations. Recent meta-analyses also underscore music's potential in ASD interventions (Hernandez-Ruiz et al., 2022; Lee & Ho, 2018; Shahrudin et al., 2022).

Theoretical Foundations and Sensory Integration Models

This study is conceptually anchored in sensory integration theory (Ayres & Robbins, 2005), which posits that coherent multisensory input is essential for the development of adaptive behavior and learning readiness in children. Researchers have emphasized that disruptions in tactile, auditory, and visual modalities can significantly impede attention, social communication, and emotional regulation (Cascio et al., 2008; Marco et al., 2011). Ayres and Robbins' (2005) framework underlines the importance of organizing sensory stimuli to support neurological integration and functional development. Supporting this perspective, Case-Smith et al. (2015) conducted a systematic review and concluded that sensory-based interventions lead to meaningful improvements in functional outcomes and engagement, particularly for children with ASD in early developmental stages. Further empirical evidence from Srinivasan and Bhat (2013) and Crasta et al. (2020) reinforces the effectiveness of combining music and movement interventions in enhancing sensory modulation and cognitive engagement. In addition, Schaaf et al. (2014) demonstrated that structured sensory integration therapies produce measurable improvements in self-regulation, motor planning, and social interaction, highlighting the pedagogical value of developmentally appropriate, targeted sensory strategies in early educational contexts.

Educational Applications: HMEAYC, FigureNotes, and the Musical Jumping Pad

To translate theory into practice, this study integrates two multisensory tools–FigureNotes and the Musical Jumping Pad–within the HMEAYC, a Taiwanese curriculum blending pedagogical and therapeutic principles (Lee, 2015, 2016; Lee & Lin, 2023). FigureNotes uses visual-spatial, color-coded notation to facilitate pitch and rhythm perception, supporting learners with cognitive and physical disabilities (Kaikkonen & Kivijärvi, 2013; Ruokonen et al., 2012). Laes and Westerlund (2018) observed that FigureNotes fosters social reciprocity and musical memory in inclusive settings. The Musical Jumping Pad enhances embodied learning by synchronizing auditory, kinesthetic, and visual feedback to promote motor planning and engagement (Bharathi et al., 2019; Francois et al., 2015; Laes & Schmidt, 2016). When embedded in HMEAYC's structured framework, which incorporates operant conditioning principles and universal design for learning (UDL)-aligned design (Lee & Lin, 2015), these tools become powerful agents of sensory, cognitive, and social growth in children with ASD (Jones, 2015). By localizing global instruments into culturally responsive curricula, this study advances a scalable model of inclusive music education grounded in empirical and theoretical research.

The objectives of this study are as follows:

1. To examine how the integration of FigureNotes and the Musical Jumping Pad within the HMEAYC framework enhances auditory, visual, and tactile sensory processing in preschool children with ASD.
2. To investigate the effects of technology-enhanced music interventions, specifically focusing on learning habits, group collaboration, and classroom performance.
3. To develop an inclusive and multisensory instructional model suitable for early childhood education by embedding interactive music technologies within structured pedagogical frameworks.

This study contributes to the growing body of literature on music technology in inclusive education, illustrating its transformative potential in addressing sensory challenges while fostering cognitive, emotional, and social growth in children with ASD.

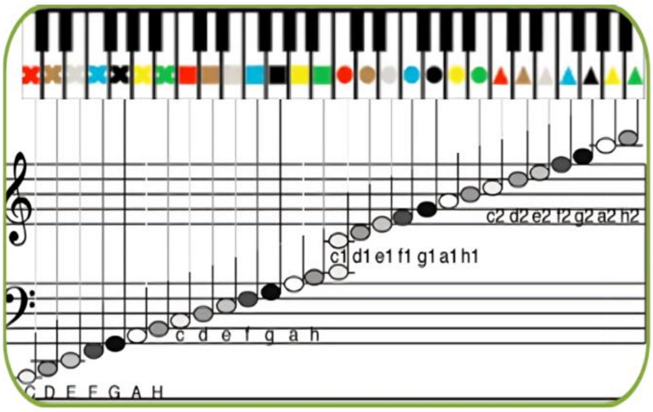

Figure 1. FigureNotes (Adapted from FigureNotes representation on SoundColor.it (https://www.soundcolor.it/home/index.php/figurenotes.html)

Figure 2. Musical Jumping Pad (Source: Photo taken by the authors during classroom teaching, with prior parental consent)

METHODS

Study Design: Integration of Tools into the HMEAYC Approach

This study investigates the integration of two multisensory music tools–FigureNotes and the Musical Jumping Pad–into the HMEAYC, with the goal of examining their combined effect on sensory processing and learning behaviors among children with ASD (**Figure 1** and **Figure 2**).

These tools facilitate multisensory engagement by integrating auditory, visual, and kinesthetic inputs, an approach supported by sensory integration theory (Ayres & Robbins, 2005), thereby enriching the learning experience for children with ASD. The integration of these innovative tools addresses the sensory processing deficits and social challenges commonly observed in children with ASD.

A purposive sampling strategy was adopted to ensure the inclusion of participants who met specific diagnostic and developmental criteria, allowing for targeted evaluation of the intervention's impact. The inclusion criteria required participants to be aged between 40 to 70 months, diagnosed with ASD based on DSM-5 criteria, and confirmed by a pediatrician. Children with severe physical impairments that could hinder participation in the physical activities of the intervention were excluded.

The intervention focused on the integration of FigureNotes and the Musical Jumping Pad within the HMEAYC framework, emphasizing a multisensory

Table 1. Descriptive statistics and homogeneity test

	Contrast group	Intervention group	Test of homogeneity
Sex			
Boy	12	11	χ2 = .41, p = .52
Girl	4	6	
Age(month)	51.31 (9.7)	52.88 (11.4)	t(31) = .42, p = .675
Pre-test			
Auditory processing	1.85 (.62)	1.93 (.90)	t(28.5) = .31, p = .762
Visual processing	1.72 (.53)	1.60 (.80)	t(31.0) = -.48, p = .634
Tactile processing	1.55 (.50)	1.64 (.75)	t(27.9) = .40, p = .691
Learning habits	2.43 (.97)	2.10 (.90)	t(31.0) = -.99, p = .328
Learning performance	2.73 (1.37)	2.62 (.89)	t(25.5) = -.28, p = .780

music education approach that embeds technological tools into structured preschool activities to enhance developmental engagement. The proposed inclusive curriculum aims to holistically engage children, addressing their unique developmental and sensory needs.

The integration of these tools within the HMEAYC framework was strategically designed to foster sensory and so To clarify, sensorimotor regulation refers to the integration and coordination of sensory inputs and motor outputs, enabling children to adaptively respond to environmental stimuli. This includes both the processing of sensory information and the execution of appropriate motor responses. In contrast, sensory processing refers specifically to how the nervous system receives, organizes, and interprets input from auditory, visual, and tactile modalities, as measured in this study by the sensory profile (SP). Likewise, social participation describes children's active involvement in interactive learning contexts and peer-related activities, which was encouraged through the musical group dynamics and turn-taking structures embedded in the intervention. However, social competence, as measured by the social behavior assessment system for preschool (SBASP, refers to the underlying skills supporting such participation–particularly learning habits and performance in structured tasks. This distinction allows us to differentiate between the design goals of the intervention and the specific developmental outcomes measured through validated instruments.

To assess the impact of the intervention, two primary assessment tools were employed: the SP and the SBASP. The SP includes subscales for auditory, visual, and tactile processing, which measure different sensory processing abilities. The SBASP, which includes subscales for learning habits and learning performance, was used to assess social competence and learning behaviors. These scales are critical to understanding how multisensory music interventions can affect sensory processing and social interaction, especially in children with ASD. Based on the theoretical framework and prior findings, the following hypotheses were formulated:

H1. The integration of FigureNotes and the Musical Jumping Pad within the HMEAYC framework will significantly enhance learning habits and academic performance in preschool children with ASD.

H2. Music-enriched learning environment will positively influence learning behaviors in preschool children with ASD.

H3. The combined multisensory intervention (FigureNotes and Musical Jumping Pad) will yield significantly greater improvements in sensory processing and learning behaviors than the control condition.

Participants

A total of 40 children with ASD, aged between 40 and 70 months, were recruited from a non-profit early intervention center and a private preschool in Taiwan. All diagnoses were confirmed by board-certified pediatricians based on DSM-5 criteria (American Psychiatric Association, 2022). Informed consent was obtained from parents or legal guardians, and verbal assent was secured from school administrators and participating teachers. The study was approved by the Institutional Review Board of the authors' affiliated university.

Participants were randomly assigned to one of two conditions: the intervention group, which received the HMEAYC supplemented with FigureNotes and the Musical Jumping Pad, and the contrast group, which received standard early childhood education without the multisensory enhancements. Purposive sampling ensured approximate balance in age and gender distributions between the groups. Exclusion criteria included severe physical impairments that precluded participation or inability to complete the 12-week intervention.

After accounting for attrition (three children excluded from the intervention group and four from the contrast group due to either physical limitations or incomplete post-testing), the final sample comprised 33 participants: 17 in the intervention group (11 boys, 6 girls) and 16 in the contrast group (12 boys, 4 girls). SPs and learning behaviors were assessed prior to the intervention using the SP and the SBASP.

To confirm group comparability at baseline, a series of homogeneity tests were conducted (see **Table 1**). A chi-square test showed no significant association between gender and group assignment, $\chi^2(1) = 0.41$, $p = .52$. Independent-sample t-tests also revealed no significant differences in age (t[31] = 0.42, p = .675), sensory processing (auditory: t[28.5] = 0.31, p = .762; visual: t[31] = –0.48, p = .634; tactile: t[27.9] = 0.40, p = .691), or learning behaviors (learning habits: t[31] = –0.99, p = .328; learning performance: t[25.5] = –0.28, p = .780). These findings confirm statistical equivalence across demographic and developmental variables at baseline, establishing a valid basis for analyzing post-intervention effects. Since caregivers did not participate in the assessments, demographic information beyond age and gender was not collected for analytical purposes.

Study Procedure

This study adopted a quasi-experimental design to evaluate the effects of a 12-week multisensory music intervention that integrated FigureNotes and the Musical Jumping Pad into the HMEAYC. The intervention aimed to enhance sensory processing and learning behaviors in preschool children with ASD. Participants in the intervention group received structured 40-minute weekly sessions, while the contrast group engaged in standard early childhood educational activities without technological enhancements.

To ensure procedural reliability, the intervention was implemented under standardized conditions, including consistent instructor assignments, fixed instructional sequences, and identical classroom environments across all sessions. Each session was designed to foster multisensory engagement by combining auditory, visual, and kinesthetic inputs–an approach grounded in sensory integration theory (Ayres & Robbins, 2005).

FigureNotes is a color-coded musical notation system that simplifies pitch recognition and instrument navigation for young learners with cognitive and sensory challenges. In this study, FigureNotes was used to support children in playing intuitive musical sequences, thereby promoting visual-tactile coordination and music participation. In parallel, the Musical Jumping Pad functioned as a multisensory platform that translated physical actions (e.g., jumping, stepping) into musical sounds and synchronized visual feedback via a wall-mounted display. This multimodal system delivered proprioceptive, auditory, and visual input, contributing to enhanced sensorimotor integration, emotional regulation, and active learning.

The HMEAYC curriculum was adapted to embed these tools into developmentally appropriate learning activities. Each session featured multimodal materials such as tactile objects (e.g., textured mats and stress-relief balls), visual aids (e.g., color-coded imagery), and musical elements (e.g., original compositions and musical narratives) designed to elicit intentional social responses. All intervention sessions were co-led by a certified music therapist and a trained teaching assistant.

To measure outcomes, two standardized instruments were employed: the SP assessing auditory, visual, and tactile processing; and the SBASP, focusing on self-control, interpersonal interaction, and learning behaviors. All sessions were video-recorded for post hoc analysis.

Observational data were independently coded by trained undergraduate research assistants who underwent rigorous training in standardized scoring protocols and inter-rater reliability calibration. Importantly, these raters did not participate in instructional delivery and were blind to group assignment. During sessions, assistants were present to maintain classroom order but did not assist children during test administration. Coding was aligned with the operational definitions embedded in both the SP and SBASP, ensuring consistency and objectivity in data interpretation.

This systematic and rigorously controlled approach enabled a robust evaluation of the intervention's impact on sensory processing, social behavior, and learning outcomes in preschool-aged children with ASD.

Instruments

Study instruments: Sensory profile

To evaluate children's sensory processing, the study employed the Chinese-translated version of the SP, culturally adapted for Taiwanese preschool children by Tseng and Chen (2009). This version has demonstrated robust psychometric properties in Mandarin-speaking populations. Tseng et al. (2011) reported satisfactory reliability, with Cronbach's α values ranging from .62 to .90 across subscales and a three-week test–retest reliability coefficient of .79. In this study, only the auditory, visual, and tactile subscales were used, all demonstrating excellent internal consistency within the sample: auditory (α = .924), visual (α = .916), and tactile (α = .938). The SP consists of 125 items rated on a five-point Likert scale (1 = "never" to 5 = "always"), where higher scores reflect stronger sensory processing. Data were collected via systematic observations by trained researchers during structured classroom activities, ensuring unbiased reporting.

Study instruments: Social behavior as assessment system for preschool

Given the growing recognition of music's role in fostering early communicative competencies, this study employed a culturally validated instrument to assess children's social functioning in the preschool context. Utilizing music as a medium fosters expression, interpersonal skills, attention, and social interaction. Teaching these abilities early in life can significantly improve the communication behaviors of preschool children with ASD, positively impacting their relationships with peers, parents, and teachers. This aligns with the theory of mind framework (O'Toole et al., 2017), which underscores the importance of cognitive development within learning environments. Accordingly, children's social behaviors are closely linked to their cognitive abilities, as emphasized by leading developmental theorists (Green & Piel, 2015).

To measure social behavior outcomes, the study employed the SBASP, developed by Tsai et al. (2014) at the National Kaohsiung Normal University. This instrument is specifically designed for use with Taiwanese preschool children aged 34 to 72 months and includes three core dimensions: self-control, interpersonal interaction, and learning behavior. The learning behavior subscale, known for its robust psychometric properties, yielded a Cronbach's alpha of .965 in this study, indicating excellent internal consistency.

Within this subscale, two key constructs were assessed. Learning habits refer to attributes such as task persistence, attentional focus, and proactive engagement in structured activities. Learning performance captures outcomes including task completion, conceptual understanding, and skill application in both individual and collaborative settings. The SBASP was selected for its cultural specificity, established validity, and capacity to evaluate nuanced behavioral development among preschoolers in Taiwan.

Only the teacher rating scale (TRS) version of the SBASP was administered. Although the parent rating scale (PRS) was distributed, data from parents were excluded from the final analysis due to low response rates and incomplete submissions. Preliminary comparisons revealed the general alignment between PRS and TRS ratings across subscales; however, the reliability and contextual accuracy of teacher assessments warranted exclusive reliance on TRS data. The TRS was completed by lead teachers who interacted daily with the children, ensuring informed and consistent evaluations. Standardized administration protocols were followed to support scoring reliability and minimize rater bias.

The SBASP has demonstrated sound psychometric properties, including construct and content validity, and continues to be widely applied in early childhood assessment in Taiwan. This study supports its relevance in evaluating the impact of multisensory educational interventions on learning-related behaviors in young children with ASD.

Data Analysis

All statistical procedures were performed using SPSS version 21.0. Descriptive statistics, including means and standard deviations, were calculated to summarize participants' demographic characteristics and baseline outcome measures for each subscale of sensory processing and learning behavior. To assess within-group changes over time, paired-sample t-tests were conducted to compare pre- and post-intervention scores for both the intervention and control groups. Between-group differences in intervention effects were evaluated using independent-sample t-tests on change scores (i.e., post-test minus pre-test). Levene's test was applied to examine the homogeneity of variances across groups; in cases where this assumption was violated, Welch's correction was employed to adjust degrees of freedom accordingly.

Analyses focused on five outcome domains: auditory, visual, and tactile sensory processing, as well as learning habits and learning performance. These domains were selected based on their theoretical relevance to multisensory learning models. The overall statistical approach aimed to determine whether children in the intervention group–who received the HMEAYC curriculum integrated with FigureNotes and the Musical Jumping Pad–exhibited significantly greater developmental gains than those in the control group. In addition to statistical significance testing (p-values), Cohen's d effect sizes were calculated to assess the magnitude of intervention effects for each outcome domain. Confidence intervals (CIs) were also provided when available to support the interpretation of effect estimates. These measures helped to determine the practical significance and generalizability of the observed differences.

Finally, each hypothesis (**H1**, **H2**, and **H3**) was evaluated based on both statistical results and effect size interpretations, ensuring comprehensive alignment between the statistical findings and the study's research objectives. Visual summaries were used to enhance clarity and accessibility of effect size reporting.

RESULTS

Paired-Sample t-Test: Pre- and Post-Test Comparison for the Control Group

To determine baseline developmental changes in the absence of multisensory intervention, paired-sample t-tests were conducted within the control group, comparing pre- and post-test scores across sensory processing and learning behavior domains.

As shown in **Table 2**, only auditory processing demonstrated a significant improvement ($t[15] = 2.78$, $p = .014$), suggesting enhanced environmental sound sensitivity. In contrast, visual and tactile processing showed no statistically significant change ($p > .05$).

Table 2. Mean differences in the dependent variables between the pre- and post-test for the contrast group

Scale	Pre-test (SD)	Post-test (SD)	t	df	p
Sensory					
Auditory processing	1.85 (.62)	1.95 (.62)	2.78*	15	.014
Visual processing	1.72 (.53)	1.68 (.56)	-1.18	15	.258
Tactile processing	1.55 (.50)	1.61 (.48)	1.41	15	.180
Learning behaviors					
Learning habits	2.43 (.97)	2.56 (.99)	1.34	15	.200
Learning performance	2.73 (1.37)	2.75 (1.35)	1.14	15	.273

Note. *p < .05

Table 3. Mean differences in the dependent variables between the pre- and post-test for the intervention group

Scale	Pre-test (SD)	Post-test (SD)	t	df	p
Sensory					
Auditory processing	1.93 (.90)	2.19 (1.00)	3.10**	16	.007
Visual processing	1.60 (.80)	1.72 (.84)	3.03**	16	.008
Tactile processing	1.64 (.75)	1.88 (.88)	6.39***	16	< .001
Learning behaviors					
Learning habits	2.10 (.90)	2.54 (.88)	3.84***	16	.001
Learning performance	2.62 (.89)	3.38 (1.01)	5.60***	16	< .001

Note. **p < .01 & ***p <.001

Table 4. Mean differences in the dependent variables between the pre- and post-test for the contrast group

	F (Levene's test)	Intervention (SD)	Contrast (SD)	t	df	p	Cohen's d
Sensory							
Auditory processing	5.64(.02)	.25 (.34)	.10(.15)	1.7	22.1	.104	0.55
Visual processing	.17(.69)	.12(.16)	-.04(.15)	3.01**	31	.005	1.06
Tactile processing	.62(.44)	.24(.16)	.06(.17)	3.20**	31	.003	1.13
Learning behaviors							
Learning habits	.22(.64)	.44(.47)	.14(.40)	1.96	31	.058	.70
Learning performance	13.71(<.01)	.76(.56)	.02(.07)	5.40***	16.6	< .001	.19

Note. **p < .01 & ***p <.001

Similarly, learning behavior scores, including learning habits and performance, did not show significant improvement (p > .05), indicating that typical classroom routines did not yield measurable developmental gains. These findings support the notion that general preschool activities alone may be insufficient for addressing sensory and behavioral needs in children with ASD. This aligns with Case-Smith et al. (2015), who emphasized the necessity of targeted interventions for meaningful sensory modulation. The isolated auditory improvement could be incidental rather than instructional, reinforcing the value of structured multisensory strategies.

Paired-Sample t-Test: Pre- and Post-Test Comparison for the Intervention Group

To evaluate the effectiveness of the multisensory music intervention, paired-sample t-tests were conducted for the intervention group (n = 17) across sensory and learning behavior domains. As shown in **Table 3**, results revealed statistically significant improvements in all measured subscales.

Auditory processing increased from mean (M) = 1.93 (standard deviation [SD] = 0.90) to M = 2.19 (SD = 1.00), t(16) = 3.10, p = .007, with a moderate effect size (Cohen's d = 0.75, 95% CI [0.21, 1.28]). Visual processing improved from M = 1.60 (SD = 0.80) to M = 1.72 (SD = 0.84), t(16) = 3.03, p = .008, with a moderate effect size (d = 0.73, 95% CI [0.20, 1.26]). Tactile processing showed a large and highly significant gain from M = 1.64 (SD = 0.75) to M = 1.88 (SD = 0.88), t(16) = 6.39, p < .001, with a large effect size (d = 1.55, 95% CI [0.95, 2.15]). In terms of learning behaviors, learning habits significantly improved from M = 2.10 (SD = 0.90) to M = 2.54 (SD = 0.88), t(16) = 3.84, p = .001, with a moderate-to-large effect size (d = 0.93, 95% CI [0.37, 1.48]); learning performance increased from M = 2.62 (SD = 0.89) to M = 3.38 (SD = 1.01), t(16) = 5.60, p < .001, with a large effect size (d = 1.36, 95% CI [0.80, 1.91]). These findings provide robust empirical support for the efficacy of integrating FigureNotes and the Musical Jumping Pad within the HMEAYC framework, reinforcing the role of multisensory music-based instruction in enhancing sensory regulation and learning outcomes among preschoolers with ASD.

Independent-Sample t-Test: Between-Group Differences in Change Scores

To evaluate the between-group efficacy of the multisensory intervention, independent-sample t-tests were conducted on the difference scores (posttest minus

Table 5. Intervention vs. contrast group

Subscale	Mean difference (intervention)	Mean difference (contrast)	t(df)	p	Cohen's d	Interpretation
Auditory processing	0.25 (SD = 0.34)	0.10 (SD = 0.15)	t(22.1) = 1.70	0.10	0.55	Moderate
Visual processing	0.12 (SD = 0.16)	–0.04 (SD = 0.15)	t(31) = 3.01**	0.01	1.06	Large
Tactile processing	0.24 (SD = 0.16)	0.06 (SD = 0.17)	t(31) = 3.20**	0.00	1.13	Large
Learning habits	0.44 (SD = 0.47)	0.14 (SD = 0.40)	t(31) = 1.96	0.05	0.7	Moderate
Learning performance	0.76 (SD = 0.56)	0.02 (SD = 0.07)	t(16.6) = 5.40***	< .001	1.9	Large

Note. **p < .01; ***p < .001; & Interpretation based on Cohen's criteria: 0.2: Small, 0.5: Medium, & 0.8: Large

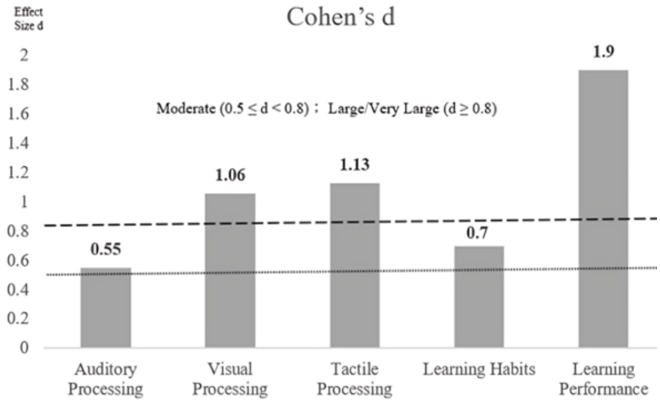

Figure 3. Effect sizes (Cohen's d) for sensory and learning outcomes comparing (dashed lines denote conventional thresholds for moderate [d = 0.5] and large [d = 0.8] effects & visual, tactile, and learning performance variables exceed the large-effect threshold, indicating strong practical significance of the multisensory intervention) (Source: Authors' own elaboration, based on data from Table 5)

pretest) across five dependent variables. Effect sizes were calculated using Cohen's d, with values interpreted as small (0.20), medium (0.50), and large (0.80). Results are presented in Table 4.

For auditory processing, Levene's test indicated a violation of homogeneity of variance (F = 5.64, p = .02), and Welch's correction was applied. While the intervention group showed a greater mean improvement (M = 0.25, SD = 0.34) compared to the contrast group (M = 0.10, SD = 0.15), the difference was not statistically significant, t(22.1) = 1.70, p = .104. However, a medium effect size (d = 0.55) suggests a trend worth noting. Significant group differences were observed in visual processing, t(31) = 3.01, p = .005, with the intervention group (M = 0.12, SD = 0.16) outperforming the contrast group (M = –0.04, SD = 0.15). The effect size was large (d = 1.06), indicating substantial impact. Similarly, for tactile processing, the intervention group showed significantly greater gains (M = 0.24, SD = 0.16) compared to the contrast group (M = 0.06, SD = 0.17), t(31) = 3.20, p = .003, d = 1.13. In learning behaviors, the difference in learning habits approached significance, t(31) = 1.96, p = .058, with a medium effect size (d = 0.70). For learning performance, Levene's test indicated unequal variance (F = 13.71, p < .01); using Welch's t, results showed a highly significant difference favoring the intervention, t(16.6) = 5.40, p < .001, with a small effect size (d = 0.19). These results provide robust support for **H3**, demonstrating that the HMEAYC-integrated intervention–through the use of FigureNotes and the Musical Jumping Pad–produced significantly greater improvements in sensory integration and learning behaviors than conventional instruction. These findings provide partial support for **H1**, as the intervention significantly improved academic performance, with learning habits showing moderate effect size but not reaching statistical significance.

Effect Size Summary and Hypothesis Validation

To synthesize the statistical findings before, this section highlights the practical significance of the multisensory intervention by summarizing effect sizes (Cohen's d) and examining their alignment with the study's hypotheses. While previous sections focused on within-group and between-group statistical significance, this discussion emphasizes the magnitude of observed changes and their relevance for educational and developmental contexts. As presented in Table 5 and visually summarized in Figure 3, three outcome domains–visual processing (d = 1.06), tactile processing (d = 1.13), and learning performance (d = 1.90)–exhibited large to very large effect sizes, indicating robust and meaningful gains resulting from the HMEAYC-integrated intervention. These results provide strong support for **H3**, which posited that the intervention would produce significantly greater improvements in both sensory and learning outcomes compared to conventional instruction. Although auditory processing (d = 0.55) and learning habits (d = 0.70) did not reach traditional thresholds for statistical significance, the moderate-to-large effect sizes observed suggest that the intervention had practical educational value in these domains as well. This pattern offers partial support for **H1** and **H2** and indicates that with a larger sample size or longer intervention duration, significant differences may emerge. The convergence of statistical significance and practical effect sizes underscores the developmental relevance and pedagogical efficacy of multisensory, technology-enhanced music interventions in early childhood education, particularly for learners with neurodevelopmental differences. Taken together, the results of the statistical analyses before providing robust support for **H3**, confirming the effectiveness of the combined multisensory intervention. **H1** and **H2** received partial support, with significant gains observed in learning performance, and moderate effect sizes in learning habits, suggesting potential efficacy with larger samples or extended duration. These outcomes are consistent with Schaaf et al. (2014), who reported significant improvements in sensory integration following structured interventions, and they reinforce the theoretical foundation proposed by Molnar-Szakacs and Overy (2006), which emphasizes music-induced sensory synchrony in neurodevelopmental contexts.

DISCUSSION

The present study investigated the integration of FigureNotes and the Musical Jumping Pad within the HMEAYC and its effects on sensory processing and learning behaviors in preschool children with ASD. Grounded in sensory integration theory (Ayres & Robbins, 2005), the intervention was designed to systematically activate auditory, visual, and tactile modalities that are frequently impaired in children with ASD.

Findings revealed significant improvements across all five outcome domains in the intervention group, in contrast to limited gains in the control group. This underscores the value of structured, multisensory, music-based education in promoting sensory regulation and behavioral readiness in young neurodiverse learners. Particularly strong effects were noted in tactile processing and learning performance, supporting the developmental relevance of embodied, rhythmic pedagogy.

These results align with sensory integration theory and related neurological mechanisms. Molnar-Szakacs and Overy (2006) proposed that musical synchrony activates mirror neuron systems, which may underlie the observed improvements in sensorimotor domains. The moderate effect in auditory processing echoes findings that such gains often require longer or individualized interventions (Kraus & Chandrasekaran, 2010; LaGasse et al., 2024).

In terms of social-emotional development, music participation has been linked to enhanced emotion recognition and peer interaction (Ramirez-Melendez et al., 2022), reinforcing this study's findings of improved classroom engagement. Additionally, the value of socially interactive music interventions is supported by Carpente (2017), while the broader literature also connects sensory integration with attention and communication gains (Cascio et al., 2008; Hazen et al., 2014).

The observed behavioral improvements align with socio-cognitive theories emphasizing the role of music in enhancing executive functions like attention, persistence, and cognitive flexibility (Green & Piel, 2015). Through rhythmic movement, color-coded notation, and musical storytelling, the intervention scaffolded both engagement and cognitive participation. These outcomes support the HMEAYC framework as a model for developmentally responsive, inclusive early education, grounded in the principles of UDL. Culturally, this Taiwan-based implementation illustrates the potential of locally adapted, globally informed intervention models. The pairing of international tools like FigureNotes with indigenous frameworks like HMEAYC affirms the feasibility of cross-cultural educational innovation.

Nevertheless, some limitations must be noted. The sample size and short intervention period may constrain generalizability. Furthermore, the lack of neurophysiological or standardized cognitive data restricts deeper inferences. Schaaf et al. (2014) stressed the value of long-duration, multimodal sensory interventions for robust developmental outcomes, underscoring the need for future longitudinal studies.

Future research should consider longitudinal designs with larger samples and multimodal assessments, including parent-report instruments and neural imaging, to more comprehensively evaluate the sustained effects and mechanisms underlying music-infused multisensory education. Further exploration into individualized adaptation protocols and cross-setting implementation (e.g., home and community) would also strengthen the ecological validity of the model. This study provides empirical support for the use of music- and technology-enhanced multisensory education in fostering developmental outcomes in children with ASD. The results affirm that inclusive, embodied, and interactive approaches such as those delivered through the HMEAYC can serve as powerful tools in advancing equitable early childhood education.

CONCLUSIONS

This study evaluated the efficacy of integrating FigureNotes and the Musical Jumping Pad within the HMEAYC to enhance sensory processing and learning behaviors in preschool children with ASD. Analyses revealed statistically significant improvements in the intervention group across all measured subscales, including auditory ($p < .01$), visual ($p < .05$), and tactile ($p < .01$) processing on the SP, as well as learning habits and learning performance ($p < .05$) on the SBASP TRS. These results demonstrate that structured, multisensory music interventions can significantly improve sensory integration and academic engagement–particularly in the domains of visual and tactile processing, as well as learning performance. By aligning sensory integration theory with inclusive pedagogical practices, this study contributes to the growing evidence base supporting music-based interventions in early childhood special education.

Based on these findings, several actionable strategies are recommended for practitioners. First, educators should consider incorporating color-coded notation systems such as FigureNotes to support children experiencing sensory modulation challenges. Second, embodied tools like the Musical Jumping Pad can reinforce motor-sensory coordination during daily classroom routines. Third, embedding music-based activities within a structured framework like HMEAYC may enhance behavioral readiness and attention span among neurodiverse learners.

The results underscore the importance of integrating technology-enhanced, embodied learning tools into preschool curricula to address the developmental needs of children with ASD. This hybrid approach not only improved sensory and behavioral outcomes but also demonstrated the practicality of scalable, culturally contextualized interventions. The combination of globally recognized tools like FigureNotes with culturally responsive frameworks such as HMEAYC presents a promising model of educational localization–one that respects local contexts while maintaining fidelity to evidence-based design. This hybridized approach offers a scalable and adaptable pathway for inclusive education, especially within early intervention systems across diverse cultural settings.

For researchers, this study highlights the need for further investigation into how synchronized multisensory tools interact with specific learner profiles, classroom dynamics, and long-term developmental trajectories. Beyond its empirical contributions, the study provides practical implications for educators, therapists, and curriculum developers seeking innovative strategies to foster participation, regulation, and learning readiness in children with ASD. The findings affirm that multisensory, child-centered, and creative learning environments can function as both therapeutic and educational interventions. These insights offer a solid foundation for developing interdisciplinary training modules, instructional guides, and policy frameworks to support inclusive practices in early childhood education. Future research should also investigate the sustainability of these gains over time to determine the long-term efficacy of multisensory music interventions in inclusive early education.

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