uCue: An Interactive Musical Interface to Enhance Formative Listening Experiences for Children with ASD

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Abstract

Children with Autism Spectrum Disorder (ASD) often face challenges with musical engagement due to unique sensory and neural processing needs. To address this, we introduce uCue, a musical interface designed to enhance active musical engagement. This interactive playback system offers modular arrangements of children's songs at an accessible tempo, enabling listeners to manipulate musical layers and create personalized renditions in real-time. Deployed in listening sessions with seven parent-child dyads, uCue facilitated self-expression through singing and gestures while fostering emotional regulation and sensory engagement. Participants quickly adapted to the interface, preferred soothing sounds, and expressed interest in more rhythmic layers over time. Our findings suggest that uCue has the potential to enhance musical interactions by allowing children to explore and control auditory experiences. We also discuss how uCue and data from its logs might support therapeutic goals in music therapy for children with ASD and provide design recommendations for similar technologies.

CCS Concepts

• **Human-centered computing → Collaborative and social computing systems and tools**.

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1 Introduction

Engaging in formative music experiences[1] plays a crucial role in children's cognitive [41], motor [53], emotional [17], and social development [27]. Children with Autism Spectrum Disorder (ASD)[2] have been shown to benefit from musical interventions [12, 20], which can improve peer interactions and provide insights into their behavioral and emotional states [12, 59]. However, some children with ASD experience sensory sensitivities, including adverse reactions to loud noises, high-pitched sounds, or certain timbres[3],

[1]Formative music experiences refer to the foundational role music plays in early development. Through listening to music familiar to others, children learn cultural and societal norms. Engaging with music fosters coordinated motor skills, while participating in developmental musical activities supports social and emotional growth.
[2]We consistently refer to children with ASD using this term, as it was identified as the preferred terminology in consultation with the stakeholders. We acknowledge differing preferences in terminology: while some prefer person-first language ('children with autism') to emphasize individuality, others advocate identity-first language ('autistic children') to embrace autism as integral to identity. Our use of person-first language aligns with stakeholder feedback and a March 2022 survey by Autistic Not Weird (https://autisticnotweird.com/autismsurvey/), which noted concerns that identity-first language might label or limit children.
[3]Timbre refers to the distinctive, identifiable quality of a sound, e.g., what makes an oboe sound like an oboe.

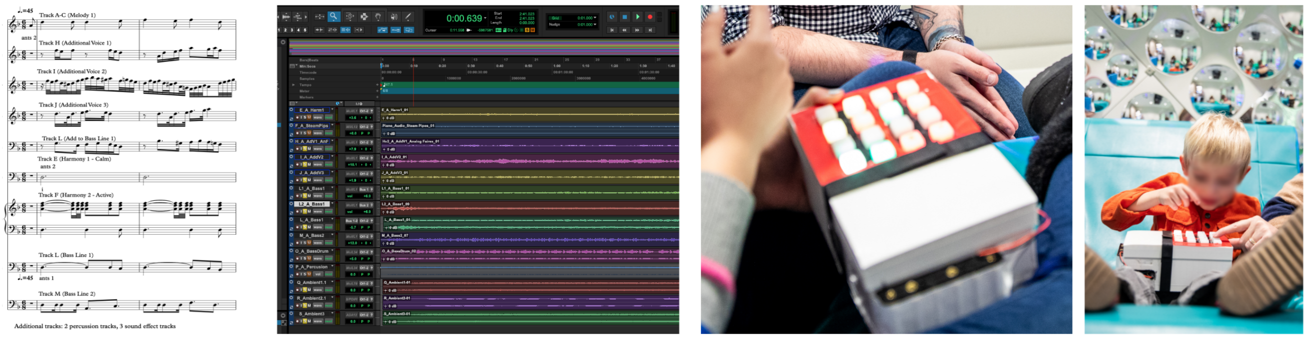


Figure 1: Modular music, mastered in ProTools, deployed on uCue, and enjoyed in a Sensory Room for Children with ASD

that make it difficult to enjoy music or participate in musical activities [2, 15]. These individuals may also exhibit variations in neural processing [34], complicating their involvement in musical activities that demand direction-following, like singing or playing instruments [55].

In 2020, the Centers for Disease Control and Prevention reported a significant rise in ASD diagnoses, affecting 1 in 36 U.S. children [11]. Music therapy, an evidence-based intervention [17], utilizes musical elements such as listening, singing, and playing along for individualized goals, aiding communication and emotional regulation in children with ASD as the structured nature of music is especially beneficial in reducing anxiety, enhancing social bonding, and facilitating self-expression, which are often challenges for children with ASD [18, 61]. Improving access to music experiences can improve therapeutic outcomes, considering the inconsistent availability of music therapy [36].

In our work, we developed an interactive music system, "uCue", with a vision of – "You create, you enjoy" –, tailored to children with ASD. uCue incorporates modular arrangements of children's songs set at an accessible tempo and allows users to modify musical layers as needed, similar to how a music conductor might cue a performer's entrance. As children use uCue to adapt musical sounds to their tastes, emotions, and expressive desires, the system collects data on listener interactions, including layer combination choices and timing, which can inform composers in creating more engaging music for this population. As early work, our research questions are exploratory and focus on the potential impact of uCue, an interactive music system, for children with ASD. Specifically, we ask: *Does interacting with uCue help children with ASD actively identify and express their musical preferences (RQ1)? Can engagement with uCue to create music facilitate emotional expression and enhance these children's enjoyment of music (RQ2)? And, How might children with ASD benefit from having greater autonomy over their listener experience (RQ3)?*

Towards answering these questions, we conducted a pilot study where we deployed uCue in listening sessions involving seven parent-child dyads across two phases of deployment at a local library's Sensory Room[4]. Parent-child dyads were guided through interactions with uCue within the Sensory Room, followed by pre- and post-session interviews to collect feedback. An analysis of our study data suggests that: (i) uCue's logs were able to gather valuable interaction data and provide insights about global musical preferences[5], including preferences and dislikes for specific musical styles, layer combinations, and energy levels, (ii) uCue supported personal expression, communication, and enjoyment through song modification, and (iii) independent use of uCue enabled children to exercise autonomy by selecting familiar songs and exploring various music combinations and emotional connections. These findings suggest that uCue has potential as an assistive, interactive musical device for children with ASD that can enhance access to formative and emotionally resonant musical experiences.

Although these are preliminary results that support the continued development of the uCue system, the specific contributions of this work include: (i) the design of a modular music template and a prototype music library (see Table 1), (ii) the prototype uCue music playback and logging system, (iii) empirical evidence suggesting uCue's potential to supports children with ASD in accessing formative music experiences, and (iv) design recommendations for developing interactive music experiences with technology for children with ASD. We also discuss future musical and technological advances that aim to better serve the needs of neurodivergent listeners.

2 Related Work

Here we explore ASD studies, covering autonomy in activities, musical preferences, the effects of music interventions on social skills and emotional perception in children with ASD , and emerging technologies in music therapy.

2.1 Children with ASD and the Value of Autonomy

The American Psychiatric Association characterizes ASD using two criteria: "Persistent deficits in social communication and social interaction across multiple contexts" and "Restricted, repetitive patterns of behavior, interests, or activities" [4, p. 50]. To address communication struggles, primary school educators prioritize social development of children with ASD, specifically targeting "interpersonal relationships, language acquisition, play, and other skills, and comorbid conditions such as cognitive deficits, physiological issues, and maladaptive behaviors" [31, p.8]. While such children may have

[4] The Sensory Room is a specially designed space for children with ASD with customizable visual, auditory, tactile, and haptic stimulation modules, all controllable by the users of the space.

[5] Global preferences refer to a listener's response to holistic features, such as individual songs, styles, textures, tempo, and loudness. Particular preferences refer to specific elements such as timbre, range, repetition, or contour.

individual auditory sensitivities [31], they have been observed to generally "respond positively to activities involving music" [63, p.3] and may exhibit unusually high musical competence and interest [52]. Given the synthesis of repeating patterns and social communication common in musical experiences, musical interventions and therapies create ideal developmental opportunities for children with ASD.

As early as 2004, the potential of technology used in special education to "enhanc[e] student engagement, motivation, and learning in various areas of academic, social and independent living" has been observed [66, p.1]. Recent advancements have expanded opportunities for inclusion and engagement, particularly among children with ASD for whom traditional instruments pose barriers [24]. Reviewing one such iPad-based music therapy program, Johnston *et al.* notes the greater "creative freedom to safely explore music making" [24, p.10] that the iPad app afforded participants, the majority of whom, according to Hillier *et al.*, "reported reduced stress (63%) and anxiety (56%) at the end of [their] programme compared to the beginning" [23, p. 276]. Researchers have explored other novel uses of music and technology as the basis of interventions for children with ASD, such as multi-sensory fabrics [14], interactive whiteboards activities [66], and VR/AR-based music therapy sessions [6, 9]. Similarly, CHIMELIGHT [33] is an IoT device designed to augment a physical hand chime to sense interactions and provide feedback to children and music therapists about engagement. Children's toy and book designers often prioritize autonomy, creating products that let children combine sounds to produce musical effects [30]. Similarly, uCue enhances autonomy by enabling users to personalize the instrumentation of songs, partially taking on the roles of composer and performer (see Supplementary Material: Page 29). Unlike typical toys, uCue offers creative freedom using a high-quality sound environment, allowing users to shape music, control timing, and influence the piece's overall character. This autonomy expands a child's range of musical responses and empowers them to modify music for different outcomes.

2.2 Exploring Musical Preferences & Sensitivities

The musical aptitude often observed in children with ASD was first noted by Leo Kanner in his seminal work on early infantile autism [25]. Research shows that individuals with ASD may have superior aural discrimination compared to neurotypical individuals, as evidenced by a study which found enhanced pitch, interval discrimination, and memory in people with ASD [21]. Another study suggested that children with ASD may have a more developed ability for aesthetic judgment of music, especially when exposed to classical music samples [35, p.5]. These results fit within a larger body of work demonstrating heightened sensitivity to musical pitch and timbre by individuals with ASD, though there was more variability in the results of subjects with ASD than with their NT counterparts [8]. Other notable auditory processing trends among listeners with ASD include the preference for familiar over environmental sounds [12], consonant over dissonant music [7], and non-vocal over vocal sounds [40]. Previous work in music therapy tools for children with ASD often lacked the ability to adapt to individual auditory preferences and processing needs, limiting their effectiveness in addressing diverse user sensitivities [24]. uCue addresses this limitation by enabling song customization, allowing children to add or remove sounds based on their likes or dislikes, while simultaneously logging these changes. This logged data facilitates opportunities to investigate global and individual preferences and sensitivities as well as further personalization.

2.3 Music Therapy & Socio-Emotional Learning

Music is a promising tool for cultivating emotional awareness and regulation in individuals with ASD [45]. Studies have demonstrated that emotion recognition in musical stimuli remains intact for some listeners with ASD, as evidenced by similar neural activity in emotion centers across control populations and high-functioning experimental participants with autism [24, p.7]. Similarly, Quintin *et al.'s* investigation found that "When 'intended emotions' were considered separately, the performance of participants with ASD and TD [typical development] could not be distinguished as happy, sad, or scared"[46, p.11], which the author notes is consistent with previous findings by Heaton *et al.* [22]. These findings are also consistent with the fMRI results discussed in Caria *et al.*, which proposes that emotion processing remains intact with music listening due to music's powerful ability to induce emotional states independent of facial cues, a locus of emotion perception impairment for some people with ASD [10]. Individuals with ASD often maintain intact emotion processing in music, providing a foundation for developing socio-emotional skills. This shared understanding of music can serve as a catalyst for forming friendships with peers [7]. From an educational and therapeutic standpoint, these intact abilities offer support for improvements in expressing positive emotions [24, p.7], maintaining eye contact and initiating interaction [17, p.22], attuned movement [47, p.15], initiating turn-taking [65], and engaging in joint behavior [3].

Recent surveys indicate increasing evidence of the benefits of music therapy for children and adolescents with ASD [60]. For example, Shi *et al.* finds support for music therapy improving mood, sensory perception, behavior, and social skills [56]. Moreover, Unwin *et al.* found that engagement in music therapy can be improved in multi-sensory environments, which can provide control over stimuli and create better conditions for learning [62]. Taken together, these studies help explain why a multi-sensory approach within music sessions encourages individuals with ASD to engage more with the act of creating music, and with the therapists; in turn, this can increase their level of communication and social interaction beyond the sessions [37, 44]. To reflect this, our work considers the importance of sensory perception in the design of a tangible interface [5, 65] and, similar to prior work (e.g., [62]), we conduct our work in a dedicated multi-sensory environment. Similar to other devices in this space, uCue allows children with ASD to interact with music in a dynamic and customizable way, aligning auditory stimuli with other sensory inputs, making it potentially suitable to support the goals of music therapy including socio-emotional learning activities.

2.4 Interactive Music Technology

Research in music technology designed for individuals with disabilities has been advancing for decades because such technology presents a transformative potential to create adaptive, interactive, and inclusive musical experiences [12, 28]. Survey work by Anderson and Smith overviews music software, controller solutions, and traces the evolution of such technologies as far back as the early 2000s [1]. More recently, Silberman's NeuroTribes highlights how neurodivergent individuals, when supported appropriately, can develop exceptional creative and intellectual capacities, advocating for inclusive design that nurtures rather than suppresses these differences [57]. As previously noted, children with ASD face challenges in fully engaging with music due to sensory and cognitive processing differences, but numerous efforts aim to overcome these barriers. For example, the OSMoSIS system (an interative musical system) [49] transforms body movements into sounds, improving musical interaction for children with ASD in therapy sessions [48, 50, 51]. Kaur (2024) explores the co-design of music-making interaction to support self-regulation, creative expression, and well-being in neurodivergent children [26]. Similarly, the BendableSound prototype, a fabric-based multi-touch surface, supports neurologic music therapy sessions, allowing children to practice movement patterns while playing music when touching the fabric [13]. Meckin and Bryan-Kinns introduced *moosikMasheens*, a system of adapted electro-mechanical musical instruments controlled via tablet interfaces, enabling musical expression for young people with physical impairments or complex needs [38]. Similarly, *Drum Duino* [64], *Block Jam* [43] and *SenseBox* [19] provide evidence that the use of tangible interfaces for personalizing music can facilitate collaboration and expression. When compared to the above interactive musical devices which are used for music therapy [13, 19, 26, 38, 43, 48, 50, 51, 64], uCue offers better portability, options for song personalization based on the needs of the child and their sound sensitivities, a musical library comprised of various childrens songs specifically composed for children with ASD and a robust logging system which can be used by educators and therapists to adjust the interventions.

3 System Design

The project aimed to develop an interactive music system that would allow (i) children with ASD to modify music to suit their listening preferences, (ii) to record interactions with the device as potential data for studying the musical preferences and sensitivities of children with ASD, and (iii) to explore the feasibility of using the system to support socio-emotional learning goals common in music therapy. The collaborative efforts of our interdisciplinary team, which included members from both music and technology backgrounds as well as subject matter experts, shaped the technology design and activity protocol of uCue [29, 39]. This collaboration brought together diverse expertise, including professionals with firsthand experience working with children with ASD in classroom settings, family members of individuals on the spectrum, and those with personal experience with ASD themselves, either as members of the research team or as subject matter experts from a partner organization consulted across a multi-year research program. These experiences directly influenced design choices, such as prioritizing sensory-friendly materials and features. Although children with ASD were not directly consulted in the initial design phase, partners and subject matter experts from Autism Delaware and the Rt. 9 Library & Innovation Center (New Castle County, Delaware), who have backgrounds in child development, autism therapy, and music therapy, provided critical feedback during regularly occurring meetings. Their input informed decisions regarding integrating visual cues, gentle lighting, and intuitive interaction mechanisms to ensure that the tool catered to the diverse needs of children with ASD while minimizing sensory overload. Further, they informed communication strategies, study protocol, and socio-emotional learning goals. The outcome of a multi-month design process resulted in combining elements of professional tools with sensory-sensitive features to create uCue, which offers a tangible, controller-based design compatible with various audio output devices (Figure 2). A standardized music composition template facilitates the efficient creation of a diverse music library. Our collaborative process ensured that uCue meets the sensory and usability needs of children with ASD. After describing the system here, we will evaluate its potential as a tool for research into listening preferences as well as its feasibility of use to support socio-emotional learning and music therapy.

3.1 Audio Template and Music Library

In this section, we present our Music Library and sound design concept, further discuss the functionality of the music control interface, and outline fundamental design principles for creating musical layers.

3.1.1 *uCue Music Library and Sound Design.*

uCue's modular music library includes arrangements of four children's songs: "Twinkle, Twinkle Little Star," "The Ants Go Marching," "The Wheels on the Bus," and "Row, Row, Row Your Boat." These songs were suggested by our partner organization based on a discussion post they made on their Facebook page about songs the parent thought their children generally liked. Songs with the highest number of hits were prioritized in the music production process. The post also asked parents to share ambient sounds enjoyed by their children; these sounds were used when creating ambient sound layers for uCue. The songs were created using high-end digital audio equipment, including a Nord Wave 2 (FM and wavetable synthesizer),[6] Arturia PolyBrute (morphing analog synthesizer),[7] and an Elektron Digitakt (sampler and drum sequencer).[8] The musical arrangements were composed using music notation software (Sibelius and MuseScore) and exported as MIDI data.[9] This MIDI data was manipulated using a ProTools digital audio workstation (DAW), which was also employed to mix the final tracks.[10] Several harmony tracks were recorded live using the Nord and Arturia synthesizers.

3.1.2 *Design Principles for Music Layers.*

The modular music composition template includes fifteen tracks across seven layers, designed to test musical preferences (e.g., timbre, rhythm) with minimal tracks. While more tracks could provide additional options, they would complicate pattern identification and significantly increase composition time. To balance consistency, productivity, and research goals, we limited the template to fifteen tracks. Each musical layer is designed to address diverse sensory and aesthetic goals while aligning with research objectives. To create an adaptable sensory experience suitable for children with neural processing sensitivities, songs were composed at slower tempos, as recommended by our partner organization.

[6] https://www.nordkeyboards.com/products/nord-wave-2
[7] https://www.arturia.com/products/hardware-synths/polybrute/overview
[8] https://www.elektron.se/us/digitakt-explorer
[9] https://www.avid.com/sibelius and https://musescore.org/en
[10] https://www.avid.com/pro-tools

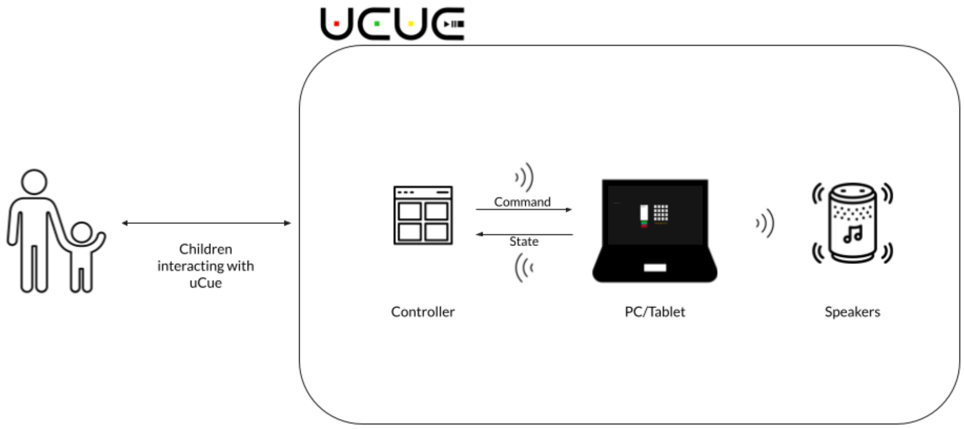


Figure 2: System Diagram
System's Interfacing Diagram, highlighting the interaction between uCue and Children

(a) Button Toy **(b) Ableton Push** **(c) Skoog**

Figure 3: uCue's design draws inspiration from several tools available commercially as well as in the Sensory Room: a Button Toy (3a), which changes colors displayed in the Sensory Room; Ableton Push (3b), which enables music playback through button presses; and Skoog (3c), a customizable musical instrument. By integrating these influences, uCue delivers a portable, customizable music experience with dynamic color changes.

Supplemental layers with higher rhythmic activity ensure a sense of forward motion despite the slower pace. Each song features unique timbral, stylistic, and motivic elements, with distinctive acoustic profiles and virtual instruments. The melody layer explores preferences for timbre and pitch range, while other layers investigate rhythmic and harmonic preferences. Songs include both calm and rhythmically active layers to examine contrasting preferences. Countermelodies enhance the main melody, and harmony layers balance calm and energetic variations, incorporating both common and unusual harmonizations. Table 1 summarizes the layers and corresponding interface button colors. This structure allows 2,303 unique combinations per song, balancing variety with manageable workload.

3.2 uCue's Construction

The uCue controller was built using commercially available components following the Sparkfun 4x4 grid interface tutorial [58]. The casing of the prototype was 3D printed and designed in SolidWorks[11]. It featured a two-part design, with a hollow box separated into upper and lower sections that fit together. The software was written in the Unity3D[12] engine (Figure 4b). The controller connects with the Unity3D application via a Bluetooth module. Internally, an Arduino was placed in the lower section powered by a 5V battery.

[11] https://www.solidworks.com/
[12] https://unity.com/

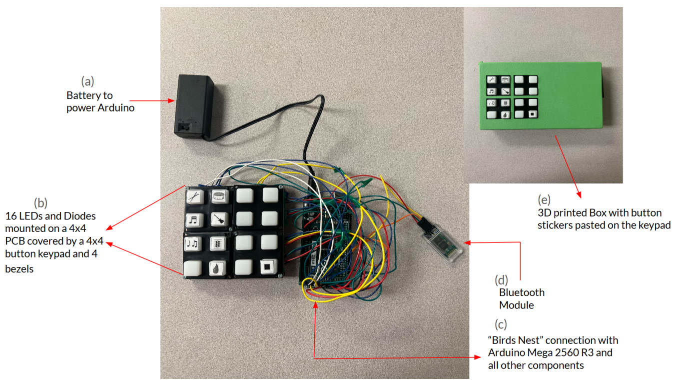
Layer		Ants Go Marching	Row, Row, Row Your Boat	Wheels on the Bus	Twinkle Twinkle Little Star
1. Melody	M1 (red)	solo piccolo, gentle attack, slow decay, very high register	solo flute, middle register, reedy timbre	solo flute, high register, traditional timbre	gentle plucked sound + sustained strings in high register
	M2 (blue)	solo trumpet, moderate attack, no decay, middle register	flute (melody) + harp (round)	synthesized, warm lead sound, w/ long delay, reverb	sharp, plucked sound
	M3 (yellow)	harp/choir hybrid, sharp attack, quick delay (harp), long decay (choir)	harp/choir hybrid (melody + round)	hard lead sound (snyth) + soft choir hybrid	bass flute + synthesized high register reverb
2. Harmony	H1 (red)	pad (calm)	choir (calm)	string pad (warm, with bursts of bright sound)	pad (calm)
	H2 (blue)	synth keyboard (active)	water glasses (calm, with ringing higher-register sounds)	synthesized, with repetitive gate and arpeggiations over expansive register	synthesized, with repetitive gate and arpeggiations over expansive register
3. Additional Melody	A1 (red)	bell sound, high register, large ambitus, moderate speed	harp+choir sound, lilting rhythm, moderate speed, large ambitus	electric piano, moves slowly with melody	plucked guitar, steady, moderate speed descant
	A2 (blue)	electric guitar, fast descant line	solo oboe, small ambitus, motivic repetition, faster speed with uneven values	synthesized bell with sine wave decay, moderate speed, medium register	plucked guitar, faster triplet speed descant, inclusion of triplets
	A3 (yellow)	synth hybrid sound, high register, stylized, uneven values (fast)	synthesized guitar, fast descant line, but in lower register	synthesized bell, fast descant line, high register	plucked guitar, fastest descant line (2x speed of A1), greater gestural variance
4. Bass Line	B1 (red)	electric guitar, simple part with light rhythmic activity	synthesized plucked sound, arpeggiated texture built on bass line	plucked bass, energetic but sticks on specific pitches, repeating them	Deep lead synth sound, melodically ornate walking-style bass
	B2 (blue)	bass guitar, faster ornamentation with syncopation	string bass, 2:3 rhythm, walking bass pattern	plucked bass, slower and mostly melodic	electric bass, chord roots doubled at the octave, note repetitions create rhythmic activity
5. Percussion	P1 (red)	trap set	trap + techno sounds	tom, hi-hat	tom, hi-hat, castanets
6. Bass Drum	D1 (red)	synthesized bass hit sound	modified bass drum sound	sharp bass attack with fast decay	sharp bass attack with fast decay
7. Ambient Sounds	S1 (red)	flowing water/stream			
	S2 (blue)	city traffic sounds			
	S3 (yellow)	train crossing sounds			

Table 1: An overview of the seven layers on the device. Colors that appear on the music-control interface button when selected are shown under variant labels.

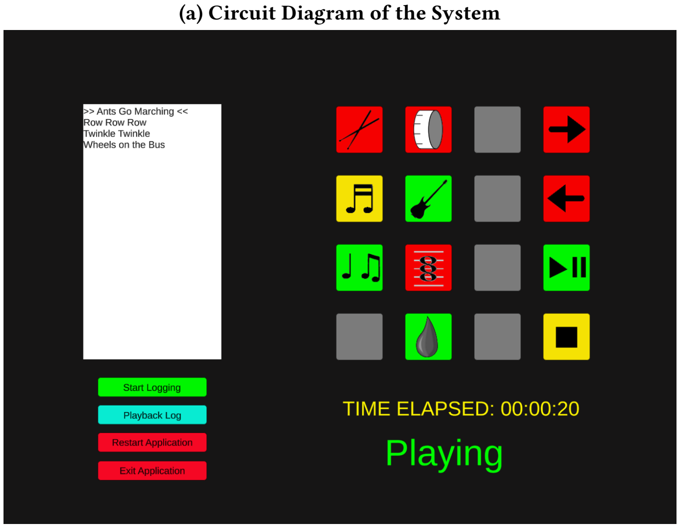
The PCB for the 4x4 grid button interface was positioned on top , aligning the interface buttons with the openings in the upper section of the case as illustrated in Figure 4a. Custom Arduino code was written to interface with our playback and logging software, where the playback software acted as an authoritative server, receiving input from the controller and sending back the updated state of the layers to be displayed on the controller's buttons using different colors.

3.3 System Interactions & Control Interface

The seven audio layers are assigned their own music-control button on uCue. Each button is marked with a musical symbol indicating the layer it controls, and buttons change color to indicate which layer is active. Different playback modes are available for each audio layer. For example, four playback modes are available for the first audio layer: three unique instruments and a mute mode. After cycling through these modes on button presses, the layer reverts to its default configuration. This behavior is consistent across all seven audio layers, allowing users to manipulate each layer's playback mode using predefined interactions. uCue supports direct on/off transitions between different tracks and layers. The interface includes a vertical pane with four dynamically loaded song options, each with checkboxes for showing selection, and a central 4x4 color-coded button grid for controlling playback, navigating tracks, and managing musical layers. Playback controls include Play/Pause, Stop, and Forward/Backward buttons for navigating songs within the selected track. Status indicators at the bottom display "Playing," elapsed time, and system controls like "Start Logging" and "Playback Log." The "Start Logging" feature records all modifications to audio layers—whether via keyboard, click, or remote input—saving timestamps, layer names, and statuses in a .csv file[13]



(a) Circuit Diagram of the System



(b) Interface of the Unity3D Build

Figure 4: Hardware and Software Architecture of uCue

4 Method

We recruited seven child participants across two phases, aged 4–12 years, with one exception of a 19-year-old adult child in a dyad, included upon parental request through email and social media outreach, direct verbal communication, and by seeking help from our community partners. Inclusion criteria required the presence of a parent or legal guardian during sessions, and children with auditory impairments were excluded. Participants were invited to complete a preliminary survey about their demographics (see Table 2) and availability. Following this, the listening sessions were scheduled at the Sensory Room.

4.1 Phase One Deployment

In the first phase, we recruited four parent-child dyads to run through our preliminary protocol. This included a parental consent and child assent process, a brief structured introduction interview, a listening session inviting children to interact with our music library using the uCue system in the Sensory Room, and a debrief interview.

4.2 Phase Two Deployment

Based on feedback and observations, the preliminary protocol was updated to shorten the duration of pre- and post-interview to increase the time for challenges and include PECS (Picture Exchange Communication System) cards[14] (see Supplementary Materials) to engage more directly with non-verbal children. PECS cards were created for each of the four songs and the various musical layers available on the uCue interface. Additional cards allowed children to indicate their preferences (e.g., liking or disliking a particular song or layer) and express their emotions using 'fill-in-the-blank'

[13]During the study, children were encouraged to interact with the hardware interface despite having access to the software interface. The software interface largely served as an interface for the researchers and a backup in case the hardware became damaged.
[14]A child or adult with autism can use PECS to communicate a request, a thought, or anything that can reasonably be displayed or symbolized on a picture card.

cards designed to capture their mood during the session[15]. This enhanced our interaction with a non-verbal participant. We recruited three additional parent-child dyad in this phase.

4.3 Procedure

Building on the foundation on the work done by Mohamed *et al.* which created a platform aimed at enhancing the focus of children with autism on specific tasks [42], we developed three challenges designed to facilitate interaction with the uCue system. The study began by introducing the child to uCue, explaining the button functionality, and, for non-verbal participants, demonstrating the use of accompanying PECS cards to express reactions through emotion and fill-in-the-blank cards. Figure 6 shows the arrangement in the sensory room and some of the images of the sessions conducted.

Once comfortable with uCue, child participants were asked to complete several challenges. In Challenge One, the participants used the device's [Play] and [Next Track] buttons to find a song they knew or liked. If necessary, cues for device functions and "liking" were provided using PECS cards. Following the song selection, participants were prompted to change the melody using the device, and their emotional responses to these changes were noted. Participants were prompted to use the buttons to explore the sound modifications and asked about specific sound changes they desired and if they wanted to try pressing buttons. They were also encouraged to adjust the song's dynamics, making it as calm or as energetic and loud as they preferred, by either verbally indicating their preferences or pointing to corresponding PECS cards. If the participant seemed disengaged at any point, they were prompted to express what they would like to hear with the use of examples and were given directions on how to achieve that. Participants were asked to reflect on their experience of modifying the song and what they thought and felt while pressing the buttons. In Challenge Two, participants were prompted to choose a new track and modify it until they liked it. Participants shared thoughts as they listened to their customized song. Participants were given the opportunity to make further changes to the song if desired. To determine whether the participant was enjoying the song, we would prompt them to confirm their preference and in the absence of a response, rely on observational evidence from the session. They were also asked if they wanted to engage in singing or dancing while listening, and if the reaction to this was positive, the team would encourage them to do so by either cheering or joining in. If they seemed enthusiastic about engaging further, they were introduced to challenge three. In Challenge Three, if the child was capable of speaking or singing, they were encouraged to find a song they knew and liked, choose the sounds they preferred, and attempt to sing along with the music, either independently or with a parent. If they were not capable of singing, they were encouraged to dance, move, or clap along. These rounds assessed their listening skills, ability to control music through uCue, and emotional connection to the tracks. During the session, they were also allowed to interact with other objects in the sensory room. Figure 5 provides an overview of the study, illustrating the steps followed during the session.

[15] For example, if the participant pointed to the *"I feel Happy"* card, the examiner would ask if they felt happy. The participant would either nod or smile, which we took as agreement, or ignore the question and/or point to the other cards; latter indicated that the participants were not pointing to the cards intentionally.

ID	Gender	Age	Verbal	Education	Diagnosis
C1	M	8	Yes	Elem. School	ASD
C2	M	4	No	Elem. School	ASD
C3	M	4	No	Elem. School	ASD
C4	M	4	No	Elem. School	ASD
C5	F	19	No	High School	ASD
C6	M	9	Yes	Elem. School	ASD
C7	M	10	Yes	Elem. School	ASD

Table 2: Participant Demographics

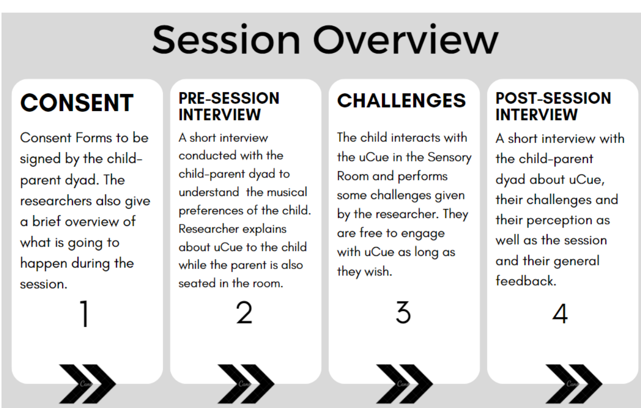


Figure 5: Session Steps Illustration

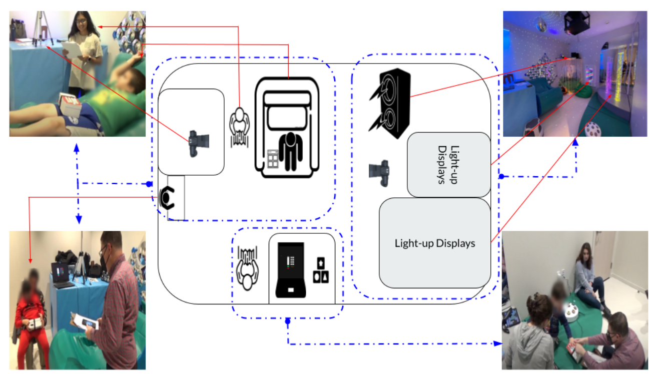


Figure 6: Sensory Room Arrangement for the Study: The blue dotted lines illustrate the different sections of the Sensory Room and their correspondence to the session images, while the red solid lines connect specific objects to their respective locations in the room. Two cameras were strategically positioned opposite each other to capture the child's interactions from different angles. The child sits on an inactive haptic chair with the uCue device placed on their lap, engaging with the session. Parents observe the proceedings from a designated seating area, and two researchers facilitate the session.

4.4 Data Analysis

Our analysis of collected data focused on understanding the child participants' music preferences, attention levels, and emotional responses, as well as their interactions with the device and music. Our sources include uCue's system application logs, session audio/video recordings, and observations made by our research team during the session. We employed a mixed-method approach, combining qualitative video analysis with a checklist and quantitative analysis of system logs. Key metrics' mean, median, and standard deviation were calculated and visualized through stacked bar plots. To analyze the video, we developed a structured checklist to assess participant actions and behaviors. The researcher team reviewed the videos, and participants' responses were tagged based on actions the research team observed. Due to the small sample size and early nature of the work, Inter-Rater Reliability (IRR) was not applied; instead, coding consistency was ensured through regular team meetings and cross-checking. We refer to members of each parent-child dyad using P# and C#, respectively, with "#" representing the session number in our analysis. We excluded C7 from the logged data dataset due to an error where no data was recorded. Additionally, data from the beginning of the session, which involved introducing uCue to the child to the start of the first challenge, was excluded to ensure consistency in identifying their preferred sound choices.

5 Results

Here, we discuss the pre-and post-interview results, the participant's interaction with uCue[16], their reactions to the different types of sound, their musical preferences, and engagement trends with uCue.

5.1 Pre-Session Interview Results

In our pre-session, we interviewed parents and children about the children's prior experiences with music.

5.1.1 ***Music Interest and Influences.*** Parents and children agreed that the children enjoyed a wide range of music, from early child songs to specific genres like Jazz, Louisiana, brass, and more complex compositions like *"Pluto's Reprisal."* Some expressed a strong love for music, while others were more reserved or even disliked certain genres. C3's statement highlighted this range of preferences, *"I tend to like a lot of different songs of different genres."* A few participants (2/7), highlighted a preference for music with a clear sound and a single dominant instrument. For example, P5, noted that their child *"...likes when there's a clear sound, one instrument that comes through [in a song]."* Their preferences were possibly shaped by their family environment and cultural background. C7 mentioned enjoying Spanish music due to his mother's influence, emphasizing the bonding experience, *"I listen to Spanish music because my mom plays it in the car. It's fun to share that experience with her."*

5.1.2 ***Listening Habits.*** The listening habits of the children were diverse. Differences in the children's responses, such as suddenly losing interest or requesting to turn off music, stand out as distinct from what might be expected in neurotypical children. As explained by P3: *"Sometimes he will listen to it, and then at the end, he'll be like, okay, turn it off, because I think it's just too much."* Some often engaged with music in specific contexts, such as in the car or playing songs at home. One child, C7, mentioned a regular music routine before bedtime, indicating a consistent pattern in their music consumption. C3 enjoyed listening to familiar music (such as child-friendly theme songs from shows, Disney films, or folk songs like "The Wheels on the Bus"). Our in-session observations further support these variations, highlighting the unique reactions and attention patterns exhibited by children with ASD.

5.1.3 ***Other Interactions with Music.*** Parents detailed a spectrum of behaviors in how their children respond to music with common expressions of enjoyment like making sounds or moving. P1 pointed out their child's discomfort with particular sounds, stating, *"There are sounds that he really responds negatively to.... He doesn't like it."* P2 noted their child's difficulty in imitating melodies, saying, *"He can't imitate the sounds in the songs... he's not able to say things like 'Moo' or make other sounds"* and also talked about their child's curiosity as, *"If he's not sure what song it is, I think he becomes more attentive (P2)."* Dislikes for certain songs or genres were expressed vocally or by attempts to change the track. However, physical engagement including activities such as singing, clapping, dancing, and tapping to express enjoyment of music was common among the children. For example, C7 said, *"I can feel the rhythm in my body, and it makes me want to move. Faster tempos and energetic beats really catch my attention."* Likewise, P1 shared their child's enthusiasm for music saying, *"He loves to sing and dance, singing the songs he knows, and he likes to roll on his belly when we sing 'Head, shoulders, Knees, and Toes', he is happy to have me sort of move his hands around."*

5.2 Session Results

We analyzed six participants' application logs to understand their music preferences in the session. We coded their reactions and engagement with uCue by reviewing the video recordings. The quantitative analysis is presented alongside qualitative observations.

5.2.1 ***Global Music Preferences.*** When analyzing children participants' music preferences, we identified sections of the session where children were adapting music intentionally (post-familiarization). We evaluated the total duration each song and each layer was played during these intentional interaction periods. Children's prolonged engagement with specific songs and layers, as indicated by play length, was interpreted as a sign of preference. Verbal and non-verbal behaviors during the sessions provided further evidence of children's preferences. The observations made in Table 3, highlight a range of engagement behaviors that reflect participant responses during the sessions. Our results indicate that music preferences varied in sessions with uCue. Particularly, "Ants Go Marching" and "Twinkle, Twinkle" emerged as favorites. Most participants (4/7, 57.14%) favored these over other songs in the playlist based on play length, corroborated by feedback during the

[16] Interaction with uCue refers to participants' exploration of musical layers by actively adding, removing, or modifying audio elements on the 4x4 button grid, enabling them to exercise creative autonomy in shaping personalized musical compositions.

session and post-session interviews. Figure 7 and 8 show the duration and interaction for each song across participants respectively.

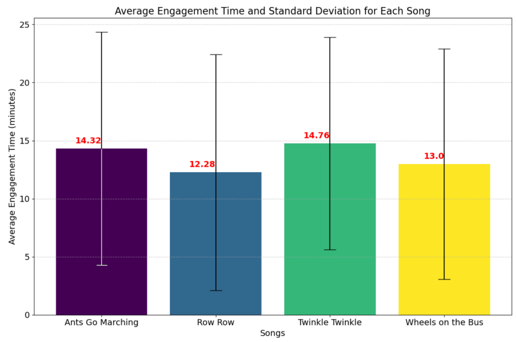


Figure 7: Cumulative Duration for Songs across Participants: "Twinkle, Twinkle" had the highest average play time at 14.76 minutes, followed by "Ants go Marching" with an average play time at 14.33 minutes. The lowest played song was "Row, Row, Row Your Boat" with an average play time of 12.28 minutes.

Observations suggest children display more enthusiasm for songs they listen to longer, indicating a preference for these tracks. Repeated interactions with the same song by different children support this view. Parent feedback confirms that some songs prompt more interaction because children genuinely enjoy them and react positively. Figure 9 suggests that children have individual preferences for songs, with some songs resulting in more interactions.

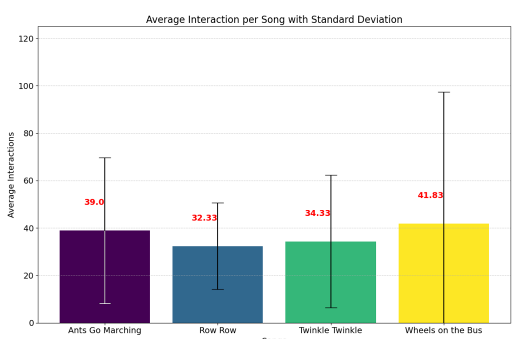


Figure 8: Cumulative Interaction for Songs across Participants: "Wheels on the Bus" had the highest average interactions at 41.83, with the greatest variability, while "Row, Row, Row your Boat" exhibited the lowest average interactions at 32.33, with the most consistent engagement across participants.

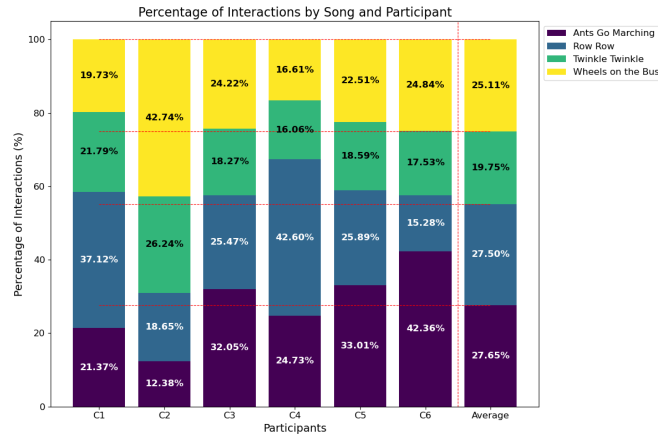


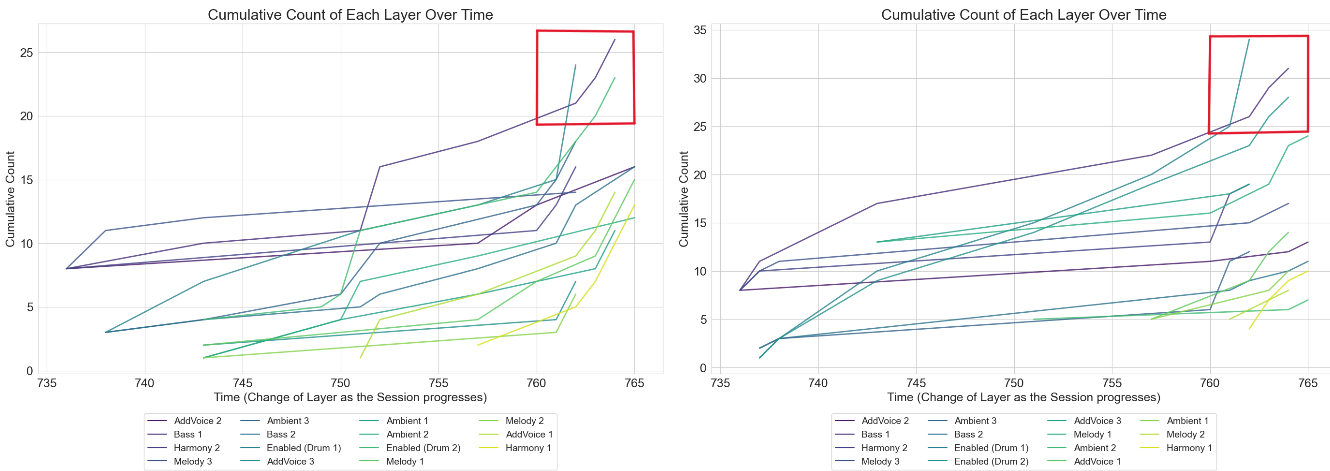
Figure 9: Percentage Interaction of each Participant to Songs:"Ants go Marching" had the highest percentage interactions with 27.65% and closely followed by "Row, Row, Row your Boat" with 27.50% while "Twinkle, Twinkle" had the least interaction percentage with 19.75% over the six sessions.

5.2.2 ***Response to the Prompts.***

As the sessions progressed and participants became more familiar with uCue, they began to favor new layer combinations. Less than half (3/7, 42.85%) transitioned from soothing melodies to faster-paced songs. The *Harmony* and *Ambient* layers were often played in conjunction with the song "Wheels on the Bus" to make it soothing. Several participants (3/7) customized the "Ants Go Marching" by adding drums and other layers, indicating a preference for personalization and active engagement. Based on the data from the logs of a few participants (for C5 and C6), the drums and bass line were added to all four songs to make the environment more energetic. The Figure 10a and 10b shows the time to layer distribution for C5 for two songs.

5.2.3 ***Individual Musical Preferences.***

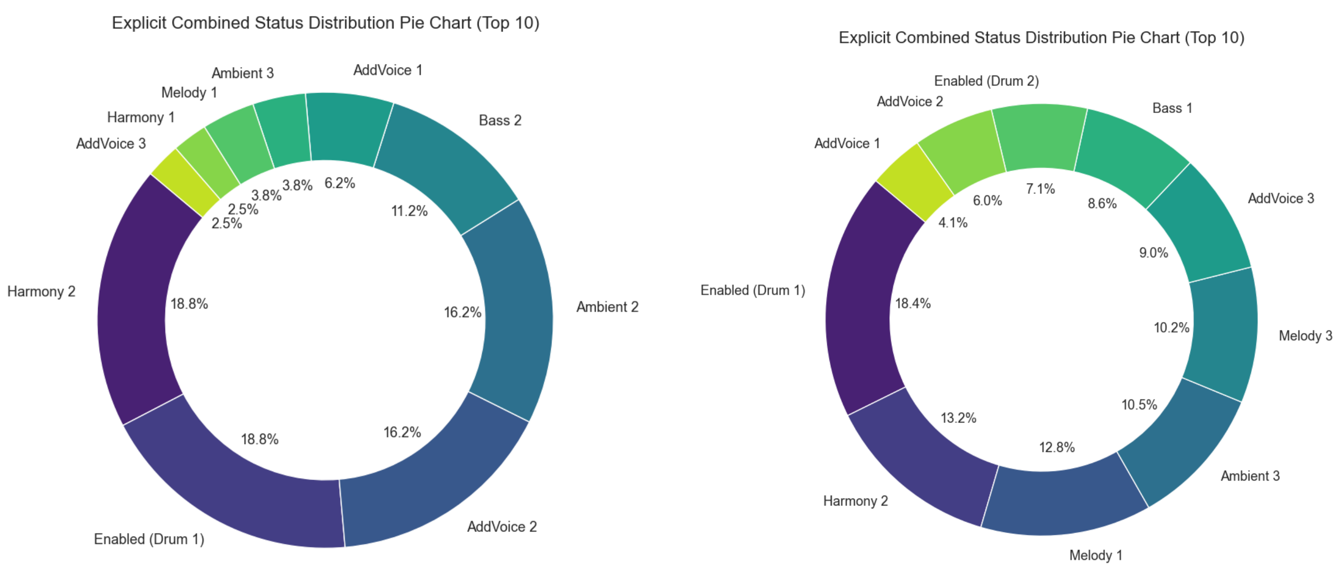
Based on the wide range of genres, tempos, and instruments uCue offers, musical preferences resonated differently with each individual. We compared these unique music preferences across participants to find patterns, outliers, and insights through the subsequent graphs and analyses. Figure 11a and 12a illustrate the distinct musical choices of participants C3 and C5 for "Ants go Marching" and Figure 11b and 12b for "Wheels on the Bus," with C3 preferring soft, harmonious layers and C5 opting for upbeat, fast-paced layers with drums.



(a) Modifications to "Twinkle, Twinkle"

(b) Modifications to "Row, Row, Row Your Boat"

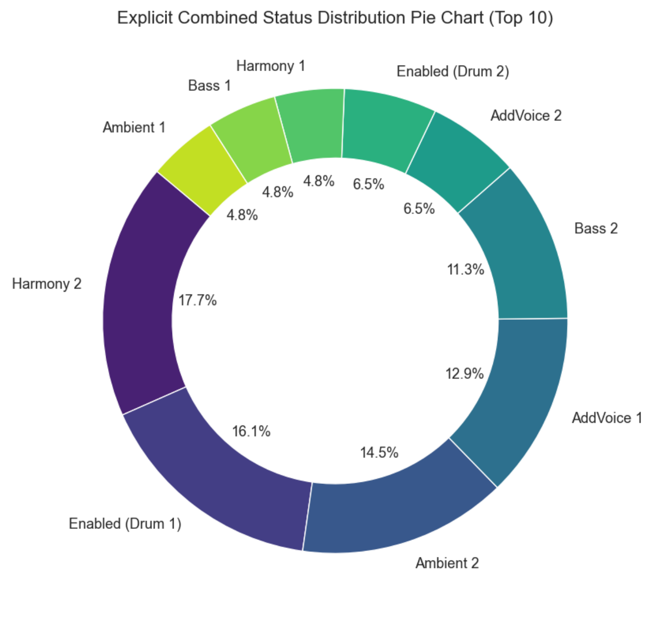
Figure 10: Time to Layer Plot The use of three layers, *Bass 1*, *Drum 1*, and *Drum 2*, keeps steadily increasing throughout the remainder of the session, highlighting the increase in energy levels towards the end.



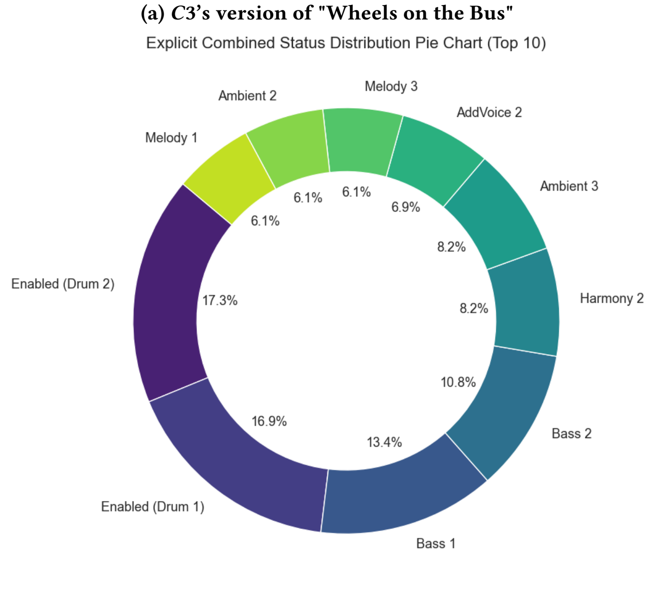
(a) *C*3's Version of "Ants go Marching"

(b) *C*5's version of "Ants go Marching"

Figure 11: Composition of "Ants go Marching" by two participants: C3 exhibited a preference for soft and soothing layers in their compositions. They particularly favored harmony layers, complemented by additional sound elements such as ambient noises. On the other hand, C5 leaned towards selections with upbeat layers and swift tempos. They particularly favored base layers, complemented by additional sound elements such as drums. These choices noticeably elevated the room's energy level. The contrasting preferences underscore the diverse musical inclinations of the two participants.



(a) *C*3's version of "Wheels on the Bus"



(b) *C*5's version of "Wheels on the Bus"

Figure 12: Composition of "Wheels on the Bus" by two participants: C3 exhibited a preference for soft and soothing layers in their compositions. They particularly favored harmony layers, complemented by additional sound elements such as ambient noises. On the other hand, C5 leaned towards selections with upbeat layers and swift tempos. They particularly favored base layers, complemented by additional sound elements such as drums. These choices noticeably elevated the room's energy level. The contrasting preferences underscore the diverse musical inclinations of the two participants.

5.2.4 *Reactions to Ambient Sound Layers.*

uCue allowed the addition of ambient sounds; being played at an average of 18-20% per session. Some children enjoyed this addition. For example, after adding the sound of running water to "Twinkle, Twinkle," C6 commented that *"It feels like I am underwater"*. In contrast, C4 seemed to become upset by the same sound and briefly exited the session. P4 offered that one possible explanation was an aversion to sounds of water. P4 explained, *"He hated the sound of ocean waves since the time he went too near the ocean for the first time"*. Similarly, most participants were indifferent to the sound of a train, though C2 had a negative reaction, as P2 noted in the post-session interview. These observations suggest a range of potential responses to different ambient sounds.

5.2.5 *Participant Reactions and Engagement Trends in Video Sessions.*

Table 3 summarizes participant's reactions across the seven sessions. We analyzed the videos by tagging actions representing key engagement features, such as enthusiastically reacting to music (i.e., by smiling, or making other positive vocalizations), exhibiting energy by moving their hands or physically reacting by dancing, rocking, singing or tapping along. Each child is represented with "C" (e.g., C1 is the first). During these sessions, we noticed that physical movement played a big role in children's engagement with music. They danced, tapped, waved, and mimicked percussion tracks. Some sang along (C3) and tapped their feet (C5, C6), while others felt compelled to move when they heard certain sounds and rhythms. Furthermore, the interactive device created an experience where children could freely explore and express their creativity or mood. For example, C7, changed a song until it made him "sleepy." Contrarily, C2 was not interested in interacting with uCue for long and preferred to engage with other devices in the Sensory Room. Unlike some of the other participants, C4 relied heavily on non-verbal forms of communication, such as making noises and physical movements, in addition to using a few words here and there. It was apparent that he initially felt overwhelmed when he entered the room and did not want to engage (i.e., in these cases the research team moved on to the parent debrief interview). P4 mentioned that visuals were a big and important component for him when enjoying music, which uCue did not support, and any unpredictable or unfamiliar sounds tended to upset him (i.e., C4).

5.3 Post Study Interview Analysis

The post-session interviews with parents and guardians, yields valuable insights for understanding each child's behavior. It provides context around their child's reactions and make observations about their child's experience, which may not have been evident to single session observers.

5.3.1 *Sensory Room and Device Challenges.*

Parents raised several concerns during discussions about their children's interactions with the Sensory Room and the uCue device. P3 mentioned confusion about the device's functions, saying, *"Because there's a lot of things happening... I don't think he understood what the buttons were doing."* Another related concern was the potential for distractions within the sensory room or from the device itself. P4 highlighted the ease with which distractions occurred, stating, *"I've noticed that with him, as is often the case with autism, distractions*

Actions/Sessions	C1	C2	C3	C4	C5	C6	C7	Total Count
Enthusiastically React to Music	✓	✗	✓	✗	✓	✓	✓	5/7 (71.4%)
Stop Button Pressing for Preferred Sounds	✓	✓	✗	✗	✓	✓	✓	5/7 (71.4%)
Smile at Preferred Sound Combinations	✓	✗	✗	✗	✓	✓	✓	4/7 (57.14%)
Engage with Prompts	✓	✓	✓	✗	✓	✓	✓	6/7 (85.71%)
Exhibit Relaxation	✓	✗	✓	✗	✓	✓	✓	5/7 (71.4%)
Exhibit Energy	✓	✓	✓	✗	✓	✓	✓	6/7 (85.71%)
Noticeable Mood Change	✓	✓	✓	✓	✓	✓	✓	7/7 (100%)
Hum or Sing Along	✗	✗	✓	✗	✓	✓	✓	4/7 (57.14%)
Interact with PECS Card	✗	✗	✗	✗	✓	✓	✓	3/7 (42.85%)
Dance, Rock, or Tap Along	✓	✗	✓	✗	✓	✓	✓	5/7 (71.4%)
Total Count	8/10 (80%)	4/10 (40%)	7/10 (70%)	1/10 (10%)	10/10 (100%)	10/10 (100%)	10/10 (100%)	

Table 3: Session Checklist: Participant Reactions and Engagement Trends: Overall high level of positive engagement was observed in most (5/7) sessions—signified by completing the actions listed in the table at least once during the session. A "Noticeable Mood Change" was observed in every session (7/7). Most elected to "Engage with Prompts" from the researcher (6, 85.71%) running the session, and most (6, 85.71%) seemed to "Exhibit Relaxation" during the calm challenge task. These actions were operationalized as slow or still movements, closing eyes, or a verbal confirmation. Energy was exhibited through actions such as quick movements, clapping, faster rocking, or a verbal confirmation. Sessions C5, C6 and C7 were notable, with a 100% occurrence rate of actions, while session C4 displayed minimal engagement at just 10% of tracked actions

come easily. It's as if the music grabs their attention, but then there are the lights over there. Sometimes, it's just the music or something where they can fully focus on that one thing." Thus, environmental distractions and other sensory stimuli may impact music focus.

5.3.2 ***Challenges in Music Listening.*** Children with autism experience unique challenges in music environments, such as sensitivity to volume, tempo discomfort, and communication barriers. For example, P6 pointed out the issue of loud music, which can be overwhelming for children with ASD, leading to sensory overload and discomfort. Furthermore, P7 mentioned their child's struggle with slow tempos. Communication barriers can further complicate matters, as these children may struggle to express their musical preferences or discomfort effectively.

5.3.3 ***Parents' Perceptions of uCue and Children's Engagement.*** Parental intervention was encouraged during the sessions to aid communication and foster engagement. Parents often rephrased researcher instructions or provided light encouragement, which helped children navigate the system. In response to questions about their child's experience with uCue, parents highlighted a sense of autonomy that their children appeared to experience while using the system. P6 noted, *"My child was excited to explore the device and try different sounds,"* suggesting a sense of independent exploration. P7 emphasized the interactive nature, observing, *"...liked changing colors and playing with the buttons. It showed they were genuinely engaged and curious."*

Parents also appreciated the variety of songs and identified specific moments where autonomy was evident. For example, P2 noted their child's preference for familiar songs, stating, *"He likes things that are familiar... he really liked that he could hit the buttons,"* indicating how the system allowed the child to make choices aligned with personal preferences. Similarly, P3 observed, *"My child's interest in the device changed with different songs,"* further supporting the idea that children could exercise control over their listening experience.

The feedback also revealed that the ability to switch between musical layers and experiment with different sounds provided opportunities for decision-making and self-expression. P7 observed, *"The rhythmic beats seemed to stimulate their movements and energy levels,"* while P6 noted moments of both joy and frustration, *"My child smiled and laughed while using the device but also got frustrated when a song stopped abruptly."* These moments highlight the children's active participation in shaping their interaction with the music, reflecting a level of autonomy even when challenges arose.

Overall, the uCue system's design—combining interactive layers with modular music—enabled children to make choices about how they interacted with the music. While fluctuations in interest and engagement were observed, these moments of decision-making provided insights into how children could exercise autonomy within the uCue framework.

6 Discussion

The findings from our study suggest the potential value, enjoyment, and access that children with ASD experience when personalizing music to their taste. Here we address our research questions, discuss how the collected data might be incorporated into music therapy and composition, and offer design recommendations for future systems before describing limitations and future work.

6.1 Interactive Music Making, Autonomy, & Enjoyment

Regarding *RQ1* addressing the effectiveness of uCue as a tool for measuring listener preferences, our results suggest uCue's data logs can help generate potential inferences about global and individual preferences. For example, preferences for soothing and energetic music (Section 5.2.3). Such inferences could have utility—particularly with higher n-values and more fine-grain analysis. Our *RQ2* explored whether engagement with uCue could facilitate emotional experience and enhance enjoyment of music for children with ASD. The findings from Table 3 highlight that most participants enthusiastically reacted to the music and all the participants exhibited a noticeable mood change. These results underscore the potential of uCue to provide an enjoyable and emotionally expressive platform for children with ASD, fostering a deeper connection to music. Regarding *RQ3*, uCue fostered autonomy by enabling children with ASD to actively shape their musical experiences. Rather than passively listening, children made decisions about adding, modifying, or layering musical components, allowing them to personalize their engagement. This autonomy was reflected in their exploration of favored sounds, selection of familiar tunes, and experimentation with rhythmic or melodic elements (Section 5.2.3). Parental feedback highlighted that the ability to control and customize the music heightened children's engagement and encouraged decision-making (Section 5.3.3). By empowering children to take an active role, uCue supported autonomy in both musical expression and listening experiences.

That said, and similar to [51] and [14], we had no control group, and these results should be interpreted cautiously. In the current stage, we focused on exploratory interactions with uCue rather than comparative analysis. Our objective is to demonstrate the potential of uCue as an interactive music system and data collection system and to document how participants engage with the system. At this juncture, we are not asserting the efficacy of uCue for specific outcomes, but rather investigating its use and the nature of interaction it facilitates.

Some additional caveats may also influence these results. While the uCue system provides numerous button and musical combinations, Table 3 shows that most participants (5/7) effectively navigated the musical layers and selected their preferred combinations, demonstrating the system's usability. During the sessions, the research team observed that the patterned musical layer to lights mapping (Table 1) appeared to aid participants by providing clear visual cues that helped them track active layers and maintain focus. This visual mapping appeared to reduce sensory overload and facilitated smoother interactions with the system. Additionally, incorporating ambient sounds made the environment more immersive and enjoyable for some, though it triggered negative reactions[17] in others, underscoring uCue's potential for studying listening sensitivities and individual sound preferences.

6.2 Application in Musical Therapy

While our study was initially aimed at better understanding listening preferences, another important dimension of uCue is its potential to support socio-emotional learning objectives commonly emphasized in music therapy. As we interacted with music therapists through our partner organizations, we increasingly focused on designing uCue-based activities to encourage participants to communicate their feelings and reflect specific moods through their musical creations, as highlighted in [24]. To better support these goals, we updated uCue's playback settings (Section 6.3), protocol and moderator guide, and implemented assistive communication tools such as PECS cards (Section 4.2). These changes aimed to improve data collection, foster communication, and enhance participant engagement.

Qualitative observations during the sessions indicated that even young participants with limited verbal communication abilities were able to engage in the activities and communicate their preferences, such as indicating when they liked a particular song or sound or when a song made them feel calm or energetic (Section 5.2.2 and 5.2.3). These observations suggest the potential for uCue-based activities to support socio-emotional learning goals, though further systematic evaluation is required. While we do not yet have quantitative evidence to substantiate these claims, the qualitative feedback from participants and their caregivers underscores the promise of refining uCue to further support socio-emotional learning and social interaction.

6.3 Musical Composition Challenges

Since its inception, one research goal has been to leverage interaction data to optimize uCue for its audience. Though issues like listener preferences for timbres, textures, song length, repetition, and ambient sounds need further exploration, current findings have significantly influenced uCue's playback and composition. Songs now start with a calm default track that users can adjust to heighten stimulation (Section 5.2.2). We discovered that not all users prefer a slow tempo (Section 5.2.3), suggesting future designs might include variable tempos to enhance user experience. Various musical introductions were tested, revealing that longer ones hinder users' timing for participation. Our ongoing refinement aims to make introductions clearer on song identity and participation cues.

While initial meetings with children were fruitful, multiple sessions could have revealed evolving user preferences. Without more data, conclusions on user preferences remain tentative. Further research is required to refine aspects like melody repetition and verse count. Another challenge was adjusting individual playback levels to achieve optimal balance across different layer combinations.

In the hands of its users, uCue is a musical instrument that enables them to exercise creative control while listening. This fact was shown clearly by one child (C2), who began the session clumsily using his palm to press multiple buttons simultaneously. Before long, and to the astonishment of his parent, the child began using his fingers to press buttons, quickly developing the same auditory-directed motor control musicians use to learn traditional instruments. Anecdotes like the one above demonstrate the potential of uCue to provide authentic and rewarding musical experiences.

6.4 Design Recommendations

We recommend design improvements to enhance uCue and similar technologies' user experience. Some recommendations depend on technology to detect and react to users' emotions, moods, and preferences, which uCue may not yet support. These are promising but require user empowerment to decide based on personal desires and feelings. A key challenge is balancing aesthetic and technology-assisted experience with user autonomy.

[17] A similar negative reaction to natural sounds was observed in Cibrian *et al.'s*. (2018) work [12]

6.4.1 Create Multisensory Engagement. Parents stressed the significance of offering age-appropriate music (Section 5.3.3) and casing design that aligns with a child's developmental stage, ensuring it resonates with their cognitive and emotional capacity. Using an interface that links different colors to different music layers created an exciting way for children to interact with music (Section 5.3.3). Flashing lights synchronized with the music may improve the visual appeal, captivating children's attention and creating a multisensory experience that supports engagement.

6.4.2 Plan for Diverse Track Selection and Feedback. When designing interactive music playback systems, offering a diverse array of music tracks to accommodate varying preferences among young children is critical. The tracks on uCue were met with mixed reactions. Some thought the tracks were perfect for the age group, while others desired more advanced material (Section 5.1.1). This highlights the importance of expanding our musical library suggesting that a more culturally diverse and extensive library would better cater to the musical preferences of children, particularly older children and those with different cultural backgrounds [18]. A set of user preference buttons might be incorporated on the device, including presets for individual users, initial track options catering to volume preferences (e.g., soft vs. loud), and buttons allowing users to provide real-time feedback about their liking or disliking of specific sounds and arrangements.

6.4.3 Include Tailored Musical Variability. Based on the parents' perceptions of their children's experience with uCue and findings from our logs, future systems could allow for dynamic and tailored musical variability (Section 5.2.1 and 5.3.3). This could involve adapting the music's volume, tempo, style, or complexity via direct interaction with the audio channels or based on the child's engagement level. For instance, if the child appears to lose interest, the system could introduce changes in the music to rekindle curiosity. Conversely, the system can provide more complex and stimulating musical elements if the child is engaged to sustain this throughout the interaction.

6.5 Limitations

It is important to acknowledge several additional limitations of this work. For example, the study's setting (i.e., the Sensory Room) may have influenced the results. Further experimentation in other settings (e.g., homes, schools) is necessary to better assess the overall potential of uCue and the setting's influence. The participant sample used while yielding promising results is small but appropriate for early design [32]. Similarly, many of our findings (e.g., heightened engagement) rely on parent observations as our study design lacked a direct comparison. While community members contributed to the design of uCue, further assessment of its therapeutic potential should be evaluated by controlled experiments, music therapists, educators, and other experts. We acknowledge the male-dominated participant pool, reflecting the 4:1 male-to-female ratio in ASD diagnoses [16]. Recruitment was not restricted by sex/gender and followed a first-come, first-served approach due to challenges in recruiting families with neurodivergent children [54]. No pre-study data were collected on participants' song preferences for the four songs, which may have influenced observed engagement. To address this, we interpret engagement patterns as indicative rather than conclusive evidence of uCue's effectiveness. Additionally, it remains unclear whether behaviors reflect genuine preferences, curiosity about the device, or prompted actions, highlighting the need for further investigation.

6.6 Future Work

uCue seeks to have a broad impact across local, regional, and national communities of children with ASD by inspiring new forms of musical creativity, listener engagement, and social interactions. uCue is designed to learn from local in-person interactions with children with ASD which can be expanded in several ways, including refining and extending uCue-supported activities to a larger and diverse population with wider range of learning objectives within music therapy, developing activities that encourage bonding between parents and children, reaching children beyond the local community members via new web-based interfaces, and studying the outcomes of their implementation. Incorporating parental feedback from this study—such as suggestions for casing designs tailored to a child's developmental stage—and co-designing with children as stakeholders could contribute to creating experiences that effectively balance engagement, accessibility, and usability. Utilizing systems like uCue to gather extensive data can nurture the musical talents of children with ASD, helping them develop a personal musical vocabulary enabling new questions related to designing and refining machine learning algorithms for enhanced personalization and optimized playback. The results from these pilot sessions pave the way for scaling the activities and technology to a larger platform to increase user access and evaluate the device in other contexts (e.g., at home and in schools) with population sizes appropriate for running controlled trials that will help generalize the results. These efforts can contribute to best practices for effectively and inclusively engaging composers of musical compositions, children with ASD and their parents, technologists, and other stakeholders in partner-driven research.

7 Conclusion

uCue provides a platform for engaging children with ASD in formative, participatory musical experiences and generating user data that can address various questions about listening preferences, emotional regulation, and social-skill development. As applied research designed to utilize the potential for HCI to inform scholarly and creative activity, this project opens new lines of inquiry within the field of autism studies. It provides a tool that can be adapted for use in a variety of listening contexts, including home, libraries, schools, hospitals, therapy sessions, and other social settings. By employing an interdisciplinary approach to addressing a societal problem, we explore a potential solution that integrates computer science, music theory, and composition, highlighting the mutually enriching nature of such collaborative efforts. uCue empowers its users to become composers as they listen and to express emotions as they experience sounds.

[18] Currently in production are "The Itsy Bitsy Spider", Bob Marley's "Three Little Birds", "Rain Rain go away" and "Pop goes the Weasel"

8 Selection and Participation of Children

Seven children participated in this study, aged 4–12 years, except one, whose age was 19 years (parent contacted research team regarding exception). Participants were recruited through email outreach, social media posts, direct verbal communication, and collaboration with community partners who shared recruitment messages via e-newsletters and social media platforms. Inclusion criteria required that a parent or legal guardian be present during all sessions. Children with auditory impairments were excluded. Recruitment followed a first-come, first-served basis to address challenges in enrolling families with neurodivergent children.

Prior to participation in the listening sessions at the Sensory Room, parents were provided with detailed information about the study's purpose, procedures, and data collection methods, and signed consent forms for their child's involvement. Children also provided assent after the researchers explained the study in age-appropriate terms. Each session lasted 60 to 90 minutes. To ensure ethical considerations, all sessions were conducted in a sensory-friendly environment (a sensory room at a local library), with the parent-child dyad present at all times. Data collection involved logging interaction data, audio and video recording the sessions and observational notes, which were all anonymized. Parents were informed that data would be securely stored and used solely for research purposes and would only be accessed by the members of the research team.

The study design was reviewed and approved by the Institutional Review Board (IRB) of University of Delaware (Protocol 2097325-1), ensuring adherence to ethical standards. Parents completed a consent process reviewing procedures, privacy, and data protection. Children, if able, participated in an assent process. Efforts were made to minimize any potential distress to participants, with flexible session pacing and the option to withdraw at any time was highlighted throughout sessions. Parent participants received digital Amazon Gift Cards for their participation, which included compensation for time and mileage.

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