SOUNDSCAPES OF THE MIND:

IDENTIFYING SOUND AND MUSICAL PREFERENCES IN CHILDREN WITH AUTISM SPECTRUM DISORDER IN RESPECT TO SOUND ENVELOPE, PITCH REGISTER, AND SOURCE

by

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A thesis submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Honors Degree in Applied Music Performance: Instrumental (Viola) with Distinction

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ABSTRACT

Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder that affects social communication, behavior, and self-regulation across emotional, motor, and verbal domains. Many individuals with ASD experience auditory sensitivities, which makes them more susceptible to experiencing a sensory overload which often triggers adverse reactions. Many individuals with ASD strongly resonate with certain kinds of music despite these sensitivities, while others may steer away from music education, performance, and therapy altogether to avoid uncomfortable stimuli. While people with ASD have varying opinions of music and sound, music therapy and intervention for children with ASD have been shown to lead to positive impacts, such as facilitating preference expression, communication, and more.

To better understand auditory preferences in children with ASD, I developed a survey featuring 30 sound samples that varied by sound envelope characteristics (ADSR: attack, decay, sustain, release), pitch register (high, medium, low), and source type (synthesized, acoustic, ambient) that was taken by 11 children with and without ASD. Results indicate that children with ASD show a stronger preference for slow decays, long sustains, and slow releases compared to their neurotypical peers. While both groups generally favored similar sound features, such as acoustic over

synthesized or ambient sources, the degree of preference varied significantly in some variable levels. Notable differences were observed in response to sharp and weak attacks, slow decays, long sustains, extreme release speeds, high pitch registers, and non-acoustic sound sources.

This study contributes to the growing body of research on auditory perception in individuals with ASD. Its findings may guide music therapists and educators in tailoring musical experiences that align more closely with the auditory preferences of children with ASD, thereby fostering more positive and effective outcomes in therapeutic and educational contexts.

Chapter 1

INTRODUCTION

General Background

For many people, listening to music stimulates positive emotions and thought processes, but what if sounds that are pleasant for many to hear are extremely overwhelming for others? Is there a way musicians could investigate what musical qualities create a positive or negative reaction for different populations or between individuals? For children with autism spectrum disorder (ASD), certain sound characteristics can lead to painful or overwhelming sensations, a phenomenon known as audio-sensory overload. Children with ASD often struggle with heightened audio-sensory sensitivity (Ludlow et al., 2014, Kellerman et al., 2005, Nieto Del Rincon, 2008, Samson et al., 2011). For these individuals, this sensitivity often can lead to difficulties in communicating with others, listening to music, watching a movie, or simply functioning in public settings that entail uncomfortable noises. When this population is surrounded by these uncomfortable noises that they cannot control, they experience sensory overload, which can cause meltdowns or other forms of negative reactions that signify a sense of being overwhelmed (NeuroLaunch, 2024). Although individuals with ASD may exhibit adverse reactions to certain sounds, both scholarly literature and personal observations, including both my own and those of others connected with members of the community, indicate that many individuals with ASD display a strong positive response to music (Molnar-Szakacs & Heaton, 2012). These observations and studies also suggest that music can facilitate emotional awareness, emotional regulation (Papoutsi et al., 2018), educational environments (Unwin et al., 2022), and many more benefits that will be discussed in this paper. Ultimately, musical experiences can cause ambivalent reactions for individuals, specifically children, with ASD. The question this study aims to investigate and open doors to start to answer are what kinds of sounds trigger both types of reactions, and what pitch, envelope, and source qualities are behind them. These findings will help to further contribute to general research findings regarding what kind of music is considered sensory friendly for children with ASD.

Previous Observations

Conducting research regarding musical accessibility for children with Autism Spectrum Disorder has been a goal of mine since I applied to the University of Delaware. Growing up as an avid musician with a younger brother on the autism spectrum, I often observed first-hand the adverse reactions he would have to musical and nonmusical sounds, including my practicing, solo and ensemble performances, and music playing in public spaces. While my brother did not typically demonstrate a positive response to musical sounds, many of his peers on the spectrum did. Some of his friends sang or played percussive instruments such as drums, bass, and guitar.

These anecdotal experiences reflect the observations found in the existing literature, which notes that some children with ASD are drawn to music despite potential for meltdowns or sensory overload.

Music as a Tool

While literature shows there is a variance in music therapy's effectiveness for children with ASD, a majority of the general findings point to positive effects for this population. This thesis seeks to open the door to research aiming to better understand which types of sounds create positive and negative reactions in children with ASD to maximize the effectiveness of music therapy and education. As the literature review will touch on, many children with ASD struggle with processing facial cues and expressions, and that missing them can often have a detrimental effect on their ability to socially interact and communicate (Sigman, Mundy, Ungerer, & Sherman, 1986). As music is purely auditory stimuli, facial cues are not taken into account when listening to and interpreting it. According to Caria et al.'s study, children with ASD's emotional processing remains intact when listening to music. This could be because music can induce different feelings through sounds, which are independent of facial cues. People with ASD's struggle to read and interpret facial cues (Gaigg, 2012) is a key reason why some members of this population struggle with emotion perception. Music's ability to transcend some challenges individuals with ASD face in interpreting facial cues makes it a possible tool for emotional expression and communication. Identifying the general qualities of sounds that elicit positive responses in children with ASD could significantly encourage participation in music therapy and education as well as making these settings more accessible for those with audio sensory sensitivities. in that finding avenues to make music listening a more positive experience through that do so.

How The Study Fits In

This combination of observations and studies of existing literature inspired me to devote all four years of my undergraduate experience to studying musical preferences for children with ASD through varying angles of children's songs, ambient noises, and more through different forms of application such as facilitating expressing preferences, working collaboratively, and teaching how to count. "Soundscapes of the Mind" contributes to this work by studying preferences for discrete sounds held by children with and without ASD. This thesis will examine if there are discernible sound preferences with respect to the envelope (attack, decay, sustain, and release), source, and register of discrete sounds through a survey taken by both children with ASD and without ASD. Both their individual and collective preferences are analyzed, and all conclusions drawn are from these participants' direct statements of preference. The goal of this study is to open the door to further research in this area, hopefully leading to future studies with more participants and specificity in the variable levels.

This study is a branch of a larger research project, "Music for Young Listeners with ASD." It explores how uCue, an interactive musical device, can assist children with ASD in music making while also informing musicians on their specific and general sound preferences. uCue's purpose is to give children with ASD an avenue to create enjoyable music that caters to their specific audio sensory needs. The music and autism research team consists primarily of our project leader, Abhishek Karwankar (Ph.D. student in the Computer and Information Sciences Department), our faculty advisors, Dr. Daniel Stevens (Interim Director of the School of Music), Matthew Mauriello (Assistant Professor in the Computer and Information Sciences Department), and me, an undergraduate music student. We collect and analyze the user interaction data recorded by uCue to determine which sound combinations seem to evoke a positive response for listeners and which ones do not. The data we have collected comes from a study in the Sensory Room at the Route 9 Library in New Castle, Delaware, The Brennen School in Newark, Delaware, and Marbrook Elementary in Wilmingtion Delaware. These studies, along with a more detailed origin story for uCue, can be found in Appendix A.

Once we collected this data, the goal was to share it with other musicians to inform them of such preferences, Abhishek created and lead a study with MusicVis, an interactive dashboard that encompasses the data. A description of this study can also be found in Appendix A. Through direct feedback from musicians, the data is displayed in a way that is comprehensible to musicians with minimal data analysis background. Instead of focusing on holistic songs, "Soundscapes of the Mind" intends to study simple, discrete sounds, focusing on bare-bones material to measure preference patterns in regard to levels of sound envelope, levels of pitch, and types of sound source. Seeing how discrete sounds measure up to sounds within the context of songs, and if these patterns stay consistent, will hopefully contribute to a more informed understanding in how to compose more music for uCue for further studies with it.

uCue

As music students, we had knowledge on music composition and production, but not building the device these songs would find a home in. Once the pieces were composed with the various layers, Dr. Matthew Mauriello, from the UD Department of Computer and Information Sciences (CIS), added the files to the software that he had coded within Unity so that they could be played using the prototype device he constructed in the Spring 2022. Matthew and the CIS team constructed the first prototype of the device using a 3D printer and available materials, such as rubber, LED lights, and duct tape.

> 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 Unity3D12 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. 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 (Karwankar et al. 5-7).

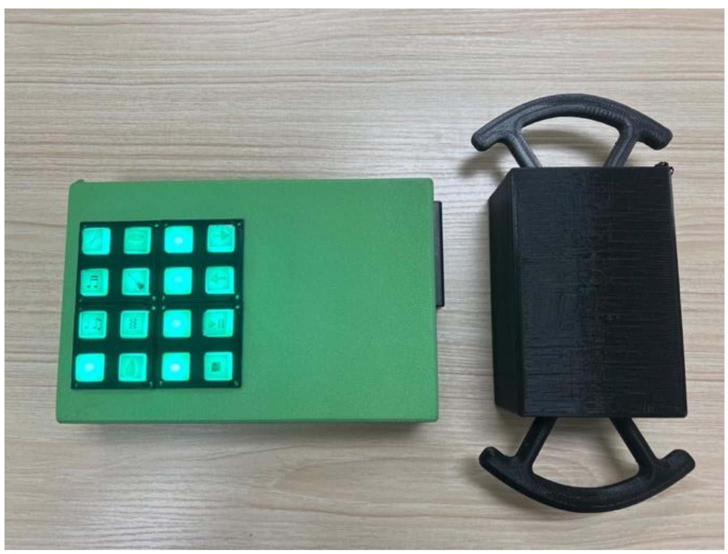
The four children's songs composed and produced by the music team were coded into the device that following summer and fall, with each button on the grid corresponding to changing layers within a track, changing the song, or pausing/playing it.

Table 1:
Overview of Layers on uCue Device (excluding option of silence), Karwankar et al. (2025)

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			

Fig. 1.
First uCue Prototype (2022)

Fig. 2
Latest uCue Prototype with Steering Wheel (2024)



During the first pilot study at the Sensory Room, which will be further discussed later in the paper, we worked with children who were nonverbal who struggled to communicate their preferences for the music they produced. In an attempt to transcend this communication barrier, the team created PECS (Picture Exchange Communication System) cards that corresponded to changing the layers, the songs themselves, pausing and playing the music, and general feelings towards the music coming from the device. The PECS cards are shown in the figure below.

New songs, such as “Rain Rain, Go Away,” “Pop! Goes the Weasel,” and “Hush Little Baby,” are currently in the works of being coded into uCue and will be used in studies starting in the Summer of 2025. In addition to these songs, others that teach counting and handwashing are currently in production, as feedback from past participants suggested that adding educational songs revolving around basic life skills may make the children more engaged in the learning process. Future ideas for songs in uCue include songs with varying ambient sounds for older populations and music from different cultures, as one participant in the study mentioned being drawn to percussive elements of Latin music that they listen to in the car.

Fig. 3.
PECS Cards for uCue (2023)

New songs, such as “Rain Rain, Go Away,” “Pop! Goes the Weasel,” and “Hush Little Baby” are currently in the works of being coded into uCue and will be used in studies starting in the Summer of 2025. In addition to these songs, songs that teach counting and handwashing are currently in production, as feedback from past participants suggested that adding educational songs revolving around basic life skills may make the children more engaged in the learning process. Future ideas for songs in uCue consist of songs with varying ambient sounds for older populations and music from different cultures, as one participant in the study mentioned being drawn to percussive elements of Latin music that they listen to in the car.

Hypothesis for This Study

Each of the studies within the "Music for Young Listeners with Autism" project has contributed to the growing work of understanding accessible music therapy and listening experiences for children with ASD. "Soundscapes of the Mind" contributes to this larger project by exploring preference levels for discrete sounds to more accurately pinpoint specific elements that may evoke a positive or negative reaction to music or other sound stimuli for individuals with and without ASD. The results of this study may further inform what sounds are used in future compositions and which sounds are better avoided. The primary goal of this study, like the other studies under this project umbrella, is to create a more accessible music listening experience for children with autism by learning about their individual and group specific musical preferences as listeners. Other goals for this study include identifying preference patterns regarding specific musical qualities for children with ASD and without ASD and then seeing whether having ASD influences these preferences by comparing the two groups. While individual preference data was not analyzed in this study, future research plans involve doing so.

Questions this research study seeks to answer revolve around similarities and differences in sound preference between children with and without ASD. Given the heightened audio sensory sensitivities many people with ASD have, I seek to understand whether the musical preferences of this population are similar or different to those without ASD. Are there variances within the ASD group's preferences, and if so, how drastic are they? Do people in the ASD group have more variance in their specific preferences than those without ASD? Is there a general preference for specific types of discrete sounds people with ASD like, and if so, how do they translate to a musical context?

Based on the uCue studies and other literature, I predict that children with Autism Spectrum Disorder will have different musical preferences than children without Autism Spectrum Disorder, but within these two groups, there will be a larger variance in preference in the group with ASD. Additionally, based on previous research and observations, it can be inferred that the group with ASD will prefer sounds with a lower pitch, more acoustic source, and sounds with a weaker attack and longer sustain levels more than the group without ASD. In regard to envelope, prior evidence suggests that despite having a strong variance in preference, children with ASD will generally prefer a weak attack, long decay, long sustain, and slow release due to the softness sounds with these qualities. Previous studies and observations show that children with ASD have a strong liking for low pitched sounds, percussion or cello specifically. If such preferences remain consistent in this study, then children with ASD will show a preference for sounds with a low register over high or medium. Finally, it can be inferred that the participants with ASD will have a preference for the acoustic sounds over the ambient or synthesized based on literature that states a liking for instrumental over environmental sounds, and the slightly harsher timbre rather than smooth.

In regard to my research question asking whether there are preferences for discrete sounds children with ASD express that remain consistent with their preferences for the sounds used in a simple melody, I am unsure of what to expect given that experiences of sound in a musical context can change the way they are perceived. Melodies encompass many outside factors discrete sounds do not, such as harmonic direction, changing pitches, and more. This context could impact a sound an individual previously stated they liked or disliked outside of the melodic context. In many respects, what the results of the survey suggest for this final question has the potential to generate new questions about how children with ASD perceive discrete sounds in both musical and nonmusical contexts. In sum, consistent with predictions for individual variables, I predict that children in both groups will prefer melodies whose individual tones share qualities consistent with those identified as preferential in the first part of the survey. Further, I predict that children with ASD will prefer the songs that have a low register, a weak attack, long decay, long sustain, and slow release over the songs with differing levels.

LITERATURE REVIEW

The research and literature regarding auditory preferences for children with ASD is minimal, while research on the benefits of music therapy for this population is quite high. Despite the varying levels of existing research, most of these studies are quite recent, as most have been published within the past two decades. This study attempts to build on this existing research while also opening new avenues of inquiry for future music therapy and preference research. There is minimal existing research regarding preference or if there is a general musical quality that makes a sound more "likable" or "unlikeable" to certain listeners.

The existing literature about musical and/or auditory stimuli, interventions, and sound sensitivities of children with ASD explores many different questions, including auditory processing, sound preferences, music therapy practices, and varying social and emotional responses. Within this field, studies involving music therapy for children with ASD and music preferences for individuals with auditory-sensory sensitivities are less common. This chapter reviews literature about sound preferences in children with and without ASD in order to better define the field of discourse to which this thesis contributes.

Music Preferences in Children with ASD

Current research suggests that those with ASD may more effectively be able to discriminate aural stimuli than those who do not have ASD. Heaton et al.'s 2005 study found that people with ASD have enhanced pitch, interval discrimination, and tonal memory. This study is supported by a study conducted by Masataka in 2017, where he found it is possible for children who have ASD to have a more developed ability to identify and make aesthetic conclusions when it comes to music, specifically classical music. In their 2003 study, Bonnel et al. found that individuals with ASD demonstrate a higher sensitivity to both musical timbre and pitch than those without ASD, however, there were more dramatic variants within the population group of individuals with ASD than those without. Other significant auditory processing trends individuals with ASD display include a preference for human-made or instrumental over environmental sounds (Cibrian et al. 2018), consonant over dissonant chordal structures (Bhatara et al. 2018), and non-vocal over vocal sounds (Michel et al. 2023). Heaton, Allen, and Hill (2009) conclude regarding general musical preferences in people with ASD that the word "power" corresponds to sounds with a fast speed and varying dynamics. Additionally, they found that individuals in the study showed a strong, unwavering preference for either energetic or calming music, showing consistency in their preferences. They also expressed positive feelings for a melody in tandem with other softer sounds. In the Cibiran 2018 study, the results also suggested that "children with autism stay more focused when listening to a melody being played with a cello in a low pitch." These results drawn by scholars along with anecdotal evidence interacting with and performing for listeners with autism suggest that the way those with ASD respond to such sounds is unique from each other and from those who do not have ASD and are a topic for further study.

Music Therapy for Children with ASD

Music has been proven to be a significant tool for promoting emotional regulation, awareness, and communication for people with ASD (Papoutsi et al. 2018). In their 2018 study, Johnston et al. found that some listeners with ASD displayed emotional recognition in musical stimuli through comparing neural activity within listeners with and without ASD. Quintin et al. conducted an investigation that found "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" (Quintin et al., 2011, p.11), which the author notes is consistent with Heaton et al.'s 2019 experiment's findings. This further shows that, similar to their neurotypical counterparts, people with ASD can identify emotions through music. Caria et al.'s study show fMRI studies that are consistent with this, in that for some people with ASD, the emotion processing area of the brain remains intact and corresponds accordingly with music listening. This is due to music's influence over emotions with the absence of facial cues; interpreting facial cues poses a common struggle for some individuals with ASD (Caria et al. 2011). Because those with ASD's emotional processing typically remain intact in music, music provides a solid avenue for the development of socioemotional skills. Because of the shared understanding of the emotional ties to music, music can serve as a catalyst for forming relationships with peers and family members (Bhatara et al. 2013). In both education and therapy, intact emotional comprehension lays a foundation for other skills, such as engaging in joint behavior with peers (Arezina 2011), attuned movement (Ragilo et al. 2011, p. 15), expressing positive emotions (Johnston et al. 2018, p. 7), initiating turn-taking (Villafuerte et al. 2011), and maintaining eye contact along with initiating interaction, which are common struggles for individuals with ASD (Geretsegger et al. 2014, p. 22).

According to Stegemann et al.'s 2019 study, these benefits of music therapy for children with ASD are shown in many recent studies. More specifically, they show that multi-sensory approaches can encourage those with ASD to engage with music in more than one way and offer a way for music therapists to engage in different levels of communication and interaction during the sessions (Mcgowen et al. 2021, Nonnis and Bryan-Kinns, 2019). z et al. found that music therapy can be more effective in multi-sensory environments in that clients can gain control over different elements of sensory stimuli in order to create conditions adequate for their best individual learning style (Unwin et al. 2022). Additionally, Shi et al. concludes that music therapy in multi-sensory settings improves mood, sensory perception, behavior, and social skills (Shi et al. 2016). Despite these findings, many current music therapy tools and practices for children with ASD often don't have the ability to adjust and adapt to their individual auditory processing needs and preferences, which prevents them from addressing the diverse spectrum of these needs and preferences (Johnston et al. 2018).

This study aims to identify what exactly these audial-sensory preferences are, and why they may occur, which could provide the first step to addressing this issue.

Measuring Preference in Children

How Dietz et al.'s 2020 study measured preference played a role in determining how preference was measured in this study. When it comes to children, whether they are considered neurotypical or neurodivergent, variables must be defined clearly and simply so they can understand what is expected of them in the study. In addition to stating the variables precisely, question formats should be stated in the most minimal way possible to maintain attention and ease comprehension. For example, Dietz et al. state that most measures for children fall into a bifurcated "This Or That" comparison or Visual Analog Scale (VAS), which uses the same format as a Likert-scale, only with images. Both measures are designed to reduce the cognitive load related to evaluating the stimulus for the child. One challenge associated with the bifurcated comparison is that it measures the child's preference of a stimulus in relation to another, rather than a standalone stimulus. The VAS also presents a challenge, in that the images presented often take away from what is actually being measured, as the child will gravitate toward the extreme positive end of the scale because they like the particular image associated with it.

This study combined these two methods, in having a bifurcated question structure, asking the participants whether or not they like the sound, and visuals, smiley and frowny faces, rather than words representing the answers. The number of questions included in the survey were also kept at a minimal number. In order to account for each possible level of each variable individually, over 80 questions would be needed. Due to the literature stating that "simpler is better," essentially, certain variables were combined, and the number of questions was narrowed down to 25 to increase engagement and attention.

Summary

These studies suggest that children with ASD have audio sensory preferences that are more extreme in sensitivity than those without ASD. This can often lead to an adverse or negative reaction to music. Despite this, it has been shown that music therapy evokes many developmental and educational benefits for children with ASD, making it an extremely valuable source for this population. Being able to incorporate music and sounds children with ASD state that they like, and excluding sounds that they do not, into educational, therapeutic, and performance settings can create a more accessible experience for this population. When asking questions to children regarding preference, literature suggests that limiting the number of options, preferably keeping it as a "This or That" question, and including pictures which are comprehensible to various education levels, are most effective. This study aims to contribute to this research by making suggestions regarding sound preferences for children with ASD and enforcing the importance that musicians keep these preferences in mind when conducting musical experiences for this population.

Chapter 2

DESIGN AND METHODS

This study is IRB-approved, with its approval number being 2240596-1 and its approval date being February 26th, 2025. Parents/Guardians and child dyads with children being between the ages of 5 and 13 and adults being 18 years or older were recruited to participate in this study through social media (Facebook, Instagram, LinkedIn), ResearchMatch, and partnerships with Autism Delaware and the Brennen School. Parents completing the online survey provided consent and confirmed child assent. Recruiting started on April 25th, 2025, and data stopped being considered in the final analysis after May 5th, 2025; the entire recruitment and data collection process lasted two weeks. The survey was online, administered via Qualtrics, and anonymous.

The study asked participants to complete a survey consisting of 30 questions about the child participant's listening preferences. The first 26 questions contained audio stimuli presented one at a time with varying levels of envelope, pitch level, and source. After playing the sound, the children were asked to express their preference for them by either clicking a green smiley face or red frowny face button labeled “I like this sound!” and “I don’t like this sound!” respectively. The last four questions apply these different variants of sounds in a musical context, with versions of “Twinkle

Twinkle, Little Star" containing levels of the variables. The children were asked to express their preference for the song with the same smiley and frowny face buttons.

Fig. 4.
Recruitment Flier Posted to Social Media and Emailed to Local Organizations (2025)

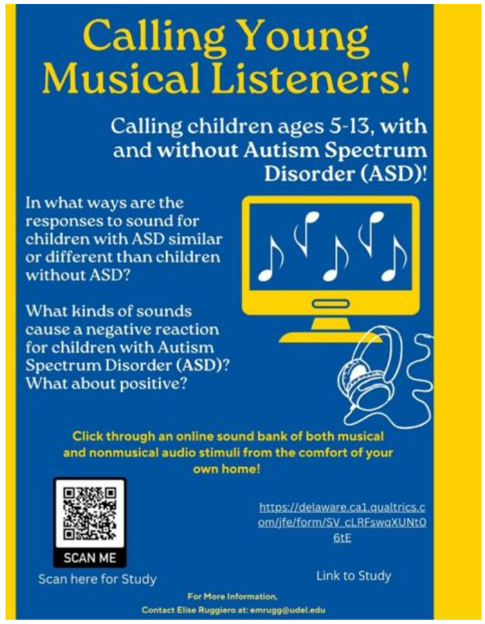
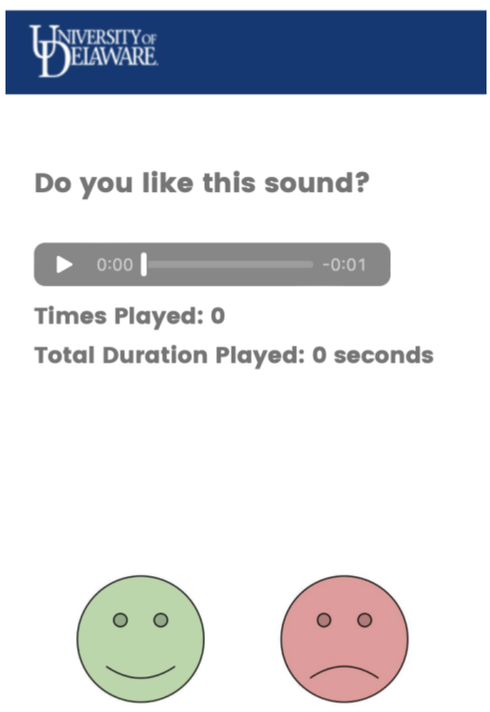


Fig. 5.
Survey Question Sample (2025)



Survey Construction

The survey was built using Qualtrics and consisted of one question per page. Parent participants were asked to provide consent to participate in the study, indicating that they have read and understood the description and that their data will remain completely anonymous in the analysis of the study and any future publications of this research. Due to the emphasis on the importance that the participants remained anonymous, nowhere on the survey asked for the child's specific age or other details. Given that the participants for this study were children, parent-child dyads were recruited for this study, and that the parent or guardian provided consent and confirmed the child assent. It was also expected, due to the age range of children for this study, that the parent or guardian would sit with the child as they took the survey. However, by nature of an online and anonymous survey—these details cannot be confirmed. Once the dyad provided consent, they were navigated to the study itself.

The auditory stimuli were presented as wav files that participants could play and pause at their own discretion. With the help of CIS members on the interdisciplinary research team, the program was coded to count both how many times each auditory-stimuli was played by the participants and how long they listened to them for as an attempt to further collect likability data; if the participant listens to a particular sound more times and for a longer amount of time, that indicates they liked the sound. Following listening to each sound, participants clicked on either a smiley or frowny face to express their preference for said sound. Once a face was selected, they hit the arrow button at the end of the page, bringing them to the next sound. They repeated this process for 26 questions, and then for the last 4 which included versions of "Twinkle Twinkle Little Star," that varied in both pitch, timbre, and envelope. The first 26 and then the last 4 questions were randomized for all the participants, but Qualtrics unrandomized the question order when presenting the results so that analysis could be conducted.

Envelope

In this study, envelope was measured using attack, decay, sustain, and release (ADSR), which is a method commonly used by music producers to manipulate sounds and musicians to measure them (Margulis 2007). Attack, decay, and release are typically measured as a percent or a ratio of sound over time. Attack is the slope of the start of the sound to the maximum height of the soundwave over time, decay is the slope of the maximum height of the soundwave to the end of the sound over time, and release is the slope of the end of the soundwave to complete silence over time. Sustain is the amount of time spent at the flattest part of the sound wave before it dies out into silence, and this is measured in decibels over time. In this study, the program "Waveform" by Qvantor was used to collect the synthesized versions of the sounds, as the program contains knob functions authentic to physical synthesizers that control levels of ADSR. Sharp attacks, fast decays, and fast releases were operationalized as anything less than 300 ms, and weak attacks, slow decays, and slow releases were defined as anything more than 600 ms. Medium attacks, decays, and releases were operationalized as anything between 300-600 ms. Short sustains were considered to be anything less than 30 decibels and long sustains were more than 60 decibels. The middle ground was removed for sustain measurements because of how few sounds fall into that category, and in discussing with music theorists, I decided to eradicate that level of measurement.

Pitch

Extremities were also used to distinguish between pitches, and the same note (pitch-class), C, was used for all the synthesized sounds to make sure the interval itself was not taken into account when participants stated their preference. High pitch was a C6, 2 octave groups above what is considered “Middle C,” for synthesized sounds, and for the ambient and acoustic levels, sounds or instruments that play in that general range (C5-C7; 1-3 octaves above Middle C) were considered high for the purpose of this study. Medium pitch centered around C4, which is Middle C, with the sounds playing variants of that pitch for the synthesized level and surrounding pitches for acoustic. Low pitch revolved around C2, two octaves below Middle C. While acoustic sounds did not exclusively stay on these variants of the note C, sounds that had minimal range were chosen so that the pitch levels were distinguishable from each other, and each audio stimulus noticeably fit into one of the three categories.

Source

The levels of source that were used in this study were synthesized, acoustic, and ambient. Synthesized sounds were gathered using the piano synthesizer provided on Waveform. Acoustic sounds were orchestral instruments, such as violin, flute, trumpet, trombone, clarinet, and cello. Ambient noises that were chosen were ones that notably varied in pitch and envelope from each other, and they were also pulled from the bank of suggestions from participants in previous uCue studies. The ambient sounds included consisted of a "boing," a bubble popping, a car running, a car tire squealing, a cash register "ding," a train whistle, a heartbeat, a wave, and running water. This variable was being tested due to Cibrian et al.'s 2018 study that individuals with ASD preferred instrumental over environmental sounds, and the findings from the Sensory Room study which suggested a strong preference for the running water sound and a general aversion from the city traffic sound, which sounds similar to the wave sound chosen for this study.

Auditory-Stimuli Collection

As stated in the previous section, Waveform was used to collect the synthesized sounds and to manipulate the envelope and pitch levels. These sounds were captured using the program Audacity, and these wav files were dropped into the Qualtrics survey. The program Epidemic Sound was used to collect the ambient sounds, and if needed, these sounds were cropped using Audacity to keep them concise for the purpose of the study. The website Noiiz was used for the acoustic instrument samples, which were also cropped using audacity if the short melodic sample exceeded 8 seconds. The melodies that were chosen for the study were the ones kept to a minimal range and had a short duration.

MuseScore 4 was used to compose and produce the short "Twinkle Twinkle, Little Star," melodies. I was able to incorporate varying levels of ADSR by using features such as dynamic controls and articulation marks. To create as few variations as possible while also accounting for the large number of levels each variable contained, one version of the song had sharp and short notes played by a high pitched instrument (piccolo), another version had this sharp and short melody played by a low pitched instrument from different family (cello) to account for timbre. There were also longer and more sustained versions of these melodies played by the same instruments, equating to four different melodies.

Table 2.
Overview of Sounds Used in Survey (2025)

Sounds	Attack	Decay	Sustain	Release	Register	Types
Q1 **C6**	Sharp	Slow	Long	Slow	High	Synthesized
Q2 **C4**	Sharp	Slow	Long	Slow	Medium	Synthesized
Q3 **C2**	Sharp	Slow	Long	Slow	Low	Synthesized
Q4 **C6**	Weak	Slow	Long	Slow	High	Synthesized
Q5 **C4**	Weak	Slow	Long	Slow	Medium	Synthesized
Q6 **C2**	Weak	Slow	Long	Slow	Low	Synthesized
Q7 **Boing**	Sharp	Fast	Short	Fast	Low	Ambient
Q8 **Bubble**	Sharp	Fast	Short	Fast	Medium	Ambient
Q9 **Car**	Weak	Slow	Long	Slow	Low	Ambient
Q10 **Car Screech**	Sharp	Slow	Long	Fast	High	Ambient
Q11 **Cash Register**	Sharp	Fast	Short	Fast	High	Ambient
Q12 **Heartbeat**	Sharp	Slow	Short	Fast	Low	Ambient
Q13 **C4**	Weak	Slow	Long	Fast	Medium	Synthesized
Q14 **C6**	Weak	Slow	Long	Fast	High	Synthesized
Q15 **C2**	Weak	Slow	Long	Fast	Low	Synthesized
Q16 **C6**	Medium	Slow	Long	Medium	High	Synthesized
Q17 **C4**	Medium	Slow	Long	Medium	Medium	Synthesized
Q18 **Train**	Sharp	Slow	Long	Slow	Medium	Ambient
Q19 **Stream**	Weak	Fast	Long	Slow	Medium	Ambient
Q20 **Wave**	Sharp	Slow	Long	Fast	Low	Ambient
Q21 **Violin**	Sharp	Fast	Long	Medium	High	Acoustic
Q22 **Cello**	Weak	Slow	Long	Slow	Low	Acoustic
Q23 **Flute**	Sharp	Fast	Short	Fast	High	Acoustic
Q24 **Trumpet**	Sharp	Slow	Long	Fast	High	Acoustic
Q25 **Trombone**	Medium	Fast	Short	Fast	Low	Acoustic
Q26 **Clarinet**	Medium	Medium	Long	Slow	Medium	Acoustic
Q27 **Piccolo**	Sharp	Fast	Short	Fast	High	Acoustic
Q28 **Cello**	Sharp	Medium	Short	Fast	Low	Acoustic
Q29 **Cello**	Weak	Slow	Long	Slow	Low	Acoustic
Q30 **Piccolo**	Weak	Medium	Long	Slow	High	Acoustic

Chapter 3

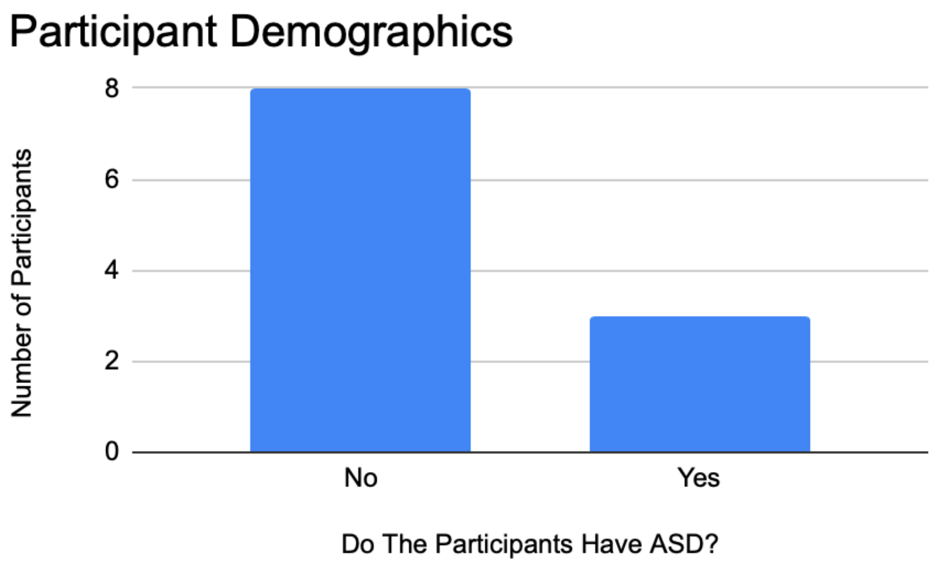
RESULTS

This section shows the results of 11 participants' preference data. 3 of these participants have ASD, and 8 do not have ASD. For this analysis, these groups will be referred to as the ASD and nonASD groups. While the number of times the participant played each sound sample and how long they listened to the sample were going to be analyzed, there was an issue in recording this data through Qualtrics. Due to this issue, these data points will not be analyzed or considered when looking at the rest of the data. Preference data for envelope (ADSR) level, pitch register (high, medium, low), and source type (synthesized, ambient, acoustic) are analyzed both separately for each group and in total. Specific sound samples that particularly evoked a general positive or negative reaction for one or both groups are also looked at.

The unbalanced groups (3 ASD, 8 nonASD) are taken into account with this analysis, as Welch Independent Samples, between groups T-Tests were used to determine statistical significance between the two groups for each sound variable level. The direction and strength of the relationship results are determined by the t-value. When the value is negative, which each are in this data, it indicates that there is a higher level of likability in the ASD group than the nonASD group. The further the number is from 0, the larger the difference is. When the p-value is less than or equal to 0.05, the results are considered statistically significant. Shapiro-Wilk tests were also run and show that the significant results show a deviation from the normality. These results show that the two groups were unequal, which is why Welch Independent Samples T-Tests were conducted to determine significance rather than the typical Student Independent Samples T-Test. These statistical tests were conducted using JASP. Cohen's d, measuring for effect size, are all over -0.8, considering them to be a large effect size, showing a large deviation between the groups.

Participant Demographics

Fig. 6.
Bar Graph Depicting Participant Demographics (2025)

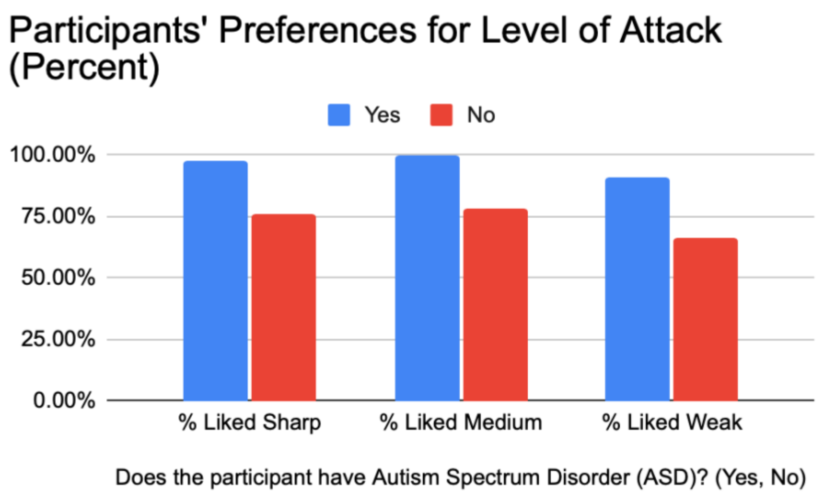


Although there was a big push for recruitment for both children with and without ASD, the groups in this analysis are unbalanced, with 8 participants without ASD and 3 participants with ASD.

Envelope

Attack

Fig. 7.



Independent Samples T-Test ▾

Independent Samples T-Test

	t	df	p	Cohen's d	SE Cohen's d
Liked Sharp (15)	−2.210	7.793	0.059	−1.126	0.733

Note. Welch's t-test.

Assumption Checks

Test of Normality (Shapiro-Wilk)

Residuals	W	p
Liked Sharp (15)	0.713	< .001

Note. Significant results suggest a deviation from normality.

Descriptives

Group Descriptives

	Group	N	Mean	SD	SE	Coefficient of variation
Liked Sharp (15)	no	8	11.625	3.777	1.335	0.325
	yes	3	14.667	0.577	0.333	0.039

Independent Samples T-Test ▾

Independent Samples T-Test

	t	df	p	Cohen's d	SE Cohen's d
Liked Weak (11)	−2.530	8.817	0.033	−1.394	0.761

Note. Welch's t-test.

Assumption Checks ▾

Test of Normality (Shapiro-Wilk) ▾

Residuals	W	p
Liked Weak (11)	0.927	0.382

Note. Significant results suggest a deviation from normality.

Descriptives

Group Descriptives

	Group	N	Mean	SD	SE	Coefficient of variation
Liked Weak (11)	no	8	7.250	2.605	0.921	0.359
	yes	3	10.000	1.000	0.577	0.100

Participants' Preferences for Level of Attack: Bar Graph and Statistically Significant T-Tests (2025)

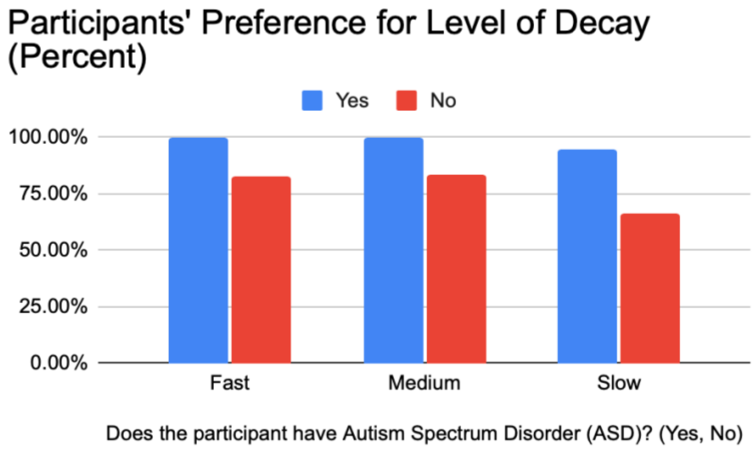
Both the sharp attack and weak attack levels showed statistical significance between the ASD and nonASD groups, where there was no significant difference for the medium attack. 15 of the sound samples were considered to have a sharp attack, with the mean likability for the nonASD group being 11.625 out of the 15 and 14.667 for the ASD group. The t-value is -2.210, showing that the ASD group preferred the sharp attacks slightly more than the nonASD group. There was not much deviation from the mean for the ASD group, while the nonASD group had more variance in their preference for the sharp attacks. The p-value is 0.059, which based on the data distribution, this study will consider the differences in sharp attack preference as statistically significant.

There is more of a statistically significant difference between the ASD and nonASD groups for the weak attack sounds, as the p-value is 0.033. Out of the 11 total sounds that were classified as having a weak attack, the average preference for the ASD group was 10 out of the 11 and 7.25 for the nonASD group. Despite the difference in preferences between each group, the percentage of individuals who liked the weak attack sounds was significantly lower than the sharp and medium attacks for both groups, showing that all the children in the study liked the weak attack sounds less than the others.

Decay

Fig. 8.

Participants' Preference for Level of Decay: Bar Graph and Statistically Significant T-Test (2025)



Independent Samples T-Test ▾

Independent Samples T-Test

	t	df	p	Cohen's d	SE Cohen's d	95% CI for Cohen's d Lower	95% CI for Cohen's d Upper
Slow Decay (19)	−2.885	6.769	0.024	−1.710	0.801	−3.267	−0.069

Note. Welch's t-test.

Assumption Checks

Test of Normality (Shapiro-Wilk)

Residuals	W	p
Slow Decay (19)	0.959	0.757

Note. Significant results suggest a deviation from normality.

Descriptives

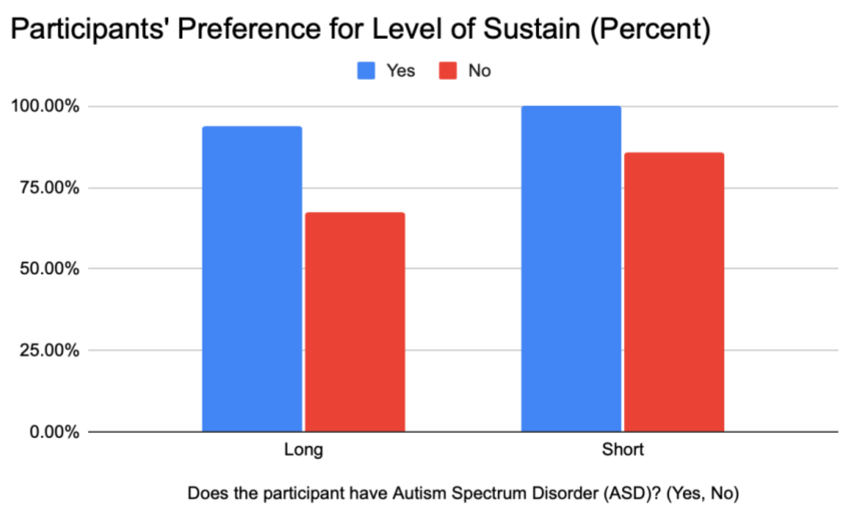
Group Descriptives

	Group	N	Mean	SD	SE	Coefficient of variation
Slow Decay (19)	no	8	13.750	3.059	1.082	0.222
	yes	3	18.000	1.732	1.000	0.096

There was no statistical significance between the two groups for the fast and medium decay levels. The ASD group showed a stronger preference for the decay sounds than the nonASD group. The slow decay level showed statistical significance (p=0.024) while the other two levels did not. On average, the ASD group liked the slow decay sounds more than the nonASD group with the former group liking 18 of the 19 sounds on average and the latter liking 13.75. Despite these numbers, both groups liked sounds with a slow decay substantially less than sounds with a fast or medium decay.

Sustain

Fig. 9.
Participants' Preference for Level of Sustain: Bar Graph and Statistically Significant T-Test (2025)



Independent Samples T-Test

Independent Samples T-Test

	t	df	p	Cohen's d	SE Cohen's d	95% CI for Cohen's d Lower	95% CI for Cohen's d Upper
Long Sustain (22)	−2.988	8.988	0.015	−1.601	0.786	−3.082	−0.054

Note. Welch's t-test.

Assumption Checks

Test of Normality (Shapiro-Wilk)

Residuals	W	p
Long Sustain (22)	0.979	0.960

Note. Significant results suggest a deviation from normality.

Descriptives

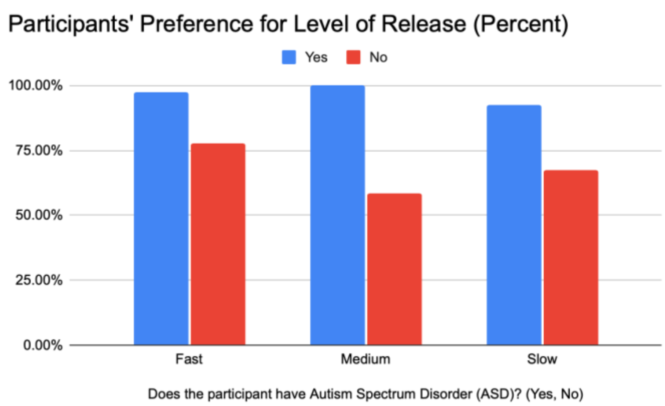
Group Descriptives

	Group	N	Mean	SD	SE	Coefficient of variation
Long Sustain (22)	No	8	14.875	4.883	1.726	0.328
	Yes	3	20.667	1.528	0.882	0.074

While evident that both groups preferred sounds with a short sustain over a long sustain, the short sustain variable did not show statistical significance between the two groups. The long sustain level showed statistical significance (p=0.015), showing a large difference in preference between the ASD and nonASD groups. There is a large standard deviation for the nonASD group though, which suggests that there are strong individual preferences within this level.

Release

Fig. 10.
Participants' Preference for Level of Release: Bar Graph and Statistically Significant T-Tests (2025)



Independent Samples T-Test

Independent Samples T-Test

	t	df	p	Cohen's d	SE Cohen's d	95% CI for Cohen's d Lower	Upper
Fast Release (14)	−2.265	7.974	0.053	−1.159	0.736	−2.569	0.311

Note. Welch's t-test.

Assumption Checks

Test of Normality (Shapiro-Wilk)

Residuals	W	p
Fast Release (14)	0.701	< .001

Note. Significant results suggest a deviation from normality.

Descriptives

Group Descriptives

	Group	N	Mean	SD	SE	Coefficient of variation
Fast Release (14)	No	8	10.875	3.357	1.187	0.309
	Yes	3	13.667	0.577	0.333	0.042

Independent Samples T-Test

Independent Samples T-Test

	t	df	p	Cohen's d	SE Cohen's d	95% CI for Cohen's d Lower	Upper
Slow Release (14)	−2.916	8.996	0.017	−1.577	0.783	−3.052	−0.035

Note. Welch's t-test.

Assumption Checks

Test of Normality (Shapiro-Wilk)

Residuals	W	p
Slow Release (14)	0.970	0.886

Note. Significant results suggest a deviation from normality.

Descriptives

Group Descriptives

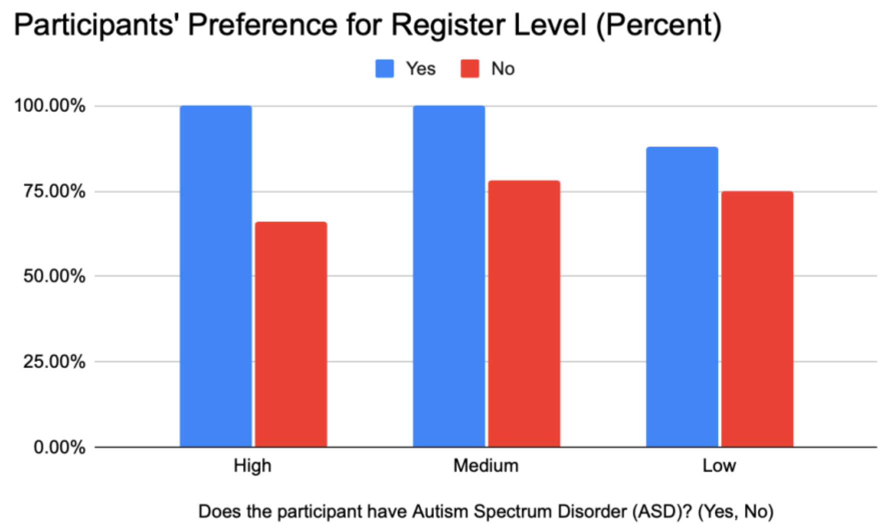
	Group	N	Mean	SD	SE	Coefficient of variation
Slow Release (14)	No	8	9.500	2.976	1.052	0.313
	Yes	3	13.000	1.000	0.577	0.077

For both groups, there was a general preference for fast and medium releases over slow releases. The fast release level's statistical significance is debatable, with the p-value being 0.053. The results are considered statistically significant in this paper. The ASD group liked the fast release level more than the nonASD group, with an average likability of 13.667 out of 14 while the nonASD group only expressed an average likability of 10.875. While the data for medium release looks like it would be significant, only 2 of the 30 sounds were classified as having a medium release, making the standard deviation quite large and difficult to adequately interpret within the bounds of this study.

The slow release level showed a strong statistical significance ($p=0.017$), in that the ASD group preferred the slow release sounds more than the nonASD groups, with an average likability of 13 out of 14 and 9.5 out of 14, respectively. It is important to note, however, the drop in the ASD's preference for the slow release over the fast and medium, which appear to be very similar. In general, both groups preferred the fast release over the slow release.

Pitch Register

Fig. 11.
Participants' Preference for Register Level: Bar Graph and Statistically Significant T-Tests (2025)



Independent Samples T-Test ▾

Independent Samples T-Test

	t	df	p	Cohen's d	SE Cohen's d	95% CI for Cohen's d Lower	95% CI for Cohen's d Upper
High Register (11)	−3.366	7.000	0.012	−1.683	0.797	−3.226	−0.059

Note. Welch's t-test.

Assumption Checks

Test of Normality (Shapiro-Wilk)

Residuals	W	p
High Register (11)	0.872	0.082

Note. Significant results suggest a deviation from normality.

Descriptives

Group Descriptives

	Group	N	Mean	SD	SE	Coefficient of variation
High Register (11)	No	8	7.250	3.151	1.114	0.435
	Yes	3	11.000	5.774×10^{-8}	3.333×10^{-8}	5.249×10^{-9}

Independent Samples T-Test

Independent Samples T-Test

	t	df	p	Cohen's d	SE Cohen's d
Low Register (11)	−1.076	6.939	0.318	−0.634	0.695

Note. Welch's t-test.

Assumption Checks

Test of Normality (Shapiro-Wilk)

Residuals	W	p
Low Register (11)	0.918	0.306

Note. Significant results suggest a deviation from normality.

Descriptives

Group Descriptives

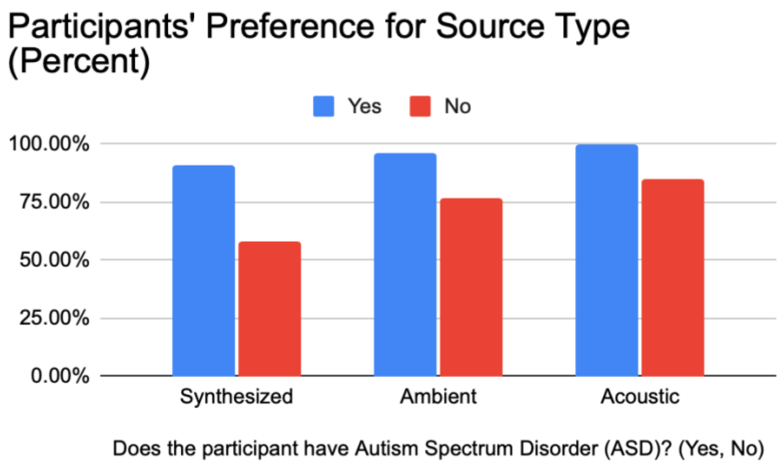
	Group	N	Mean	SD	SE	Coefficient of variation
Low Register (11)	No	8	8.250	2.765	0.977	0.335
	Yes	3	9.667	1.528	0.882	0.158

There was a strong statistical significance between the ASD and nonASD groups within the high register level, with the p-value being 0.012. Each member of the ASD group stated they liked every sound with the high register, while the nonASD's average likability for the high register sounds was 7.25 out of 11. The data for the medium register sounds was not statistically significant, however both of these groups showed the highest level of likability for this range. While the low register level did not show statistical significance between the two groups, the ASD group reported a lower likability than the high register. The nonASD group reported a higher likability rate for the low register than the high register, showing a difference in preference between the groups where register is concerned.

Source Type

Fig. 12.

Participants' Preference for Source Type: Bar Graph and Statistically Significant T-Tests (2025)



Independent Samples T-Test

Independent Samples T-Test

	t	df	p	Cohen's d	SE Cohen's d	95% CI for Cohen's d	
						Lower	Upper
Ambient Source (9)	−2.331	8.939	0.045	−1.240	0.745	−2.654	0.231

Note. Welch's t-test.

Assumption Checks

Test of Normality (Shapiro-Wilk)

Residuals	W	p
Ambient Source (9)	0.895	0.160

Note. Significant results suggest a deviation from normality.

Descriptives

Group Descriptives

	Group	N	Mean	SD	SE	Coefficient of variation
Ambient Source (9)	No	8	6.875	1.959	0.693	0.285
	Yes	3	8.667	0.577	0.333	0.067

Independent Samples T-Test

Independent Samples T-Test

	t	df	p	Cohen's d	SE Cohen's d	95% CI for Cohen's d	
						Lower	Upper
Synthesized Source (11)	−2.565	6.214	0.041	−1.547	0.780	−3.075	0.066

Note. Welch's t-test.

Assumption Checks

Test of Normality (Shapiro-Wilk)

Residuals	W	p
Synthesized Source (11)	0.940	0.522

Note. Significant results suggest a deviation from normality.

Descriptives

Group Descriptives

	Group	N	Mean	SD	SE	Coefficient of variation
Synthesized Source (11)	No	8	6.375	2.825	0.999	0.443
	Yes	3	10.000	1.732	1.000	0.173

For the synthesized source type level, the difference between the ASD and nonASD groups was statistically significant (p=0.041). The ASD group preferred the synthesized sounds significantly more than the nonASD group, although both groups seemed to like this level the least of the three. The ASD group also preferred the ambient sound level more than the nonASD group, and there is statistical significance between both groups, with the p-value being 0.045. Both groups showed a higher likability for the ambient sounds over the synthesized sounds. There was no statistically significant difference between the two groups when it came to the acoustic level. This level had a high likability level for both groups, scoring the highest of all the variables and levels besides short sustain. When comparing it to the other data, it can be concluded that despite variance in pitch register and envelope, both groups preferred the acoustic instrumental sounds over the rest.

Songs

Table 3.
Variants of "Twinkle, Twinkle, Little Star," (2025)

Questions	Participants With ASD's Preference	Participants Without ASD's Preference	Total Preference
Q27 - Piccolo (sh,fa,sr,fa-hi-aco)	100.00%	87.50%	**90.91%**
Q28 - Cello (sh,md,sr,fa-low-aco)	100.00%	87.50%	**90.91%**
Q29 - Cello (we,sl,lo,sl-low-aco)	100.00%	87.50%	**90.91%**
Q30 - Piccolo (we,md,lo,sl-hi-aco)	100.00%	75.00%	**72.73%**

These short songs contained half of "Twinkle, Twinkle, Little Star" with varying envelope, instrument, and timbre, which describes the quality of sound for the instruments. For example, the piccolo would be considered to have a "bright" sound while the cello would be considered "warm." Each individual in the ASD group liked all four versions of the song, and while not individuals in the nonASD liked all the songs, percentage of likability for each version of the song remained the same, with the exception of Q30, which combines a high register with a weak attack, medium decay, long sustain, and slow release.

Significant Preferences for Combinations of Variables

Low Preferences

Table 4.
Sounds That Had the Lowest Preference Rate (2025)

Questions	Participants With ASD's Preference	Participants Without ASD's Preference	Total Preference
Q1 - C6Synth (sh,sl,lo,sl-hi-syn)	100.00%	25.00%	**45.45%**
Q6 - C2Synth (we,sl,lo,sl-low-syn)	100.00%	37.50%	**45.45%**
Q9 - Car (we,sl,lo,sl-low-amb)	66.67%	75.00%	**72.73%**
Q10 - Car Squeal (sh,sl,lo,fa-hi-amb)	100.00%	37.50%	**54.55%**
Q15 - C2Synth (we,sl,lo,fa-low-syn)	66.67%	62.50%	**63.64%**

Overall, the sounds that scored the lowest in likability were the ones that contained the combination of a slow decay and a long sustain for either a medium or high pitch level. These sounds either came from a synthesized or ambient source.

High Preferences

Table 5.
Sounds That Had the Highest Preference Rate (2025)

Questions	Participants With ASD's Preference	Participants Without ASD's Preference	Total Preference
Q11 - Cash Register (sh,fa,sr,fa-hi-amb)	100.00%	100.00%	**100.00%**
Q18 - Train (md,sl,lo,md-hi-syn)	100.00%	100.00%	**100.00%**
Q22 - Cello (we,sl,lo,sl-low-aco)	100.00%	100.00%	**100.00%**
Q23 - Flute (sh,fa,sr,fa-hi-aco)	100.00%	100.00 %	**100.00%**

Every participant in this study, both with and without ASD, stated that they liked these sounds. Q11 and Q23 have the same levels of envelope and pitch, with the only difference of levels being source type. There does not seem to be a pattern between Q18 and Q22, besides that they have slow decays and long sustains. Q22 is interesting in that it has the same variable levels as Q6 and Q9, with the only difference of levels being source type. Q22 is acoustic rather than synthesized or ambient.

Chapter 4

DISCUSSION

The data collected supports some hypotheses but not others. I predicted that there would be differences in preference between the ASD group and nonASD group, and the results do show that the ASD group liked the sounds more than the nonASD group did, having a higher general likability rate for each variable and level. Another prediction from this study was that there would be more variance of preferences in the ASD group than the nonASD group, but the data supports that the opposite is true; however, this could be due to the larger sample size of nonASD participants. For envelope, it was predicted that participants in the ASD group would have a preference for weak attacks and long sustain levels. There was a significant difference of likability between ASD and nonASD participants, with the ASD group in fact expressing more of a preference for these types of sounds than the nonASD group. Despite these statistics, both ASD and nonASD groups preferred strong and medium attacks over weak attacks, and short sustains over long sustains. The study also predicted that low registers and acoustic source types would be more strongly and consistently preferred by the ASD group. While the ASD group did have a stronger preference for than the nonASD group, the results were not statistically significant, as the nonASD group also had a strong likability for these variable levels. All of the

Cohen's d values being greater than -0.08 shows that the data between the ASD and nonASD groups noticeably differ from each other.

Envelope

Attack

The hypothesis stated that the ASD group would have a stronger preference for the weak attacks than the nonASD group, and that they would prefer the weak attacks over strong and medium attacks. The results show that there is a significant difference in preference for weak attacks for the ASD group than the nonASD group, which supports this element of the hypothesis. In addition, the results also show that the ASD group had a stronger preference for the sharp attacks than the nonASD group, although these results are barely considered significant. This may simply suggest that the participants in the ASD group liked the sounds more than the participants in the nonASD group, although it cannot be confirmed due to the unequal groups and small sample size.

The part of the hypothesis that predicted the ASD group would prefer weak attacks over strong and medium attacks is not supported by this data. The results show that both ASD and nonASD groups preferred the sounds with strong or medium attacks over the weak attacks. The ASD group state an average liking of 14.667 out of the 15 sounds with sharp attacks, while their average liking for the sounds with weak attacks is 10 out of the 11 sounds. The preference for each may not greatly differ, but the small sample size could be a contributing factor.

Decay

Due to the softness of sounds that have a longer decay, it was predicted that the ASD group would have a higher preference for sounds with a long decay than a short or medium decay. There was a significant difference in preference for long decay between the ASD and nonASD groups, with the ASD group, on average, preferred 18 out of the 19 sounds. The nonASD only preferred an average of 13.75 of the 19 sounds. The original hypothesis did not touch on a difference in preference between the two groups for sounds with a long decay. Despite these results not originally being considered, children with ASD having a higher likability for sounds with a long decay aligns with studies which touch on audial processing delays that many children with ASD have (Boets et al., 2014, Jorgensen et al., 2021). Sounds that take a longer amount of time to decay gives individuals with ASD more time to process the sound, while individuals without ASD may not care for that extra time.

Despite these results, the data suggests that the ASD group may have preferred the sounds with a long decay more than the nonASD group, but out of the three levels, the ASD group preferred the sounds with the short and medium decays the most. The participants preferred 100% of sounds with these levels, while only preferring 94.74% of the slow decay sounds. The small sample size does question the validity of these results, so no solid conclusion can be drawn from these results regarding preferring one level of decay over another.

Sustain

This study predicted that, like decay, the ASD group would prefer sounds with long releases more than the nonASD group. The other prediction regarding sustain level was that the ASD group would prefer songs with long sustain levels over short sustain levels. The data supports the first prediction, showing a strong statistically significant difference between the ASD and nonASD groups' preferences for sounds with a long sustain. Due to the ASD group's average preference for the long sustain sounds being 20.667 out of 22, and the nonASD group's average being 14.875 out of 22. Reasons for the ASD group liking sounds with long sustains more than the nonASD group could be similar to the proposed explanation regarding audio processing for decay.

There was also a larger standard deviation for the nonASD group (4.883) than the ASD group (1.528), which rejects the hypothesis that there would be a larger variance in the ASD group's preferences. Another element of the hypothesis that the data does not support is that the ASD group would prefer sounds with long sustains over the ones with short sustains. Each participant with ASD stated that they liked every sound with a short sustain, making the average likability 100%. The ASD group's average likability for the long sustains was 93.94%. While these results are not what we hypothesized, it is sensible that a sound that is sustained for a distinguishably long amount of time may be overwhelming to some listeners and cause a sensory overload. Additional studies producing supporting data would be needed to confirm this possible reason, as the minimal number of participants does not allow these findings to be generalized.

Release

There was no hypothesis for a variance in preference between the ASD and nonASD groups regarding release, but the results show a weak statistically significant difference between the two groups for sounds with a fast release and a strong difference in those with a slow release. With regard to the difference in preference for the slow-release level, the ASD group's average likability for the sounds was 13 out of 14, and the nonASD group's was 9.5 out of 14. While not confirmed, the possible explanation for this could be delayed audio processing, with a slow release giving the listener time to hear the sound before processing and creating a gradual change from the end of the sustain to silence. This proposal is drawn from sources that suggest individuals with ASD often have adverse reactions to fast change (National Autistic Society, Morrison, 2023).

While individuals with ASD may be more tolerant of sounds that take a longer time to descend into silence than those without ASD, that does not mean they prefer these sounds over ones with a shorter release. While there is not a very large difference between the ASD group's average preference for the long, medium, and slow releases, the results do indicate a preference for a fast or medium release over slow. Like their nonASD peers, the participants with ASD preferred sounds with a fast or medium release over sounds with a slow release, although they do seem to have a more positive response to sounds with a slow release than the nonASD participants.

Pitch Register

Due to published studies and personal observations supporting children with ASD having a preference for low pitch registers over medium or high, this study hypothesized that the ASD group would show a higher preference for low register sounds than the nonASD group. It also hypothesized that the ASD group would have a higher likability rate than the medium and high register sounds. While there was a difference between the groups' preferences for low-register sounds, with the ASD group having a stronger preference, it is not statistically significant. The level that showed a statistically significant difference in preference was high-register sounds, which was not predicted. The ASD group liked all 11 sounds that were classified as having a high register, while the nonASD group, on average, liked 7.25 out of the 11. The standard deviation for the nonASD group is quite large, being 3.151, showing that there was variance in the nonASD group's preferences for the high register sounds. This data rejects the hypothesis that there would be more variability in the ASD group's preference data than the nonASD group's, however it is important to note that the nonequivalent groups and small sample size could have impacted these results.

The hypothesis that the ASD group would prefer low register sounds over the other levels is also not supported by the data, with an average likability for 9.667 out of the 11 sounds. The ASD group stated a likability for all 11 high register and all 8 medium register sounds. Overall, both groups showed the highest preference for the medium register sounds, revolving around the pitch C4. Further research studying pitch register preference is encouraged, considering many musicians initially gravitate towards learning distinguishably high or low instruments, the latter seemingly attracting more musicians with ASD than the former, than medium register instruments.

Source Type

Where source is concerned, the study predicted that the ASD group would have a stronger preference for the acoustic source level than the nonASD group. In addition, it predicted that the ASD group would have a more significant preference for the sounds with an acoustic source than the synthesized and ambient due to literature that finds a preference for instrumental over environmental sounds in this population. There was a notable statistical significance for the ASD and nonASD group's preferences for the synthesized and ambient sounds. While the ASD group had an average likability for 10 out of the 11 sounds, the nonASD group had an average likability of 6.375. This is quite a stark difference, which can possibly be explained by the nonequivalent groups, although additional research would need to be conducted in investigating why the nonASD group may have more of a distaste for synthesized sounds than the ASD group.

The ambient sounds were liked by both groups more than the synthesized sounds, which rejects the hypothesis that instrumental sounds would be preferred over environmental sounds. These results could then lead to an analysis of the envelope levels for the synthesized sounds, for maybe that is a contributing factor for the lower likability score. On average, the ASD group liked 8.667 of the 9 ambient sounds, and the nonASD group liked 6.875, showing a moderate difference between the groups' preferences. Further studies and analyses would be needed to determine whether envelope and pitch register levels influence the likability of different ambient sounds.

The hypothesis that the ASD group would prefer the acoustic source level over the synthesized and ambient is supported by the data. Both groups had the highest likability rate for the acoustic sounds, showing a preference for those over the synthesized and ambient. Despite the hypothesis only addressing the ASD group's preference for acoustic sounds, it is unsurprising that the nonASD group also showed the same preference. As both group's average likability rate were quite similar for the acoustic source, the difference between the two was not statistically significant. A possible reason for this could be the sound samples used for the acoustic instruments. While each audio file contains the instrument playing a limited number of notes, they are still playing more than one pitch, which could have made the sound more interesting for the children to hear than the other source's samples; this could have influenced their preference level, and further research would need to be done in order to draw more firm conclusions. The takeaway from the results regarding this variable is that both the ASD and nonASD groups had a preference for acoustic sounds over synthesized and ambient, with no statistical difference between their levels of preference.

Songs

While the hypothesis predicted that the preferences for the individual discrete sounds would translate to the songs, there was no significant difference in the preferences for each version across the two groups. The ASD group all stated that they liked all 4 samples, while the nonASD group did not, 87.50% of the group liked the first three songs (Q27-29), showing no difference in likability. 72.73% liked the fourth song (Q30) showing a dip in likability for the nonASD group. This could be the combination of weak attack, long sustain, and slow release, as the nonASD group showed a preference for strong attacks, short sustains, and fast releases. While there is no significant data from the ASD group, the nonASD group's data from Q30 supports the hypothesis that the preferences for the discrete sounds translate to the context of a song. Despite this, only one of the four questions showed this result, so this hypothesis cannot be supported or rejected. Rather, additional research will need to be conducted to further investigate these results.

Significant Preferences for Combinations of Variables

Low Preferences

As depicted in Table 4, the pattern identified in the sounds that scored the lowest in likability contained the combination of a slow decay and a long sustain. This was consistently the case for sounds with either a medium or high pitch register level and a synthesized or ambient source. When the sound had these decay and sustain combinations with a low register or an acoustic source, both groups' preferences drastically increased. This slow decay and long sustain combination scored lower for the ASD group when the attack was weak, and the register was low. Q6 and Q15 had the same levels for each variable except for release level, but the ASD group liked Q6 more than Q15, and the nonASD group liked Q15 more than Q6. Q6 has a slow release, where Q15 has a fast release. This difference and differing preferences across the two groups supports the conclusion drawn from the other data that the ASD group has a stronger preference for sounds with a slow release than the nonASD group. It also suggests that the nonASD group has a stronger preference for sounds with a fast release, which is not supported by the rest of the data and requires further study.

High Preferences

Table 5 shows the four sounds that every participant in the study, regardless of ASD diagnosis, stated they liked. The commonalities between Q11 and Q23 are that they have all of the same envelope levels and pitch register level. In regards of envelope, both sounds have sharp attacks, fast decays, short sustains, and fast releases, which is the polar opposite of what the study predicted would be preferred by the ASD population. Both groups strongly preferred sounds with these envelope levels, contradicting some existing literature and prior observations, both emphasizing variability for individuals' sound preferences and calling for future studies. Q18 and Q22's sole commonalities are the fact that they contain slow decays and long sustains, which is the combination that many of the disliked sounds possessed. With regard to an identifiable pattern, the difference between these liked sounds and the disliked sounds lies in the attack level. The disliked sounds had a sharp attack associated with their slow decay and long sustain, resulting in a sound that turns out to be quite strong and aggressive while remaining this way for a longer amount of time before it recedes. The liked songs with these levels of decay and sustain had weak and medium attack levels, suggesting a more gentle and gradual build up into the peak of the sound.

Q22 is interesting in that it has the same variable levels as Q6 and Q9, with the only difference of levels being source type. Q22 is acoustic rather than synthesized or ambient, and is played by a cello, an instrument that both literature and personal observations have found children with ASD particularly like. Because of this prior knowledge, it is not surprising that the cello sound was one of the highest preferred sounds. Further studies and analyses are needed to determine whether the distinguishable preference for the cello over other instruments is due to its timbre, pitch, natural envelope, or a combination of these variables. While the cello sound sample had a perceptively large likability, when put in the context of “Twinkle, Twinkle, Little Star,” there was no discernible preference for the versions played by the cello over the piccolo. Additional research with more participants and more variants of sound samples is needed to determine why this may be.

Chapter 5

HINDSIGHTS AND IMPLICATIONS

While this study produced interpretable data that was able to lead to conclusions about sound preferences for individuals with and without ASD, several aspects could have been done differently in order to strengthen the results.

What Could Be Done Differently

To ensure that participants were actively engaged for the duration of the study, certain combinations of the different variables had to be sacrificed. For example, the original goal was to ensure that no confounding variables got in the way of each individual level, in that there would be one sound designated for a sharp attack that was high pitched and acoustic, a sound for a sharp attack that was medium pitched and ambient, ect. When accounting for all of the different levels of attack, decay, sustain, release, pitch, and source, there would be 81 different sounds in the survey, not including the sounds being put into the context of a song at the end of the survey. Since the target population for this survey are children aged 5-13, 81 questions would ultimately prove to be excessive and unnecessary, while taking a lot of time to complete. This would run the risk of some studies going uncompleted for various reasons, such as a parent being busy, a child losing the desire to take the study, and much more. Additionally, other studies with child participants have reported that shorter studies have proven to be more effective and provide more reliable and usable data than longer studies due to the attention element, so keeping this study as brief as possible was the goal. I also did not request for the children and parents to set their listening devices to a particular volume, making volume a confounding variable that could have impacted certain individual's preferences for the sounds. Additionally, as this study was conducted asynchronously and anonymously, there is no way to confirm whether the child was the primary taker of the survey or their parent or guardian.

In order to account for this, many variables had to be either sacrificed or combined. For instance, some of the sounds collected had a sharp attack while also having a short sustain, or a long decay would have a longer sustain. While this does not test for preference specifically regarding levels of ADSR, certain combinations of these elements are seen in more popular sounds and go hand in hand, cutting down the number of questions needed. Additionally, when it came to pitch level, medium pitch was a variable that was sacrificed in the acoustic instrument department. This was due to the fact that many instruments that are considered "middle voices" have ranges large enough to play high, low, or both voices. As the medium pitch range was included in the synthesized sounds as well and is included in some of the acoustic instrument sound samples, it was not a difficult decision to cut down on those questions.

In regard to the short songs, “Twinkle, Twinkle, Little Star” played in contrasting levels of ADSR with a flute representing the high pitched instrument and the cello representing the low pitched instrument. This ultimately led to four different versions of the song. However, the timbre of the instruments is not a variable that is being tested in this case, as the high instrument and the low instrument come from two different groups (woodwinds and strings). A participant could state a liking for the low pitched song over the high pitched song due to being drawn to the lack of brightness string instruments have compared to winds, and this preference would be unidentifiable. Accounting for this would have doubled the amount of song samples needed and would have made the survey itself about two to three minutes longer, which could have posed issues in the attention span and timing of the study.

Another issue encountered with this study is a small sample size. Unfortunately, recruiting for the study exceeded the amount of time predicted, and the numbers received from each group were smaller than preferred for this study. This also led to nonequivalent groups, with the ASD group having less than half the members the nonASD group had. In future research, more time should be allotted to recruit a larger sample size with more evenly distributed groups of participants with and without ASD.

More time being allotted for the survey construction and distribution would also benefit solving the problem involving collecting data the amount of time the participant played the sound and the duration they listened to the sound for. The data collected for these variables did not translate properly, in that there was a mistake in the code for the final four questions involving the songs. In future research, these variables would be interesting to study, as a child playing a song more or listening to it longer could indicate a stronger preference for it.

Another aspect that can be conducted differently in the future is the collection of acoustic samples. The acoustic samples used in this study contained more than one pitch, although the range of pitches played was very minimal. The synthesized sounds only contained one pitch, indicating that it is possible the acoustic sounds were preferred over the synthesized ones due to the more engaging sound sample used.

Where it comes to the statistical analysis, I should have ran Levene's Test to check if the groups had similar variances in their preferences. To determine this, I analyzed the standard deviations, the effect sizes, and compared the likability percentages. However, running Levene's Test is a more reliable comparison of the data, and future studies should consider this analysis when comparing data between the groups.

Positive Outcomes

The distribution of the survey went smoothly, and it was accessible to all the participants who took it. No issues were posed while participants were actively taking the survey, suggesting that it was constructed in a clear manner for the ASD group, nonASD group, and their guardians. Additionally, while the original number of sound samples had to be cut down in the respect of time and attention span, there seemed to be an adequate distribution of the different variables, with the exception of the medium levels for certain variables. Despite this, it was most reasonable for the medium levels to have a reduced amount of samples rather than the surrounding extremes, as the potential for a central tendency bias naturally decreases. The data analysis was also quite efficient and reliable, as JASP conducted the Independent Groups T-Tests and provided an in-depth statistical analysis of the difference between the ASD and nonASD groups.

Ideas for Future Research

If this study were to be mimicked in future research, acoustic sound samples should be collected by live musicians rather than online samples of instruments. This could be done by collecting acoustic samples from peers and colleagues, asking different musicians to play the same note on their instrument various times with differing levels of articulation to account for envelope. The live recordings of these acoustic instruments would more accurately encompass what individuals hear in a concert, music therapy, or music education setting. The authenticity of these samples could further lead music researchers, therapists, and educators to drawing conclusions regarding the preferences for and accessibility of these instruments.

Future research would also benefit from a larger sample size and expanded variable testing. For example, volume was not looked at in this study, but a loud volume oftentimes causes adverse reactions to children with ASD, causing them to cover their ears or carry headphones with them. Despite this, members of the research team and I have heard through interacting with various individuals with ASD and their family members that they like loud sounds when they can feel the vibrations in their body, for instance, when there is a heavy bass or percussive level. These experiences support existing research indicating that multisensory engagement (e.g., hearing and feeling music) enhances the effectiveness of music therapy for children with ASD. Therefore, testing volume and multisensory aspects would be valuable directions for future research. Testing for volume as well as additional testing for these variables would be effective next steps to take in this research.

Chapter 6

CONCLUSION

Summary

From this study's data, it can be concluded that the children with and without ASD's sound preferences align in preferring certain variable levels over others, but their groups' preference for individual levels themselves differ from each other, many in a statistically significant way. The ASD and nonASD groups' variable preferences align in that, in regards to envelope, they prefer sharper attacks to weaker attacks, faster decays to slower decays, shorter sustains to longer sustains, and faster releases to slower releases. Where pitch register is concerned, both groups prefer higher over lower, and when looking at source, both groups have a strong preference for acoustic sounds over synthesized and ambient. Children with and without ASD's preferences differ when looking at each individual level, where statistical significance shows children with ASD have a higher preference than children without ASD for sharp and weak attacks, slow decays, long sustains, fast and slow releases, high registers, and ambient and synthesized sources. Their preferences differed from the nonASD group the most for the high pitch register and the long decay. This data suggests that children with ASD would have a more positive experience than those without ASD when listening to sounds that have a higher register and a gentler envelope, though still preferring the more abrupt envelope qualities.

While children without ASD may have less of a tolerance for sounds with a longer duration, including a slow decay, long sustain, and slow release, children with ASD still have a high preference for them despite liking their counterparts more. A reason behind this could be that many individuals with ASD take a longer time to process audio stimuli, and these levels of envelope allow for them to listen and process the sound before it ends. Another reason could be the extended amount of time it takes for the sound to change, reaching the different levels of the envelope, as studies show people with ASD often react negatively to change or disruption. These similarities and differences in preferences should be taken into consideration when arranging, performing, and choosing music for children with ASD, in that it will guide musicians into choosing more sounds that evoke positive emotions and avoid the sounds that evoke negative ones.

Next Steps

While the data collected in this study is statistically valid, it should not be exclusively used to draw any specific conclusions regarding sound preferences for children with ASD. The sample size for this study was small, and the ASD group was substantially smaller than the nonASD group, which impacted the results produced. Very little research regarding sound preferences in children with ASD has been conducted, especially studies that examine variables as specific as the ones used in this study. The next steps for this study include collecting more data for this specific study, specifically more participants with ASD, and seeing if the increase in numbers impacts the preference data. Because the amount of times each individual sound was played and the duration they were played for did not end up being recorded and analyzed, the next step for this study would be to run it again. In this round, this numeric data will be recorded and taken into consideration when determining preference levels; playing a sound more and listening to it longer could be strong indicators of a listener feeling positively towards it.

While a fair amount of sound variables were tested in this study, there are numerous additional variables that may drive listeners to or away from certain sounds. For example, a variable to be examined in the future would be volume level, as many sources and observations state that many individuals with ASD's audio sensory sensitivities are driven by volume. Many children carry around headphones to prevent a sensory overload provoked by loud noise, and some performances include sensory friendly shows during their runs. A question to be further investigated in the near future is determining whether volume/dynamic level would be a moderating variable, in that children with ASD's preference level for the other variables would be impacted by it.

Closing Thoughts

The research this thesis presents invites future studies in the music therapy for children with disabilities area, including those with larger sample sizes, more allotted time, and additional variables being taken into consideration. Music is a powerful tool that leads to endless benefits for mental health, physical health, and education. If a child, regardless of whether they have ASD, shows a desire to engage with music, it is important for educators, performers, and therapists to understand which sound variables are generally linked to positive and negative emotions and why that may be. This knowledge, as well as considering the child's individual listening needs and preferences, enables them to facilitate musical experiences that are both more enjoyable and accessible.

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APPENDIX

MUSIC FOR YOUNG LISTENERS WITH ASD: DETAILED VERSIONS OF uCUE, MUSICVIS, LIBRARY, & SCHOOL STUDIES

uCue Background

This study is a branch of a larger project titled "Music For Listeners with ASD," that began in September 2021. This project began as a community-engaged learning experience in an honors music theory course at the University of Delaware. This course, taught by Dr. Daniel Stevens, utilized problem-based learning (PBL), a pedagogical approach in which students develop and apply newly acquired knowledge in order to solve a problem (Duch, Groh, and Allen, 2001). PBL invites teamwork approaches to problem solving through peer learning, critical thinking, and creativity, and it promotes greater learning retention for students (Albanese and Mitchell, 1993). The goal of this class was to use music theory and composition skills to create a novel solution that addresses a real problem or opportunity that exists in the larger community. For the first few weeks of the class, we generated ideas about which local organizations could benefit from a musical partnership and how to go about that.

This problem has a personal connection to my role with a sibling with ASD. Growing up with a younger brother on the autism spectrum who experiences severe noise sensitivity, my mission has been to make music more sensory friendly and how myself and other performers and educators can cater music to this population. Based on observations and existing literature, it is evident that people on the autism spectrum do in fact experience heightened auditory sensitivities, making music listening different from individuals without ASD and often more challenging. Although the class discussed multiple possible organizations that could benefit from a musical investigation or intervention, we ultimately decided on exploring this topic and reaching out to Autism Delaware.

Autism Delaware is “Delaware’s largest provider of advocacy, support, and services for people on the spectrum and their families and caregivers,” and their vision for their organization is “that all people with autism will have opportunities to learn, grow, and live full lives as included and valued members of their communities” (Autism Delaware). Their mission of community-driven advocacy and emphasis on partnerships with local groups appealed to the students in the class. The class reached out to Autism Delaware and connected with Heidi Mizell, the organization’s Family Navigator. Heidi shared her personal experiences observing people with ASD’s reactions to music, both her family member’s and members of the organization. This sparked numerous conversations between her and the class regarding similarities and differences between people with ASD’s reactions to music and why these reactions may occur. In multiple meetings, the class, with Heidi’s help, generated ideas for how music students could get involved with Autism Delaware, including making music for a promotional video, playing at an Autism Walk, and bringing music to a multi-sensory room, known as the Sensory Room, Autism Delaware created at the Route 9 Library.

The Sensory Room intrigued the class, as this type of space does not commonly exist in public libraries. Heidi graciously brought some members of the class to the Sensory Room and provided a tour of the room to help the class better understand the room and see it in action. While the entire team was not able to attend this visit due to scheduling challenges, the members who did documented notes and pictures to share with the rest of the team. “The [library’s] 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,” (Karwankar et al. 2025, pg 2). The class was inspired by the room, which contained accessible and simple devices that enabled children to tamper with certain atmospheric elements of it. For example, one device allowed the children to change the color, pattern, and intensity of the lighting in the room. The students realized while there was a device for lighting that allowed modification for lighting, there was not one that modified musical patterns, color, and intensity for children with ASD and audio sensory sensitivities; the class quickly decided that developing such a device would be the goal of their project. There was also a beanbag with a built-in subwoofer, which allowed the user to feel pulsations of low frequency sounds that were played in the room.

In the meetings with Heidi Mizell, the class came to the conclusion that the most effective way to gather enjoyable music and sounds for as many children on the spectrum as possible was to directly ask them for their preferences. The class sent out a survey to families involved in Autism Delaware which asked questions regarding certain sounds, songs, and ambient noises the children particularly liked and did not like. The most well-liked songs, as stated by the survey takers, were “Row, Row, Row, Your Boat,” “The Ants Go Marching,” “The Wheels on the Bus,” and “Twinkle, Twinkle, Little Star.” Preferences for slow versus fast music were split, although parents did suggest making the lyrical melodies of the songs slightly slower than their typical tempi so that their children had time to process the words and sing along. For each of the four songs, we had three different melody layers (acoustic, synthesized, and a combination), two harmonies (one calm/enveloping and the other rhythmically active/stylized), three additional melodies (slower pace, moderate pace, fast pace and/or stylized), two bass lines (one synchronous with slow harmony layer and the other rhythmically active/stylized), one percussion layer, one bass drum, and three ambient sounds (running water, city traffic, and a train whistle). The goal of having these variants was so that the children could switch through the layers within the individual track according to their unique preferences. The bass drum layer was specifically added because many families expressed that their children had a strong preference for sounds in a low register that create physical sensations. The beanbag chair in the Sensory Room emphasized the importance of including both bass and bass drum options in the device.

Sensory Room Pilot Study

During the Winter of 2023, the team solidified into a smaller group of CIS and School of Music students, along with Drs. Stevens and Mauriello. This team launched an IRB approved study, which involved working with parent-child dyads at the Sensory Room. The study, which ran from December of 2022 to August 2023 as a part of the Summer Scholars Program at UD, consisted of a pre-interview with the parent and child in order to get a general idea of their individual sound preferences. Each study session consisted of three parts: first, the child was asked to create a song they found "calming," followed by a song they found "exciting," and finally, a song they could sing, dance, or move along with. The interdisciplinary team spent the following semester further analyzing the data collected with the uCue device from the Sensory Room studies and interpreting it in a paper that is now a part of the Interactive Design & Children journal. The feedback we received from this study indicated that although some children did in fact enjoy the slower tempos of the songs, which made singing along easier, the majority wanted to speed the songs up so they could dance. The solution the team came to was to create a steering wheel, with the purpose of giving each individual child control over the tempo of the song they're listening to. Its construction and purpose are inspired by the work of Dr. Elaine Chew (Chew, 2010). The steering wheel is programmed in a way that when the user turns it to the right, the tempo gradually accelerates, and when the user turns it to the left, the tempo decelerates.

Fig. A1.
Visual Representations from Sensory Room Studies at Rt. 9 Library (2023-2024)

School Studies

In Spring 2024, the research team launched a second study that focused on the use of uCue to facilitate communication and turn-taking between children with ASD in classroom settings. This study took place in a small 5th grade classroom at Marbrook Elementary in Wilmington, Delaware, where each student in the class had an ASD diagnosis. This IRB-approved study involved the class being split into groups of 3, with one child in charge of pushing the buttons on the uCue, one child controlling the tempo of the music using the steering wheel, and one student telling the others what to do with the devices. While no conclusive data was collected during these sessions, it was evident that the more familiarity with the device and individual roles, the more collaborative they were as a group. This study is being resumed in May 2025 at the Brennen School, a school in Newark, Delaware that exclusively serves children with ASD.

Fig. A2.
Marbrook Elementary Study (2024)

Our work at the Brennen School has also involved participating at their annual event, Artapalooza (April 2024 & 2025), that introduces different forms of the arts to children with ASD in an accessible way. The team had two stations set up at this event: one table for the uCue, and one live interactive performance. At the uCue station, while data was not collected, children had the device briefly explained to them and then were given the opportunity to play with the device and create their own sensory friendly song. Some notable observations made were paraprofessionals voicing that for about two of the children, this was the most they had seen them engage in any activity at the event. In addition to this, some children created a baseline track and sang their own song over it, making the uCue a backing track that sparked creativity. At the interactive performance stations, small chamber groups played Disney songs and other well-known music. Egg shakers and other percussive instruments were available for the children to use, so they could also perform with the musicians. Notable observations from this station were children not only using the egg shakers and clapping along, but many danced or even sang the lyrics to the Disney melodies with the instrumentalists. Conversations about the instruments were also sparked between the children and the performers, with one child showing excitement towards the cello, as he stated that he plays the instrument himself at home.

MusicVis and its Impact on Future Music Production

MusicVis is the latest advance to "Music for Young Listeners with ASD." Created by Abhishek Karwankar, MusicVis is an interactive dashboard that displays the data from the Sensory Room studies in a way that is comprehensible to composers, music educators, and music therapists. The interdisciplinary team of CIS and music students collaborated to make the graphs on MusicVis as comprehensible to musicians as possible. The team landed on ten different graphs to represent the frequency of the layers played, the level of soundwaves and brightness of each layer, how long each layer was played, and how often the user switched between them. The graph descriptions and specific functions are shown in the figure below. The participants recruited for the study were eight music majors at the University of Delaware who had experience with music composition or therapy. The main activity of the study involved music students analyzing different types of interactive graphs encompassing the user interaction data collected by uCue, and the researchers observed whether or not the musicians were able to draw accurate conclusions from them.

The study used a measurement tool consisting of a pre- and post-test interview. In the pre-test interview, participants were asked for their experience with data analysis and how they would compose music for listeners with ASD. The study itself consisted of three parts, determining: how rhythmic and dynamic elements between layers complimented each other, how the popularity and consistency of the most used layers correlate their energy and brightness levels, and how the transitions between layers correspond to the change in pitch over time. After each part, participants completed the Raw NASA-TLX workload questionnaire to express their feelings for using the system in the task and the System Usability Scale (SUS) to rate the usability of the dashboard. After the three parts were completed, the participants completed the pos-test before ending the study.

The average SUS score across all the participants was 70.71%, suggesting a moderate usability of the dashboard for musicians with some room for improvement.

While the dashboard was quite complex, when the team provided explanations and some contextual information to the users, the users were generally able to understand the dashboard and generally felt more confident in understanding how to produce music for a population of listeners with ASD.

Fig. A3.
Graphs from "MusicVis." From left to right: Waveplot, Spectral Centroid, Mel Spectrogram, Spectral Rolloff, Mel-frequency Cepstral Coefficients MFCCs), Sankey Diagram, Covariance Matrix, Bar Graph, Full Session Diagram, Time Series Engagement Plot

Happening simultaneously with the MusicVis study, "Music For Young Listeners with ASD" was a part of the Summer Scholars Program once again. The goal of the music-specific work in Summer 2024 entailed using the user interaction data gathered from uCue and presented in MusicVis to create additional songs for uCue. This was conducted by the two composition majors and me. The data from the first study drove the compositional structure and musical elements used in producing the next round of songs that will be used in 2025 studies. Our next step, which is taking place in Spring-Summer 2025, is bringing uCue to the Brennan School and conducting sessions with students and the new songs to determine whether or not they produce similar results to the previous songs.

Grants

From 2021-2025, this study has earned over $225,000 in grant funding, with support coming from the UD Partnership for Arts and Culture (College of Arts and Sciences, the Maggie E. Neumann Research Fund (College of Health Sciences), and the UD Institute for Engineering Driven Health. This funding has provided for upgrades to the music production lab to produce high quality music and audio samples for the children while also providing travel funds for conference presentations related to this research. The research team is grateful for our grant support and our partnerships with the Route 9 Library, Autism Delaware, The Brennan School, and Marbrook Elementary. The support we have received continues to drive our research and work to achieve our goal, which is using uCue to gather data which identifies larger patterns and preferences children with ASD and sensory sensitivities may have in music as well as unique individual ones. These preferences can ultimately inform future composers and music creators on how to better give those with ASD a pleasurable listening experience.