Designing Sensory NIME for Autism

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ABSTRACT

This paper explores how sensory NIME design principles may inform the design of musical interfaces tailored for children with Autism Spectrum Disorder (ASD), focusing on their sensory processing challenges. Given the prevalence of sensory over-responsivity (SOR) and under-responsivity (SUR) in ASD, traditional sensory interventions often fail to accommodate the highly individualized and fluctuating sensory needs of autistic individuals. The authors highlight the potential for multisensory NIME to address the diverse range of sensory needs, promoting emotional regulation and sensory balance through new creative musical opportunities and activities. This paper presents research in the form of a narrative review and comparative case study of recent NIME and sensory intervention research, exploring emerging approaches, rhythm-based interventions, generative algorithms, play-centered designs and other possibilities for enhancing sensory engagement and emotional regulation. Drawing on insights from 30 recent NIME papers, this research explores the boundaries of current approaches and seeks to establish an understanding of multisensory NIME for ASD. The research underscores the profound variability in sensory profiles for ASD, necessitating a shift from clinician-directed interventions to creative, inclusive, multisensory solutions. Finally, a set of sensory NIME design principles are offered, emphasizing the importance of sensory perception, sensory equilibrium and the promotion of emotional regulation for ASD.

Author Keywords

NIME, proceedings, MS Word, template

1. INTRODUCTION

In recent years, the prevalence of Autism Spectrum Disorder (ASD) has significantly increased due to improved awareness, advancements in diagnostic criteria prompting a more nuanced understanding of its diverse manifestations. This evolution of understanding highlights the importance of addressing sensory processing challenges experienced by many individuals with ASD. These challenges profoundly impact emotional regulation, social interaction, and daily functioning, (themes reflected in the concept of Entangled NIME) thereby making developing practical sensory modulation tools essential, including the potential benefits of autism specific musical interfaces for younger users.

Autism Spectrum Disorder (ASD) any one of a group of disorders with an onset typically occurring during the preschool years and characterized by varying but often marked and persistent deficits in social communication and social interaction, including difficulties with social-emotional reciprocity, nonverbal communication behaviors, and social relationships, along with restricted and repetitive patterns of interests, behaviors, and/or activities [1].

Among these, sensory modulation difficulties are particularly pervasive, with up to 95% of individuals with ASD experiencing either sensory over-responsivity (SOR) or sensory under-responsivity (SUR) [2].

SOR manifests as heightened sensitivity to auditory, visual, or tactile stimuli, often leading to overstimulation, anxiety, and avoidance behaviors [3]. In contrast, SUR is characterized by a diminished awareness of sensory inputs, resulting in disengagement or repetitive sensory-seeking behaviors [4].

These distinct sensory profiles highlight the need for interventions that are both adaptable and responsive to real-time sensory needs. Traditional sensory interventions, such as Sensory Integration Therapy (SIT), rely on clinician-directed exposure to structured sensory inputs, limiting their effectiveness in accommodating the diversity of sensory experiences in ASD [5]. By integrating user-centered, adaptive technologies that cater to both SOR and SUR, musical interfaces can provide real-time flexibility, enhancing sensory modulation and emotional regulation.

Given these variations in ASD there are significant challenges in addressing sensory modalities, including auditory, tactile, proprioceptive, and visual systems, emotional regulation, social functioning, and daily life activities. For example, individuals with hyper-responsivity may perceive ordinary sounds or textures as distressing, while those with hypo-responsivity may require heightened stimuli to engage with their surroundings. The research underscores the profound variability in sensory profiles among individuals with ASD, necessitating tailored intervention strategies to address these diverse sensory needs.

2. SENSORY INTERVENTIONS

Sensory processing challenges in Autism Spectrum Disorder (ASD) are highly complex and require targeted interventions. Elwin et al. [6] highlight the coexistence of hypersensitivity and hyposensitivity in individuals with high-functioning autism, with external senses such as vision and touch more prone to hypersensitivity, while internal modalities like proprioception and pain perception are often hyposensitive. This variability disrupts daily functioning and underscores the need for personalized interventions that address these distinct sensory needs. Similarly, Tomchek and Dunn [7] found that 95% of children with ASD experience sensory dysfunctions, including sensory-seeking behaviors, auditory filtering difficulties, and tactile sensitivities, all of which hinder attention and social engagement.

The biological basis of these sensory challenges is linked to genetic and neural factors. Schaffler et al. [8] identify mutations in ASD-related genes such as Shank3, Mecp2, and Fmr1 as contributors to sensory irregularities, particularly in tactile processing, suggesting that the peripheral nervous system plays a significant role in sensory abnormalities and may present therapeutic intervention targets. Kern

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et al. [9] further demonstrate global sensory dysfunction across auditory, tactile, visual, and multisensory domains, with a strong correlation between sensory challenges and ASD severity in childhood, though this association diminishes with age, potentially due to sensory adaptation or neural maturation.

Sensory modulation difficulties also profoundly impact emotional regulation and social interactions. Sensory over-responsivity is closely linked to anxiety and avoidance behaviors, with Ben-Sasson et al. [10] reporting that toddlers exhibiting both over- and under-responsivity are more likely to experience heightened anxiety, withdrawal, and depressive symptoms. These findings indicate that sensory challenges extend beyond physical responses, affecting emotional well-being and social participation. Additionally, Baum et al. [11] identify reduced neural connectivity between brain regions as a key factor underlying sensory integration difficulties in ASD, further impairing social communication and cognitive function. These findings emphasize the urgent need for adaptive sensory interventions that accommodate the diverse and evolving sensory profiles of individuals with ASD.

2.1 Limitations of Conventional Musical Interfaces for ASD

Traditional sensory interventions, such as Sensory Integration Therapy (SIT) [12] and Multisensory Integration Theory (MIT) [13], have been widely used to address sensory processing challenges in individuals with Autism Spectrum Disorder (ASD). However, these approaches often fail to accommodate the highly individualized and fluctuating nature of sensory needs across the spectrum. SIT, developed by A. Jean Ayres [12], relies on structured sensory activities to enhance sensory processing and integration. While it has shown some success in improving adaptive behaviors and self-regulation, its rigid, clinician-directed framework limits its effectiveness in addressing the dynamic and diverse sensory profiles of individuals with ASD. The SenITA randomized controlled trial [14] found no statistically significant improvements in primary outcomes such as behavior and quality of life when comparing SIT to usual care. Although caregivers reported increased satisfaction and perceived progress in specific goals, these findings highlight that SIT's benefits are context-dependent rather than universally effective. Additionally, SIT remains resource-intensive, making widespread accessibility and scalability challenging in broader public health settings.

Similarly, Multisensory Integration Theory (MIT) [13] emphasizes engaging multiple sensory modalities simultaneously to enhance sensory processing and emotional regulation. Multi-Sensory Environments (MSEs) have been developed to offer children control over sensory variables such as light, sound, and tactile inputs, promoting engagement and reducing defensive sensory behaviors. While this autonomy aligns with the preferences of many children with ASD, MSEs are not without limitations. Their reliance on specialized equipment and complex setups restricts their accessibility outside of clinical environments, and their effectiveness varies due to a lack of standardization across studies.

De Domenico et al. [15] reported that while MSEs facilitated self-regulation and sensory engagement in specific domains, they did not consistently outperform traditional therapies in achieving broader developmental outcomes. Moreover, conventional interventions, including SIT and MSEs, lack the flexibility to adjust sensory inputs in real time, a crucial limitation given the fluctuating and individualized sensory responses of those with ASD.

These limitations underscore the need for sensory interventions that are adaptive, user-centered, and capable of responding dynamically to the moment-to-moment sensory fluctuations experienced by individuals with ASD. Conventional approaches, with their static and pre-determined frameworks, often fail to support the full range of sensory processing differences. The design of musical interfaces for ASD must prioritize real-time adaptability, personalization, and user autonomy, moving beyond the constraints of traditional methodologies to create more inclusive and effective sensory engagement tools.

2.2 Emerging Adaptive Alternatives

Given the highly individualized and fluctuating sensory needs of individuals with Autism Spectrum Disorder (ASD), conventional sensory interventions often fall short in providing effective, sustainable support. Emerging adaptive approaches seek to address these limitations by incorporating flexibility, real-time adaptability, and user-centered design. In the context of musical interfaces, these innovations present a compelling opportunity to enhance sensory engagement, self-regulation, and emotional well-being for young users with ASD.

Rhythm-based interventions have demonstrated significant promise in supporting sensory processing challenges in ASD. The structured yet flexible nature of rhythmic auditory patterns provides a predictable sensory input that enhances focus, reduces anxiety, and improves motor coordination [16]. Unlike conventional interventions, which often impose fixed sensory stimuli, rhythm-based therapies offer an adaptable framework that can be tailored to individual sensory thresholds. This aligns with the need for dynamic, user-responsive systems capable of addressing hypersensitivity and hyposensitivity in real time.

Similarly, algorithmic modulation presents a breakthrough in sensory-based therapies by allowing real-time adjustments to auditory, visual, and tactile stimuli. De Domenico et al. [15] emphasize how algorithmic systems can actively modify sensory inputs in response to user feedback, promoting sensory balance and reducing overstimulation. This adaptability is particularly valuable in ASD, where sensory experiences fluctuate and rigid, pre-defined interventions may fail to accommodate moment-to-moment needs. By fostering self-regulation and sensory autonomy, these systems empower individuals with ASD to engage with their environments in ways that traditional interventions cannot.

Play-centered interventions further highlight the importance of flexible, engaging, and child-led approaches to sensory modulation. O'Keeffe and McNally [17] found that interactive, play-driven sensory experiences improve sensory tolerance, emotional regulation, and social communication in children with ASD. These interventions leverage intrinsic motivation and creativity, ensuring that sensory engagement occurs in a low-pressure, enjoyable environment. By prioritizing personalization and adaptability, play-based approaches move beyond the limitations of static interventions, offering a more inclusive and responsive method for addressing sensory challenges.

Musical interfaces for children with ASD exist at the intersection of sensory intervention and play-based engagement. While not designed as rigid therapeutic tools, they may provide structured, flexible environments and accommodate diverse sensory needs, supporting self-regulation, emotional expression, and social interaction. Unlike traditional interventions, which often impose external frameworks, these interfaces empower children to explore sound, rhythm, and multisensory experiences on their own terms. By integrating principles from adaptive sensory interventions—such as real-time modulation, rhythmic structure, and interactive play—these systems create an inclusive and enjoyable medium that naturally fosters developmental benefits while prioritizing autonomy and creativity.

These contemporary developments underscore the critical need for adaptive, interactive, and user-driven design in musical interfaces for children with ASD. The limitations of traditional interventions highlight the urgency of developing systems that respond to the diverse and evolving sensory needs of autistic individuals. Building on these principles, the following NIME papers provide a foundation for proposing a new set of design guidelines tailored to autism-specific musical interfaces. By integrating rhythm-based structures, real-time modulation, and play-centered engagement, these interfaces can better support sensory regulation, emotional expression, and creative exploration in young users with ASD.

3. METHOD

This study employs an integrative review methodology to synthesize existing research on New Interfaces for Musical Expression (NIME) designed for individuals with Autism Spectrum Disorder (ASD). The scope of this review is limited to peer-reviewed NIME conference papers, reflecting the most recent and relevant innovations in musical interface design for autism.

The corpus of literature analyzed consists of 30 NIME papers selected through a structured synthesis matrix. Inclusion criteria required that studies explicitly address sensory or cognitive engagement within the context of musical interfaces and autism-related interventions. literature that focused solely on technical innovations and considering user-centered interaction or ASD-specific adaptations. The primary objective of this review is to critically assess how existing musical interfaces accommodate sensory diversity, with particular attention to real-time adaptability, rhythmic structuring, and multimodal interactions.

A synthesis matrix was prepared to facilitate a comparative analysis, highlighting methodological strengths, limitations, and research gaps. In addition, thematic coding was employed to identify dominant intervention strategies, including rhythm-based engagement, adaptive sensory modulation, and play-centered interactivity. Given the complexity of sensory processing in ASD, the analysis places particular emphasis on how musical interfaces address hypersensitivity, hyposensitivity, and fluctuating sensory thresholds.

4. RESULTS

The review of 30 NIME studies is presented in table 1 overleaf. The synthesis matrix reveals three primary themes in the design of musical interfaces for autism: (1) Rhythm-based interventions for sensory modulation, (2) Real-time adaptive systems for sensory engagement, and (3) Play-centered multisensory interfaces. These themes encapsulate the predominant approaches adopted within the NIME community to address sensory and cognitive challenges in ASD.

Rhythm-based interventions emerged as a recurring strategy across several studies, reflecting the intrinsic relationship between rhythmic predictability and sensory self-regulation [16]. Multiple studies emphasize the role of rhythmic entrainment in stabilizing attention, reducing anxiety, and promoting motor coordination. Unlike traditional sensory integration therapies, which rely on structured sensory exposure, rhythm-based interfaces offer flexible, user-driven interaction, allowing individuals with ASD to modulate their engagement based on personal sensory thresholds.

The second major theme involves real-time adaptive sensory interfaces, which adjust auditory, visual, and haptic stimuli in response to user interaction. These interfaces leverage algorithmic modulation to dynamically alter sensory inputs, ensuring that the interface remains responsive to moment-to-moment changes in sensory tolerance. This approach aligns with neurodiversity-informed principles [15], which emphasize customization and self-directed sensory engagement as opposed to rigid, externally imposed sensory protocols.

A third critical theme is the integration of play-centered multisensory engagement within musical interfaces. Studies indicate that play-based interaction fosters intrinsic motivation, leading to greater sensory tolerance and enhanced social communication [17]. Many NIME interfaces designed for ASD incorporate game-like mechanics, interactive soundscapes, and exploratory sound synthesis, enabling children to engage with music and sensory stimuli in a non-threatening, enjoyable environment.

While these approaches demonstrate significant promise, the review also highlights key gaps and limitations. Many studies focus primarily on auditory and visual modalities, with less emphasis on proprioceptive and vestibular engagement, which are critical for sensory integration in ASD [7]. Moreover, the majority of NIME interventions rely on short-term experimental evaluations, with limited longitudinal data on sustained sensory and behavioral impact. RESULTS

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Table 1. Synthesis Matrix of selected NIME papers

Title	Date of Article	Authors	Study Type	Summary	Methods	Results	Gaps	Perception vs Sensation	Discussion
VESBALL: A Ball-Shaped Instrument for Music Therapy	**2023**	Ajit Nath	Case Study, Therapeutic Design – Explores the impact of tactile, ball-based music therapy on users with ASD.	Describes the VESBALL, a tactile, spherical digital musical instrument designed for use in music therapy sessions.	Focused on participatory design with therapists and patients, emphasizing intuitive interaction and adaptability.	Enhanced engagement and participation in therapeutic settings. Demonstrated adaptability across different patient needs.	Limited evaluation beyond music therapy. No long-term impact studies.	Sensation: Tactile interaction with a soft ball, motion-based sound generation. Perception: Recognition of cause-effect relationships between movement and sound, supporting social and musical engagement.	Suggests tactile DMIs can enhance therapy, supporting multisensory engagement and emotional expression.
Music Making to Scaffold Social Playful Activities and Self-Regulation	**2019**	Antonella Nonnis, Nick Bryan-Kinns	Case Study, Experimental	Investigates the impact of Olly, a musical textile tangible user interface (TUI), on social interaction and sensory regulation in autistic children. A 5-week study in a SEN school demonstrated its effectiveness in fostering collaborative play and emotional engagement.	Observational study with five autistic children in a SEN school over 5 weeks. Sessions lasted 30 minutes using Olly, an inflatable gym ball with elastic ribbons that triggered musical responses. Teacher observations and behavioral analysis (eye contact, engagement, shared play) were recorded.	Children showed increased social engagement (smiling, singing, shared play). Teachers noted Olly's accessibility and effectiveness in encouraging interaction and sensory relief. The study supports the role of TUIs in enhancing social and emotional	Small sample size (n=5), short study duration (5 weeks). Future work should include diverse participants, long-term impact analysis, and comparisons with other interactive musical tools.	Sensation: Tactile interaction with elastic ribbons and auditory feedback. Perception: Recognizing musical cues, linking physical interaction to social and emotional engagement.	Highlights the role of multisensory engagement in fostering social interaction and self-regulation in autistic children. Music-based interfaces like Olly enhance joint attention, collaborative play, and emotional expression.
SnoeSky and SonicDive: Accessible Digital Musical Instruments for SEN Schools	**2020**	Andreas Förster, Christina Komesker, Norbert Schnell	Educational Research, Case Study – Evaluates the impact of accessible musical instruments in special education.	Presents two ADMIs—SnoeSky and SonicDive—designed for students with intellectual disabilities in a SEN school, aiming to improve accessibility and self-efficacy.	Multidisciplinary participatory design involving students, teachers, and researchers. Iterative prototyping tailored to the school's needs and infrastructure.	Demonstrated effectiveness in fostering relaxation, activation, and engagement in SEN students.	Limited to one school with specific needs; scalability and diverse applications need further exploration.	Sensation: Touch-sensitive and motion-based musical interactions for SEN students. Perception: Users develop structured engagement with sound, fostering cognitive and emotional learning.	Highlights self-efficacy through ADMIs, encouraging broader adoption in SEN settings.
Participatory Design of Collaborative Digital Musical Interfaces for Children with Autism Spectrum Condition (ASC)	**2023**	Balázs András Iványi	Participatory Design, Case Study, User Research – Incorporates ASD children in co-design workshops.	Investigates collaborative DMIs designed to enhance social skills in children with ASC through participatory design.	Co-design approach with educators, therapists, and children. Evaluations based on social interaction metrics.	Increased social interaction and engagement in group music-making. Positive feedback from educators.	Limited by small sample size. Long-term social impact not evaluated.	Sensation: Tactile and auditory engagement with musical interface; immediate sensory feedback from touch. Perception: Children develop social and collaborative skills through structured musical interaction.	Emphasizes the importance of collaborative DMIs in therapeutic and educational contexts for children with ASC.
Participatory Design of a Collaborative Accessible Digital Musical Interface	**2023**	Balázs András Iványi	Participatory Design, Autism Research – Focuses on collaborative accessibility-based instrument development.	Investigates the development of collaborative accessible digital musical interfaces (CADMI) for children with autism spectrum condition (ASC).	Co-design approach with children, educators, and therapists. Focused on iterative prototyping and evaluations in classroom settings.	Enhanced collaboration and communication among children with ASC. Positive feedback from educators and therapists.	Limited exploration of scalability beyond the specific user group. Long-term social impact not evaluated.	Sensation: Tactile and auditory feedback from an accessible musical interface. Perception: Users recognize interaction patterns, fostering collaborative and social engagement through music.	Highlights the potential for collaborative DMIs to foster social interaction and inclusivity in therapeutic contexts.
dB: A Web-Based Drummer Bot for Finger-Tapping	**2023**	Çağrı Erdem	AI and Computational Music Research, Usability Study – Evaluates AI-generated rhythm interactions with human input.	Presents dB, a web-based drummer bot that uses finger-tapping as input for real-time rhythm generation.	Web-based interface with machine learning algorithms for detecting and replicating finger-tapping rhythms. Iterative user testing included.	Demonstrated effectiveness in capturing and reproducing rhythmic inputs. Received positive feedback from testers for usability.	Limited testing with diverse musical styles. Integration with other musical systems not explored.	Sensation: Tactile interaction with keyboard tapping; auditory feedback from AI-generated rhythms. Perception: Users interpret rhythmic variations, recognizing groove patterns shaped by AI modulation.	Highlights potential for democratizing rhythm creation through simple and intuitive interfaces.
Kinesynth: A Hybrid Kinesthetic Synthesizer	**2023**	Don Derek Haddad, Joseph A. Paradiso	Experimental Design, Interactive Performance Study – Examines how capacitive sensing influences sound perception.	Introduces the Kinesynth, a synthesizer combining kinesthetic input with sound modulation.	Utilized a hybrid of motion tracking and traditional synthesizer interfaces. Tested with performers and educators.	Enabled expressive sound control through kinesthetic movements. Received positive reviews for performance usability.	Complexity of motion tracking may limit accessibility. Long-term impact on performance techniques not studied.	Sensation: Tactile and electrical sensations from capacitive skin conduction. Perception: Users develop awareness of bioelectric modulation, linking bodily interaction with sound control.	Suggests potential for blending traditional and gestural inputs in music creation and performance.
ClimaSynth: Enhancing Environmental Perception through Sonic Interaction	**2023**	Eleni-Ira Panourgia	Experimental Design, Human-Computer Interaction (HCI) Study – Investigates how users engage with sound-driven climate models.	Explores ClimaSynth, a sonic interface designed to enhance awareness of climate change through interactive soundscapes.	Iterative design based on environmental data mapping to sound. User testing focused on perceptual engagement.	Increased user awareness and emotional connection to climate data. Demonstrated engagement through interactive soundscapes.	Limited long-term evaluation of behavioral changes. Requires scalability for wider audience integration.	Sensation: Auditory and tactile engagement with climate-related soundscapes, manipulated through a web-based interface. Perception: Users interpret climate change effects through sonic variations, linking environmental changes to acoustic perception.	Highlights the potential for sonification to evoke emotional responses and inspire environmental action.
Accessible Digital Musical Instruments: A Review of Musical Interfaces in Inclusive Music Practice	**2023**	Emma Frid	Systematic Review, Literature Analysis – Surveys 113 publications on accessible digital instruments.	Systematic review of accessible digital musical instruments (ADMIs) in inclusive music practices.	Reviewed literature on ADMIs, focusing on usability, accessibility, and inclusivity. Identified gaps and best practices.	Provided a comprehensive overview of trends and challenges in ADMI development. Identified best practices for inclusivity.	Lack of standardized evaluation frameworks across studies. Limited focus on long-term impacts.	Sensation: Interaction with ADMIs via touch, gaze, and haptic feedback, providing alternative sensory pathways. Perception: Users develop an understanding of sound control through multimodal feedback, expanding access to music-making.	Emphasizes the importance of iterative, user-centered design in developing inclusive ADMIs.
MusiCane: An Accessible Digital Instrument Inspired by the White Cane	**2023**	Emmanouil Dimogerontakis	Applied Research, Human-Centered Design Study – Investigates how blind and visually impaired users engage with vibrotactile music interfaces.	Introduces the MusiCane, a digital instrument for blind and visually impaired users that combines mobility and music-making capabilities.	Iterative prototyping with visually impaired users. Evaluation based on accessibility, usability, and musical output.	Effective in combining mobility with creative expression. Users reported increased confidence and enjoyment.	Limited sample size for evaluation. Scalability in broader contexts unexplored.	Sensation: Haptic vibrations and auditory cues provide spatial awareness through cane movement. Perception: Users construct an auditory map of their surroundings and engage in collaborative music-making, transforming raw sensory input into structured interaction.	Highlights the potential for accessible DMIs to transform mobility aids into creative tools.
SnakeSynth: New Interactions for Generative Audio Synthesis	**2023**	Eric Easthope	Computational Music Research, AI-driven Usability Study – Analyzes user engagement with AI-powered generative synthesis.	Explores SnakeSynth, a generative audio synthesizer emphasizing gestural interactions for dynamic sound design.	Utilized motion-based interaction via a tangible interface. Iterative testing with sound designers and musicians.	Enhanced engagement through physical interaction. Positive feedback for creative possibilities in sound exploration.	Limited testing across diverse user groups. Integration with existing DAWs not fully explored.	Sensation: Touch-based interaction with a generative synthesis system; gestures mapped to musical expressions. Perception: Users develop an understanding of how gestures modulate sound, learning emergent generative patterns.	Highlights the potential for tangible interaction in expanding expressive capabilities in sound design.
BioSynth: An Affective Biofeedback Device	**2023**	Erin Gee	Experimental, Case Study – Uses physiological data as a generative music method and examines biofeedback interactions.	Explores the BioSynth, an instrument leveraging biofeedback for emotional expression through sound synthesis.	Combined physiological sensors with sound synthesis algorithms. Iterative design process with testing on diverse user groups.	Successfully captured emotional states and transformed them into musical outputs. Users found the experience engaging.	Limited by sensor accuracy and latency issues. Scalability to performance contexts needs further exploration.	Sensation: Physiological feedback (heart rate, respiration, skin conductance) generates real-time sound output. Perception: Users interpret biofeedback sounds as emotional expressions, blurring the line between felt and externalized emotion.	Discusses the role of biofeedback in enhancing emotional connection in musical interactions.
Evaluation of Timbre-Based Control of a Parametric Synthesizer	**2023**	Jeff Gregorio, Youngmoo E. Kim	Experimental Design, Usability Study – Examines how timbre-based control influences user experience in parametric synthesis.	Evaluates user interaction with a parametric synthesizer using timbre-based controls.	Conducted user studies comparing traditional and timbre-based interfaces. Statistical analysis of user performance and satisfaction.	Demonstrated improved usability and creative potential of timbre-based controls.	Limited exploration of user diversity. Scalability for complex sound synthesis scenarios not addressed.	Sensation: Tactile control of timbre parameters and auditory feedback from spectral changes. Perception: Users develop cognitive models of timbre interaction, refining their understanding of sound transformation.	Highlights the potential for timbre-based interfaces to simplify complex synthesis tasks.
The Harvester: A DIY Sampler and Synthesizer Demo	**2023**	Johann Diedrick	User Research, Experimental, Workshop-Based Study – Combines questionnaires, field research, and participatory design workshops.	Describes The Harvester, a DIY sampler and synthesizer enabling creative sound manipulation.	Developed through hands-on workshops with musicians and hobbyists. Iterative prototyping and feedback.	Empowered users to create unique soundscapes. Accessible to non-experts through its DIY nature.	Limited evaluation in professional contexts. No exploration of long-term user engagement.	Sensation: Capturing everyday sounds via tactile and motion-based interaction; hearing raw audio snippets. Perception: Spatially manipulating recorded sounds to shape them into structured music, altering auditory meaning.	Highlights the democratization of music technology through accessible DIY tools.
The Timbre Explorer: A Synthesizer Interface for Educational Purposes and Perceptual Studies	**2023**	Joshua Ryan Lam	Educational Research, Usability Study – Explores how users engage with timbre learning through an interactive interface.	Presents the Timbre Explorer, a synthesizer designed for exploring sound timbre for educational and research purposes.	Developed through iterative prototyping with educators and students. Evaluated in classroom and laboratory settings.	Enabled intuitive exploration of sound timbre. Effective as an educational tool for sound perception studies.	Limited application beyond educational contexts. Scalability to other instruments not explored.	Sensation: Tactile and auditory manipulation of timbral parameters. Perception: Users develop cognitive models of timbre through interactive sound exploration.	Discusses the role of simplified interfaces in fostering sound understanding and exploration in educational settings.
An Embedded Wavetable Synthesizer for the Electronic Bandoneon	**2023**	Juan M. Ramos	Applied Research, Technical Sound Design – Studies how digital wavetable synthesis recreates acoustic bandoneon timbres.	Describes an embedded wavetable synthesizer integrated into the electronic bandoneon for enhanced musical expression.	Combined acoustic measurements with parameter mapping. Iterative testing with bandoneon players.	Achieved seamless integration of acoustic and electronic elements. Improved expressiveness in performances.	Limited exploration beyond traditional bandoneon players. Scalability for other instruments not studied.	Sensation: Auditory experience of synthesized bandoneon tones shaped by bellows pressure and keystrokes. Perception: Musicians compare and interpret synthesized vs. acoustic sounds, adapting their playing techniques accordingly.	Suggests potential for enhancing traditional instruments through embedded electronic synthesis.

AI-terity 2.0: An Autonomous Music Agent	**2023**	Koray Tahiroğlu	AI and Computational Music Research, Experimental Study – Studies how machine learning models generate music and interact with human improvisation.	Explores AI-terity 2.0, an autonomous AI-driven music agent designed for live performance and collaboration.	Developed using AI frameworks and tested in live performance contexts. Iterative refinements based on user feedback.	Demonstrated ability to improvise and adapt in live performances. Users appreciated its collaborative potential.	Limited evaluation of AI's adaptability across genres. Ethical implications of AI creativity not fully addressed.	Sensation: Algorithmic sound transformations driven by machine improvisation. Perception: Users interpret AI-generated patterns, adjusting expectations of musical form and authorship.	Highlights the evolving role of AI as a collaborator in music creation and live performance.
NAKANISYNTH: An Intuitive Freehand Drawing Waveform Synthesizer Application for iOS Devices	**2023**	Kyosuke Nakanishi	Experimental Design, Usability Study – Evaluates how users interact with the freehand waveform synthesizer.	Introduces NAKANISYNTH, an iOS-based synthesizer that generates waveforms through freehand drawing.	Developed and tested on iOS devices with iterative user feedback. Focused on intuitive gesture-to-sound mapping.	Provided a highly intuitive interface for waveform creation. Positive feedback for its creative possibilities.	Limited evaluation beyond iOS devices. Scalability to other platforms not explored.	Sensation: Tactile drawing of waveforms and real-time auditory feedback. Perception: Users associate drawn waveforms with sound characteristics, refining their understanding of synthesis parameters.	Discusses the potential for intuitive interfaces in democratizing sound design.
BoomBox: A Haptic Instrument for Deaf and Hard-of-Hearing Children	**2023**	Lloyd May	Co-Design Study, Accessibility Research – Evaluates physical accessibility in drum machine interfaces.	Introduces BoomBox, a haptic instrument designed to make music accessible for children who are deaf or hard of hearing.	Developed using participatory design with educators and students. Evaluated for tactile feedback and accessibility.	Enhanced inclusivity in music-making for users with hearing impairments. Received positive feedback for tactile interaction.	Limited exploration of integration with broader educational tools. Long-term user impact not evaluated.	Sensation: Tactile engagement with capacitive sensing, magnetic placement of pieces, and auditory feedback. Perception: Users construct rhythmic structures, understanding groove and tempo through interactive sequencing.	Discusses the importance of multisensory DMIs in expanding accessibility for marginalized communities.
BLIKSEM: An Acoustic Synthesis Fuzz Pedal	**2023**	Lloyd May	Experimental Design, Technical Performance Analysis – Studies nonlinear acoustic synthesis effects in fuzz pedals	Presents BLIKSEM, a fuzz pedal with a focus on acoustic synthesis for expressive sound manipulation.	Prototyped with iterative testing by guitarists and sound designers. Evaluated for expressiveness and usability.	Provided a unique acoustic synthesis experience. Received positive feedback for expressive control.	Limited testing beyond experienced musicians. Scalability for commercial production not addressed.	Sensation: Tactile foot pedal control over a driven cantilever, modifying electromechanical vibrations. Perception: Users shape distortion and timbre dynamically, experiencing material-driven acoustic synthesis.	Suggests potential for novel synthesis approaches in guitar-based performance tools.
Co-Designing Haptic Instruments With Deaf and Hard-of-Hearing Children	**2023**	Lloyd May	Participatory Design, Accessibility Research – Engages DHH children in haptic music interaction.	Explores the co-design of haptic instruments to make music creation accessible for children who are deaf or hard of hearing.	Participatory design involving children, educators, and engineers. Evaluations focused on usability and inclusivity.	Enabled engaging and accessible music creation. Received positive feedback from children and educators.	Limited long-term impact studies. Scalability in educational settings not fully addressed.	Sensation: Direct tactile experience of haptic vibrations with varying frequencies and intensities. Perception: Interpretation of vibrotactile stimuli as musical and artistic expressions, forming structured compositions.	Highlights the role of participatory design in creating inclusive musical tools for marginalized groups.
Design and Evaluation of Accessible Digital Musical Instruments for Pupils with Neurodevelopmental Disorders	**2024**	Matteo Olivo, Florence Carrouel, Emily Darlington, Laurent Pottier	Accessibility Research, Case Study – Evaluates the usability of assistive musical technology in SEN classrooms.	Highlights participatory design of Accessible Digital Musical Instruments (ADMIs) for students with neurodevelopmental disorders (NDDs). Evaluated in a special education setting.	Participatory and iterative design approach with input from students, teachers, and assistants. Conducted evaluations in a French middle school, focusing on usability and engagement.	Enhanced accessibility and engagement for students with NDDs. Iterative refinements improved user experience and teacher involvement.	Limited scalability beyond the specific school environment. Evaluation was qualitative, with minimal quantitative data.	Sensation: Multisensory interaction through touch, vision, and sound in accessible musical interfaces. Perception: Users develop structured learning of musical patterns, enhancing cognitive and motor skills.	Emphasized the importance of involving multiple stakeholders in ADMI design to improve usability and social engagement.
GrooveTransformer: A Generative Drum Sequencer Eurorack Module	**2024**	Nicholas Evans, Behzad Haki, Sergi Jordà	Computational Music Research, Experimental Design – Examines AI-driven generative drum sequencing.	Presents the GrooveTransformer module, which uses a Variational Auto-Encoder (VAE) for generative drum sequencing. Designed for real-time performance and user-defined exploration of generative models.	Built around a VAE generative model adapted to Eurorack modular synthesis format. Used iterative prototyping and integration tests with musicians.	Demonstrated potential for redefining generative processes, enabling users to explore latent spaces for novel musical patterns.	Hardware complexity in real-time contexts. Limited testing with non-expert users. Scalability challenges for diverse Eurorack setups.	Sensation: Tactile control over generative drum sequencing, with real-time auditory feedback. Perception: Users analyze rhythmic patterns, distinguishing between AI-driven and manually programmed grooves.	Highlights opportunities for expanded generative model use in creative performance, emphasizing user adaptability and exploratory design.
The Effectiveness of Mirroring- and Rhythm-Based Interventions for Children with Autism Spectrum Disorder	**2021**	Phoebe Morris, Edward Hope, Tom Foulsham, John P. Mills	Therapeutic Case Study, Neurodevelopmental Research – Investigates rhythm-based interventions in autism therapy.	Systematic review evaluating mirroring and rhythm interventions for improving communication and social development in children with Autism Spectrum Disorder (ASD).	Reviewed 11 studies using SPIDER and PICO frameworks, focusing on communication and social skills outcomes in children under 12 years old.	Both interventions were effective, with mirroring enhancing social connectedness and rhythm improving communication skills.	Lack of standardization in methodologies, duration, and outcome measures. Need for quantitative studies and long-term evaluations.	Sensation: Tactile and auditory feedback from rhythmic mirroring exercises. Perception: Children improve motor coordination and social interaction through structured rhythmic engagement.	Suggested integrating these techniques in broader educational and therapeutic practices, such as physical education.
SketchSynth: A Browser-Based Sketching Interface for Sound Control	**2023**	Sebastian Löbbers, György Fazekas	Usability Study, Interaction Design Research – Examines how visual sketching translates into sound synthesis control.	Describes SketchSynth, an interface for mapping visual sketches to sound characteristics using cross-modal perception research.	Developed using iterative prototyping with real-time visual feature extraction linked to sound synthesis via Open Sound Control (OSC).	Enabled meaningful and creative gesture-to-sound mappings. Demonstrated in musical contexts with positive user feedback.	Overstimulation for users with sensory sensitivities. Limited exploration of diverse synthesis types.	Sensation: Visual sketching of waveforms with real-time auditory feedback. Perception: Users associate drawn shapes with sound characteristics, linking visual forms to musical structure	Highlights the potential of perceptual research in designing engaging and accessible sonic interfaces.
About TIME: Textile Interfaces for Musical Expression	**2024**	Sophie Skach, Victor Shepardson, Thor Magnusson	Experimental Design, Human-Computer Interaction Study – Studies textile-based tactile interfaces for music-making.	Explores textile-based interfaces for musical expression, emphasizing the potential of malleable and soft materials for interaction.	Developed textile prototypes tested with musicians using qualitative user studies. Combined insights on textile interaction and sound mapping.	Showed promise in creating expressive, tactile, and engaging musical interactions. Provided insights for future textile-based designs.	Limited evaluation on diverse demographics. More iterative prototyping needed for refinement.	Sensation: Tactile interaction with textile surfaces to control sound parameters. Perception: Users interpret fabric deformations as expressive musical input, redefining instrument interaction.	Suggests textiles as a promising material for expanding inclusivity and interaction in musical interfaces.
Buttons, Sliders, and Keys – A Survey on Musical Grid Interface Standards	**2022**	Beat Rossmy	Survey, UI Design Analysis	This paper investigates the presence of emerging design standards in musical grid interfaces by analyzing 40 applications, instruments, or controllers. It identifies 18 UI elements and proposes three design theses for standardizing UI elements in musical grids.	Survey-based analysis of 30 independent user scripts from the monome norns community and 10 commercial grid-based musical devices. Examined UI elements, interactions, and usability heuristics.	Identified recurring patterns in musical grid UI designs, such as common button interactions (click, hold, double-click), standard UI elements (buttons, sliders, keyboards, drum matrices), and navigation structures (pages, tabs). Proposed a formalized classification of grid UI components.	Lack of formalized, universally agreed-upon standards. Usability issues in some designs due to inconsistent feedback mechanisms. Limited exploration of alternative UI paradigms beyond WIMP (Windows, Icons, Menus, Pointer) influences.	Sensation: Users engage with tactile button presses, visual grid illuminations, and haptic feedback. Perception: Users recognize patterns in UI interactions, understand grid-based navigation, and develop an intuition for step-sequencing and note entry.	The study suggests that while grid UIs lack formalized design standards, common conventions have emerged. It proposes structured design principles for improving usability, visibility, and interaction consistency in grid-based musical tools. Highlights the importance of balancing accessibility with expressive musical interaction.
User-Friendly MIDI in the Web Browser	**2022**	Jean-Philippe Côté	Usability Study, API Evaluation, Open-Source Software Development	This paper explores the usability of the Web MIDI API, its limitations, and the improvements introduced by the WEBMIDI.js library. It discusses the challenges of interacting with MIDI devices via browsers	Conducted a usability survey with 58 respondents, analyzing their challenges with the Web MIDI API. Iterative design cycles, user feedback, and real-world testing informed the development of the WEBMIDI.js library.	Findings indicated that the Web MIDI API is too low-level for most users. 93% of survey respondents supported the need for a higher-level library. WEBMIDI.js introduced	Limited browser support (Apple does not support the Web MIDI API). Web MIDI API documentation was incomplete for several years, delaying adoption. Further work needed on accessibility and cross-platform compatibility.	Sensation: Users interact with MIDI devices via web-based interfaces, sending and receiving MIDI messages in real time. Perception: Developers benefit from semantic abstractions, making MIDI integration in web applications more intuitive.	It emphasizes the importance of high-level abstractions in fostering accessibility, usability, and developer engagement. The research sets the stage for further innovations in web-based music technology.
Towards User Interface Guidelines for Musical Grid Interfaces	**2022**	Beat Rossmy, Maximilian Rauh, Alexander Wiethoff	Experimental Study (pre-study and main study)	Musical grid interfaces are becoming an industry standard for interacting with music software and instruments. However, the absence of unified design standards creates challenges due to competing design approaches.	Pre-study: Online survey with 23 participants focusing on challenges in using grid interfaces. Key themes: navigation, button functionality, visual feedback. Main Study: Online interactive grid interface with 24 participants. Metrics included task completion time, errors, distance from targets, and perceived workload.	1. Color Use: Multicolored UIs improved recognition and reduced errors; monochromatic UIs caused more errors in complex setups. 2. Movement Emphasis: Amplified movements improved accuracy; non-amplified movements were faster but less accurate. 3. Animated Transitions: Preferred by users for spatial context but slightly slower navigation.	Limited sample diversity; focused only on statistical measures; did not include cultural and creative experiences.	Enhanced visual and tactile perception improves cognitive mapping and memory retention.	Adaptive color schemes improve usability but need personalization options. Amplified movements reduce focus strain but require optimization. Animated transitions improve spatial understanding but may slow navigation.
Squeeze, Twist, Stretch: Exploring Deformable Digital Musical Interfaces Design Through Non-Functional Prototypes	**2022**	Jianing Zheng, Nick Bryan-Kinns	Qualitative design exploration study with a remote workshop (n=23)	Investigates how deformable interfaces can be used in digital musical instruments (DMIs). A workshop study invited designers to create non-functional prototypes of deformable DMIs. The study identifies key design approaches, interaction styles, and mappings between gestures and sound.	Conducted eight remote design workshops with 23 participants. Participants created non-functional prototypes of deformable DMIs using everyday materials. Open-ended tasks explored mappings between gestures and sound. Thematic analysis of qualitative data (transcribed discussions and observation	Mappings between deformable input (e.g., stretch, twist, press) and sound output emerged naturally. Designers categorized their prototypes into four interaction styles: handheld, surface-based, wearable, and hybrid. Unexpected affordances and gesture-based and form-driven design approaches emerged as primary methods for developing deformable DMIs.	Study lacks real-world implementation; findings are based on non-functional prototypes. No technical validation of how deformable DMIs would perform in live settings. Limited discussion on how such interfaces would integrate with existing digital music workflows.	Explores tactile and proprioceptive sensation in musical interaction. Highlights how material properties shape perceived affordances and user expectations. Study suggests that physical sensation plays a crucial role in intuitive sound control.	Demonstrates that open-ended, material-driven design fosters creativity in DMI development. Highlights the potential for deformable DMIs to enable novel musical expression. Raises questions about how such interfaces would be perceived by audiences versus musicians.

5. DISCUSSION

The findings underscore a crucial paradigm shift in sensory intervention: moving from static, interventions to dynamic, user-responsive adaptive systems. The limitations of conventional sensory therapies—such as Sensory Integration Therapy (SIT) and Multisensory Environments (MSEs)—stem from their inflexibility and lack of real-time adaptability [14]. NIME-based interventions, by contrast, prioritize self-regulation, sensory autonomy, and interactive engagement, offering a more inclusive and sustainable approach.

The review also suggests that rhythm may serve as a powerful regulatory mechanism for individuals with ASD. The

neurocognitive basis for rhythmic entrainment suggests that predictable, structured auditory inputs can enhance sensory processing and motor coordination, making rhythm-based musical interfaces particularly well-suited for ASD interventions. However, while rhythmic predictability enhances engagement, excessive rigidity may limit creative exploration. Future NIME designs must balance structured rhythmic input with elements of free-form exploration to ensure a flexible yet supportive interactive experience.

The integration of algorithmic sensory modulation represents another significant advancement, allowing interfaces to adjust to individual sensory profiles in real time. This adaptability is critical, given that sensory needs fluctuate dynamically in ASD. Unlike traditional interventions, which often impose fixed sensory frameworks, real-time adaptive NIME systems empower users to self-regulate sensory input, thereby reducing sensory distress and promoting engagement. Therefore, adaptive NIME may offer new solutions to assist with the challenges of catering for SOR and SUR sensory profiles for ASD.

6. CONCLUSION

This review establishes the foundation for a new paradigm in NIME-based sensory intervention for autism, emphasizing real-time adaptability, rhythmic structure, and play-based engagement. While traditional approaches to sensory intervention have relied on rigid, clinician-driven frameworks, emerging research in NIME highlights the potential of interactive, user-centered interfaces to accommodate individualized sensory needs. Based on the study's findings we offer the following concise list of design recommendations for NIME practitioners interested in engaging the Autism space and its challenges for SOR and SUR sensory profiles.

6.1 Design Recommendations for Sensory NIME for Autism

1. Real-Time Adaptive Sensory Modulation

- Incorporate algorithmic modulation to dynamically adjust auditory, visual, and tactile stimuli based on user interaction.
- Implement biofeedback-driven adjustments to respond to physiological and behavioral cues in real time.
- Support both sensory over-responsivity (SOR) and sensory under-responsivity (SUR) by offering customizable thresholds for sensory input.

2. Rhythm-Based Sensory Regulation

- Use structured rhythmic elements to enhance focus, reduce anxiety, and improve motor coordination.
- Balance predictability with flexibility, allowing users to engage with structured rhythmic patterns while exploring variations.
- Leverage rhythmic entrainment to promote sensory stability and social synchronization.

3. Play-Centered, Multisensory Engagement

- Design interactive, game-like experiences that foster intrinsic motivation and encourage sensory exploration.
- Integrate multisensory feedback (auditory, haptic, and visual) to support diverse sensory profiles.
- Allow child-led exploration, prioritizing autonomy and low-pressure engagement.

4. Inclusive and Accessible Interface Design

- Develop low-cost, scalable solutions to ensure accessibility beyond research settings.
- Offer customizable interfaces that accommodate individual sensory preferences and needs.
- Use open-source platforms to foster broader adoption and collaborative development.

5. Interdisciplinary and Longitudinal Research Integration

- Collaborate with occupational therapists, neuroscientists, and human-computer interaction specialists for evidence-based design.
- Conduct longitudinal studies to assess the sustained impact of sensory NIME interventions.
- Establish standardized sensory terminology for clarity in interface design and evaluation.

7. NEXT STEPS

Future research should prioritize longitudinal studies to assess the sustained impact of sensory NIME interventions. The integration of biofeedback-driven sensory interfaces, which adapt to real-time physiological and behavioral responses, presents a promising avenue for future development. Additionally, interdisciplinary collaboration with occupational therapists, neuroscientists, and human-computer interaction specialists will be critical in refining evidence-based design principles.

Expanding accessibility remains a key challenge. Many existing NIME prototypes require specialized hardware, limiting their application beyond research settings. Open-source development initiatives should be encouraged to foster scalability and inclusivity. By addressing these next steps, the field of NIME can pioneer a new era of interactive, sensory-responsive musical interfaces, fundamentally transforming the landscape of autism-specific interventions.

8. ETHICAL STATEMENT

This research follows NIME's ethical guidelines for responsible and inclusive practice in music interface design. We aim to contribute to accessible, user-centered tools that respect sensory diversity. We acknowledge that we are not autistic or neurodivergent.

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