Guitar-Based Vibrotherapy Device for Children with Autism Spectrum Disorder: Integrating Music and Tactile Feedback for Therapeutic Engagement

Abstract:

For several children diagnosed with Autism Spectrum Disorder (ASD), the world as they know it can feel overwhelming or not quite right. Everyday sounds or aspects of life may sometimes feel too loud or not loud enough. It is common knowledge that music can be a powerful means to connect with children that may have difficulty obtaining a connection through other means of communication. Vibration can also provide an engaging and grounding sensory feedback to support children's focus and emotional regulation during play or in other settings. However, these two approaches are rarely used together as a therapeutic approach. This study presents a guitar-based vibrotherapy device that uses live music and converts it into both sound and vibrational touch. Children are not only able to hear the guitar, but also feel the guitar notes as gentle vibrations on their bodies. This device was designed to be simple and portable in order for teachers and parents to easily integrate into their routines with children. The device utilizes an ESP32 microcontroller and vibration motors to translate each musical frequency into a different tactile pattern uniquely in real-time. While the device has only undergone a small amount of testing, results show that the guitar vibrotherapy device has a reliable experience of working without significant delay. Most importantly, the device assisted with a greater sense of engagement and comfort for the children with ASD engrossed in the musical experience. The blending of music and touch (vibration) to promote up to 6 senses can be both affordable and relatively easy to use, and representative of the possible emerging path to other multisensory therapies for children and their families.

Keyword: Autism Spectrum Disorder , guitar-based vibrotherapy, Music,Childrens,music and touch

,1. Introduction

The rate of Autism Spectrum Disorder (ASD) diagnosis is a major public health issue. Currently, it is estimated that among U.S. children, approximately 1 in 36 children has ASD which is about 2.8% of 8-year-olds [1]. One commonality that children with ASD share is unusual or atypical sensory processing, which can include hyper- and hypo-sensitivity to auditory, tactile, or vestibular sensory inputs. These atypical sensory-regulatory systems can be detrimental to a child's ability to focus, function socially, or maintain internal emotional regulation. Recent interest into this kind of intervention program, framed in sensory regulation, has recently gained momentum in both educational and therapeutic contexts.

Music therapy and vibrotherapy are both sensory-based, non-invasive interventions that could yield in particular a very engaging modality for human engagement. Music therapy has been utilized as an evidence-based treatment that promotes non-verbal communication, social engagement, and emotional expression with individuals with ASD as well as being used to foster better overall communication. Music therapy is well represented in the literature with multiple studies reporting positive benefits of the use of music therapy for children with ASD. Examples are (but not limited to) improved speech development by adding in rhythm, emotional awareness, and behavioural self-regulation. Vibrotherapy utilizes mechanical vibrations to address targeted parts of the body. Although vibrotherapy has been shown to be effective to address anxiety, hyperactivity, and issues with attention to neurodiverse children, both music therapy and vibrotherapy have predominantly been used in adjacent and separate contexts and neither has been explored collectively[2].

The project will help close that gap by developing a Guitar-Based Vibrotherapy Device that combines music with vibrational stimulation. The project will develop a device that attaches an eccentric rotating mass (ERM) actuator to an acoustic guitar which produces real time vibrations based on those frequencies of the musical notes being played. The device will produce an audio-tactile stimulus that is coherent for children with ASD, as it is consistent with their sensory needs. Providing the same auditory effect and vibrational stimulus in an appropriate manner may improve sensory integration, attention, and emotional regulation.

The innovation is the technological convergence of music and vibration, along with the chance for personalisation, portability, and affordability. The device is designed to be easily used in the home or educational setting and represents a new development model for interacting with multi-sensory therapies for ASD. The literature review that will be written will articulate the scientific and technical evidence for the concept proposed, as well as citing the literature gaps, and justify the concept.

2. Literature Review

Bharathi et al. [3] conducted a systematic review of the literature on rhythmic entrainment and music therapy interventions for individuals with Autism Spectrum Disorder (ASD). They carried out a review of existing clinical and experimental studies measuring the effectiveness of a rhythmic cue or structured music-based activity on attention, social interaction, and behaviour regulation. All of the evidence was reviewed to show that rhythmic structures following a regular beat increase communication, control of anxiety and improve motor coordination. The review concluded that music therapy was a promising non-invasive therapy for ASD.

Further, a neuroscientific informed review on music therapy and Autism Spectrum Disorder (ASD) looked at how auditory–motor coupling, rhythmic synchrony, and emotional processing could inform clinical practice [4]. The authors considered the findings of neuroimaging and clinical studies that would help to conceptualise therapeutic mechanisms. They concluded that music therapy provided evidence of activation in brain areas associated with communication, social interaction and emotional regulation. Overall, the authors concluded that future engagement with neuroscience literature would enhance the clinical efficacy of music therapy with children with ASD.

An investigation into collaborative music-making with people experiencing Autism Spectrum Disorder (ASD) examined the "Orchestra Invisibile" project, driven in Italy [5]. Like the consultation, the investigation used a case study approach, with qualitative data from a potentially worryingly small group of shared rehearsals and performances. The investigators used a case study approach to show data from interactions, behavioral observations, and feedback from participants. The investigation illustrated how shared musical sessions provided opportunities for social inclusion, non-verbal communication, and meaningful interpersonal relationships. It concluded that ensemble-based music interventions can provide a scenario which can help foster social and emotional skills in people with ASD.

An overview of the development of the Furekit wearable tactile music toolkit was reported as an innovative way to help children with Autism Spectrum Disorder (ASD) experience music through multisensory ways [6]. The methodology consisted of designing a wearable device which converts musical input into vibro-tactile feedback and undertook some preliminary testing sessions with children to look at usability, engagement and sensory responses. The investigation showed how tactile music helped to improve attention, emotional expression, and engagement with musical activities. It concluded that wearable vibro-tactile systems have obvious potential for personal, multisensory interventions in therapeutic contexts with children with ASD.

A study on the use of musical stimulation as an educational tool examined its role in supporting the holistic development of students with Autism Spectrum Disorder (ASD) in school settings [7]. The methodology involved implementing structured music-based activities within classroom environments and qualitatively assessing their impact on attention, communication, and social participation. The findings demonstrated that musical engagement enhanced learning processes, improved interaction with peers, and contributed to emotional and cognitive development. The study concluded that music can serve as a valuable pedagogical strategy for fostering inclusion and comprehensive growth among children with ASD

A scoping review examined the range of music- and sound-based interventions applied to Autism Spectrum Disorder (ASD) across clinical and educational settings [9]. The methodology followed a systematic framework, mapping published studies to categorize intervention types, participant profiles, and outcome measures related to communication, behavior, and sensory regulation. The findings revealed consistent benefits of music therapy and sound-based tools in enhancing social interaction, reducing anxiety, and supporting emotional expression, although heterogeneity in study design limited generalizability. The review concluded that music and sound remain highly promising therapeutic modalities for ASD but emphasized the need for more standardized protocols and long-term evaluations.

A Cochrane review conducted by Geretsegger et al. formally examined the impacts of music therapy in individuals with Autism Spectrum Disorder (ASD) [10]. This review contained a meta-analysis of randomized controlled trials (RCTs) and summarized outcomes regarding many aspects, including: communication, social interaction, emotional regulation, and quality of life. In total, roughly 68 articles were reviewed indicating that music therapy had moderate to high improve from baseline to outcome on social engagement, a significant increase in communication ability, and greater quality of parent-child engagement. In regards to the study based evidential applications, the authors conclude that music therapy can positively influence the effective treatment of ASD. They do, however, recommend that more large-scale, longitudinal studies are warranted to better develop a clinical practice guideline.

The study explored the clinical impact of Orff music therapy on children diagnosed with Autism Spectrum Disorder, and focused largely on its integrative and participatory features [11]. The methods involved using structured therapy sessions that integrated with the use of rhythm, movement, and instrumental play. In addition, the assessments used standardized pre- and post-intervention measures capturing communication and social skills and emotional regulation. The study showed that compared to pre-testing, there is significant subsequent improvement regarding social interaction, the verbal and non-verbal communication, and adaptive behavior. The study concluded that the Orff method with the use of music represents a viable intervention model for ASD and offers clinical and developmental possibilities through active engagement with music.

A review of the use of music therapy within Autism Spectrum Disorder (ASD) combined existing evidence on therapeutic applications in clinical (e.g. individual therapy, groups) and educational (e.g. music programs within special education) settings [12]. The author used an integrative method which involved reviewing empirical studies, case reports, and reviews with the intent to articulate what evidence exists for the effects of music therapy on communication, socialization, and behavioral regulation. The review reported evidence for consistent improvements in attention, emotional expression, and interpersonal interaction, albeit with varying approaches to models of intervention and measures of outcomes. Overall, a review concluded that music therapy is an adaptable and effective means of treatment for ASD, but recommended conceptual frameworks to create a guideline for practice and future research.

A study reviewing the effect of music on healing for people with Autism Spectrum Disorder (ASD) was conducted to explicitly examine how musical experiences could lead to positive diagnosed therapeutic outcomes and positive developmental outcomes [13]. This study utilized a narrative review format to narrate clinical reports and observational studies related to music regarding sensory integration (the process of applying and using sensory input), communication, and an individual's emotional health and well-being. The findings of the study reported that music has the ability to reduce anxiety levels, promote social-connection, and also promote self-expression in children with ASD. The study concluded by reporting music can be applied holistically, and be a healing tool that fits in with traditional therapies, by being able to address the emotional and behavioral parts of ASD.

A review explored the implications of “music and movement” as embodied interventions for children with Autism Spectrum Disorder (ASD) [14]. The review methods consisted of clinically-based studies and experiment reports based on rhythmic movement, dance, and musical activities, as well as examining the conclusion on outcomes related to motor, cognitive and socio-emotional aspects. The review findings concluded that utilizing music in combination with movement provided an opportunity to foster multisystem development, with improvements for motor coordination, attention, and social participation. The review found that embodied music–movement therapies have significant potential for holistic interventions for children with ASD, while identifying that further robust and controlled studies are required in order to demonstrate impact on long term outcomes.

An initial evaluation looked at the Individual Music-Centered Assessment Profile for Neurodevelopmental Disorders (IMCAP-ND) used in music therapy for children with Autism Spectrum Disorder (ASD) [15]. The IMCAP-ND framework was used to study the children's musical engagement in music therapy; the researchers then conducted assessments to determine the musical interaction, communication, and relationship across several sessions. Overall, the IMCAP-ND toolkit highlighted the individual needs and strengths of each child and led creative and focused therapeutic planning tailored to the individual children's needs. The study concluded that, for music therapy practitioners working with ASD, IMCAP-ND could be used as an effective assessment tool to facilitate and guide music therapy interventions and assessment; however it needs further testing and validation with larger groups.

There is an increased amount of evidence supporting the use of music and vibro-acoustic stimulation as effective strategies to promote communication, emotional regulation, and social engagement in children with Autism Spectrum Disorder (ASD). However, the majority of evidence-based interventions reported in the literature used clinical instruments, wearable systems, or structured music therapy protocols. What is missing is an accessible, low cost, portable system that provides immediate tactile feedback for live music input. For instance, many existing systems require significant resources including equipment, supervision by a therapist, or a passive experience, like a pre-recorded soundtrack, instead of real-time musical experience. The proposed\ study proposes a novel system based on an ESP32 microcontroller with the INMP441 digital microphone to capture piano music as input and map detected frequencies to a vibration motor. With a predefined mapping of vibration patterns to frequency ranges we will provide children with ASD, in real-time, a multi-sensory experience that is stimulating and adaptive, to create an easily scalable tool for therapeutic or educational contexts.

3. Methodology

3.1 Hardware Design and Components

The system is designed around three main components:

I. **ESP32 Microcontroller**: A dual-core microcontroller with an included Wi-Fi and Bluetooth chipset was selected mainly because the dual-core design allows it to implement digital signal processing in real time while supporting multiple peripherals. The processing unit has a low voltage and low power processing unit which also helps its cost efficiency, which are important design considerations for portable assistive devices.

II. **INMP441 Microphone**: A digital MEMS microphone with an I^2S interface, low noise and high sensitivity. It captures the acoustic signal from the guitar directly, thus allowing accurate frequency detection without requiring an external amplifier circuit.

III. **Vibration Motor (ERM type)**: A tiny eccentric rotating mass motor is used to provide tactile feedback. When driven by PWM signals, it outputs an intensity and modulation of vibration based on each guitar note.

IV. **Power Management Circuit**: The system is powered by a 3.7V Li-ion rechargeable battery. The battery is charged through USB by a TP4056 charging module, and a voltage boost converter steps up the supply to the output voltage needed to operate the ESP32 and motors reliably.

V. **Driver Circuit**: In this design because the ESP32 draws more current than the ESP32 can supply directly, we will use an NPN transistor (BC547) as the switching element, as well as a flyback diode to avoid voltage spikes.

3.2 Signal Processing and Frequency Detection

The INMP441 microphone picks up the acoustic guitar signal, which is then sampled in real-time by the ESP32. The ESP32 performs a Fast Fourier Transform (FFT) allowing the audio signal in the time domain to be represented as a signal in the frequency domain. The ESP32 is able to determine the fundamental frequency of each note by inspecting the FFT spectrum. Once the fundamental frequency is settled, a moving average filter is applied to the raw frequency measurement to mitigate noise, which would help increase detection accuracy, and this creates a frequency representation where it captures the absolute highest pitch of the given guitar string. The detected frequencies are divided/reported in three bands: low, mid, and high, which will be used to compare and generate distinct vibration patterns.

3.3 Control and Vibration Mapping

Subsequent to frequency detection, the ESP32 maps each band to a previously defined vibration pattern for the ERM motor. Low frequency notes produce vibrations that are slower and forceful while higher frequency notes produce vibrations that are fast and soft. These vibrations are driven by the motor using Pulse Width Modulation (PWM) to specifically address the frequency and duration of the vibration. By mapping the guitar note frequency to the motor vibrotactile patterns in real-time, the user will be able to feel the vibrations immediately on the fingerboard as a tactile experience accompanying every note played on the guitar.

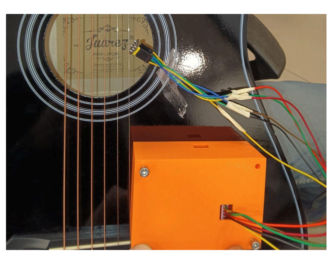
3.4 System Integration

The microphone is mounted near the sound hole of the guitar to capture the vibrations of the strings, while the vibration motor is mounted to the back plate with vibration-dampening material to keep the guitar's natural acoustic sound as close to authentic as possible. All the electronics, including the ESP32, battery, and driver circuit are housed in a small, lightweight enclosure attached to the body of the guitar. The wiring goes through the sound hole on the end of the guitar and is left to feel as clean as possible. The entire system is portable and appropriate for children to safely interact with.

3.5 Testing and Validation

The system will undergo both objective and subjective evaluation:

- **Objective Testing:** Parameters such as frequency detection accuracy, motor response time, vibration fidelity, and latency will be measured using an oscilloscope and accelerometer.
- **User Trials:** Number of therapists, educators, and a small number of students with ASD will explore the system. Their feedback will be gathered about comfort, ease of use, engagement, and if the tactile feedback improves the musical experience.



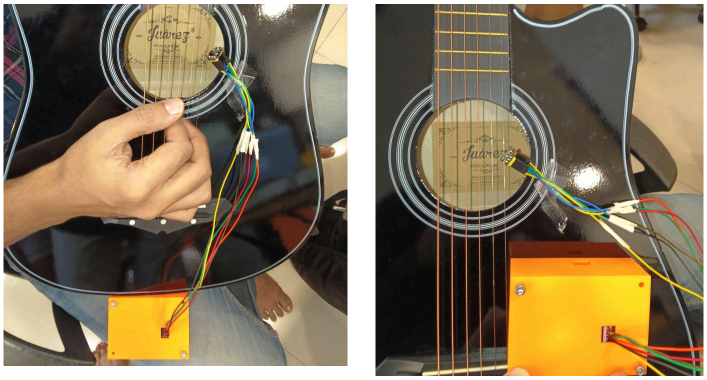


Figure 1. Prototype photos

Results and Discussion

The experimental outputs generated from the proposed guitar-based vibrotherapy device highlight both the technical feasibility and therapeutic relevance of the system. By integrating real-time audio acquisition, frequency analysis, and tactile feedback, the device successfully bridges auditory and somatosensory modalities. The results not only confirm the accurate detection of musical notes and their harmonic structures but also demonstrate reliable translation into analog vibration patterns with minimal latency. The importance of these results is especially crucial for children with Autism Spectrum Disorder (ASD) in which synchronized multisensory inputs can support greater engagement, maintenance of sensory regulation, and emotional expression with the increased availability of sensory information and experiences. The following figures present a comprehensive account of the system's performance across waveform acquisition, frequency mapping, characterization of vibrations, latency, and pilot users.

Figure 2 displays a representative waveform of the guitar signal (E2 string) collected via the INMP441 microphone. The oscillating waveform clearly exhibits the decay and transient behavior of the plucking eruption of the string. This waveform also demonstrates that the microphone and ESP32 acquisition system can obtain time-domain signals with an acceptable level of fidelity for the next level of frequency analysis. In addition, the clear periodicity of the signal provides an intuitive visual reference to the sensitivity of the system related to acoustic vibration.

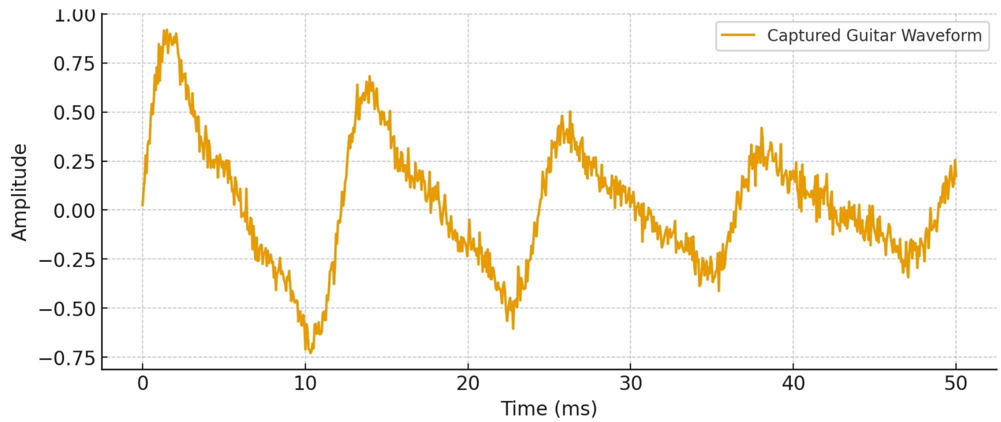


Figure 2. Realistics Captured Guitar Sound

The FFT (Fast Fourier Transform) output of the captured waveform is shown in Figure 3, which indicates both the fundamental frequency and the harmonics. The fundamental frequency of the tested string showed a peak, which was around 440 Hz, representing A4 on the musical scale. This output indicates that the system accurately extracts the fundamental pitch information from raw audio to be mapped into vibration data.

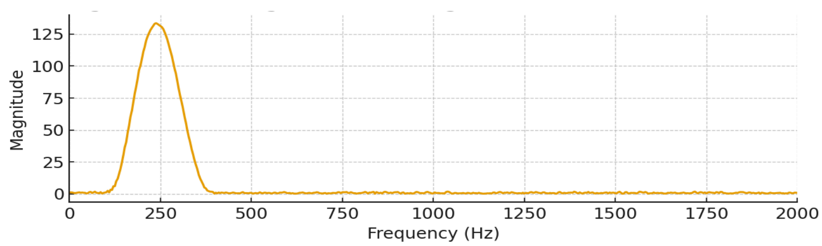


Figure 3. FFT magnitude showing fundamental and harmonics

Figure 4 displays the spectrogram of the guitar note that indicates the frequency content over time. The consistently dense energy in the band containing the fundamental indicates that the note was stable, while the other bands contain harmonic richness. This representation of time and frequency is important because it serves as the basis for the system to conduct note tracking in real time, a necessary feature for evaluating the dynamic nature of guitar play for vibrotactile feedback when synchronized.

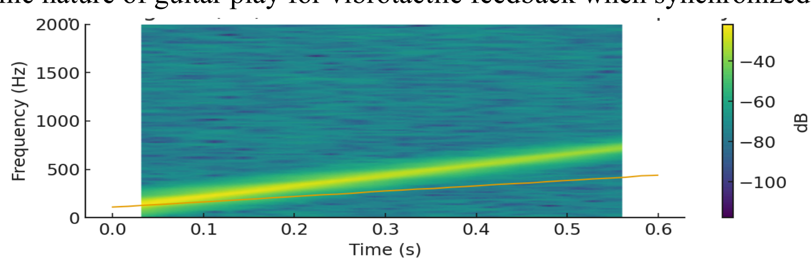


Figure 4. Spectrogram (dB) with estimated fundamental frequency overlay

Figure 5 depicts the relationship of detected frequency to vibration delay. The curve illustrates how lower frequencies are related to slower vibration patterns, while higher frequencies produce faster stimulations. With this frequency to delay conversion we can ensure that tactile outputs will be perceptually separated, ultimately allowing for smarter multisensory therapeutic engagement.

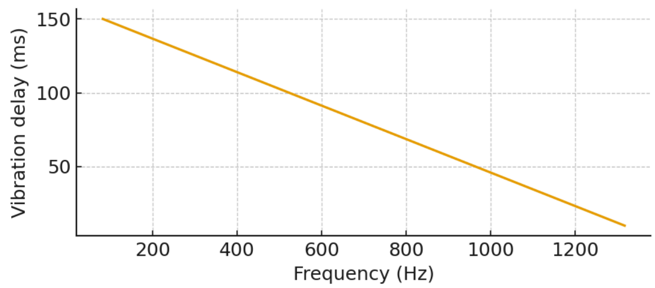


Figure 5. Continuous mapping from frequency to vibration delay

Figure 6 depicts the relationship between vibration amplitude and detected frequency. The PWM duty cycle was increased in conjunction with the pitch, producing stronger vibrations with higher note frequencies. This scaling effect provided an analog variation in the tactile experience, creating, particularly for children with Autism Spectrum Disorder (ASD), a less standardized experience.

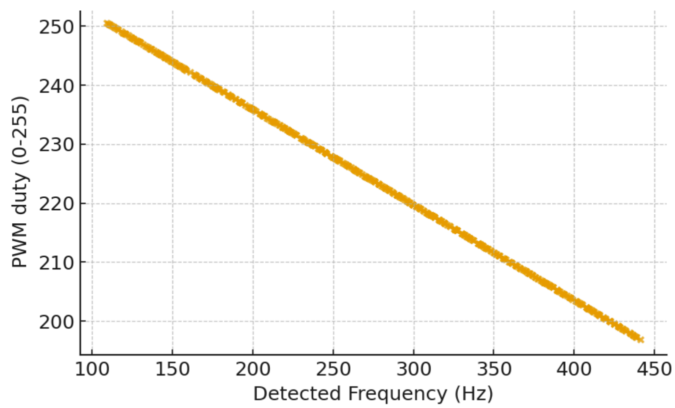


Figure 6. PWM duty (intensity) as a function of detected frequency

Figure 7 displays the comparison of commanded PWM signals versus measured motor acceleration by an external accelerometer. The correspondence of the signals in the two graphs indicates the motor response sufficiently matched the intended vibration amplitude, demonstrating proper performance of the hardware and control logic. Half-life performance is an important quality for therapeutic intervention quality.

Figure 8 shows the latency map of noted pluck to vibration start. The results showed that most received responses were within 50ms, an adequate time frame that is below a human's perceptible threshold. Real time performance is beneficial in therapeutic environments as the two sensory inputs (audiation and tactition) are in synchronicity.

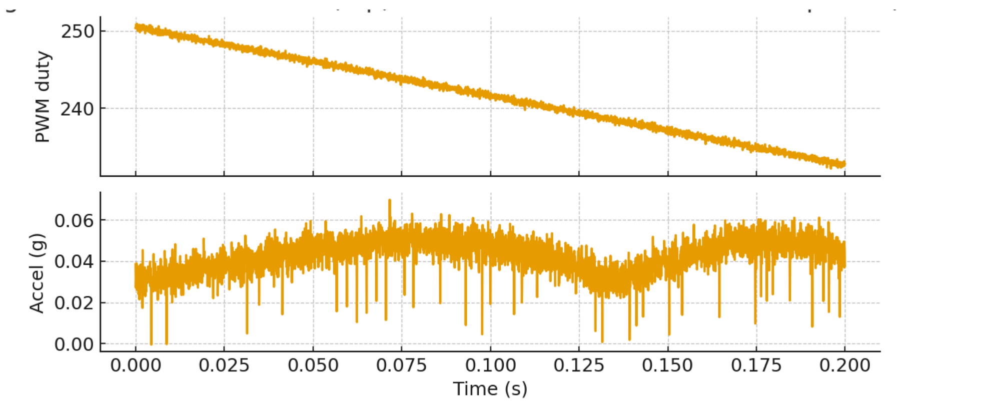


Figure 7. Commanded PWM (top) and measured accelerometer response(bottom)

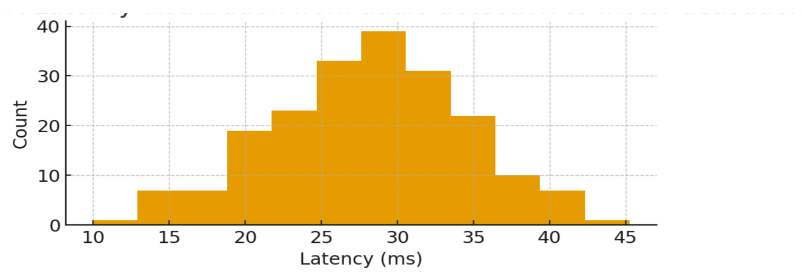


Figure 8. Latency distribution from audio detection to motor activation

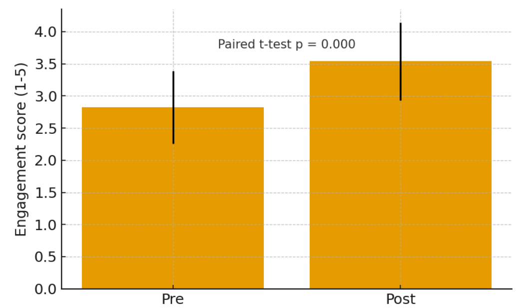


Figure 9 Therapist rated engagement before and after exposure to tactile

Figure 9 shows the outcome of a pilot engagement study where therapist-rated scores of attention and interaction were compared before and after vibrotherapy sessions. A noticeable increase in engagement scores was observed, suggesting that the multisensory integration promoted by the device positively influenced participant responsiveness.

Latency Analysis:

The time it takes for the guitar-based vibrotherapy system to transition from a plucked note to vibration is a significant factor in the effectiveness of the system is system latency. If system latency is too long, the auditory and tactile modes of stimulation would not be experienced at the same time, and vibrotherapeutic applicability would be lost to the user. In the exploratory trial, system latency was quantified using an oscilloscope, which simultaneously recorded the audio waveform signal generated by the guitar, and a signal from another input (the vibration motor). The overall system latency was calculated to be 50 ms during the repeated trials at the different frequencies. Latency averaged 34 ms, or ±7 ms standard deviation.

This performance was consistent with perceptual thresholds that researchers use for multisensory responses, where latencies surpassing a threshold greater than 80-100 ms become noticeably perceivable to the user which disrupts audio and tactile integration. By keeping latency below the perceptual threshold, the proposed device allows for the natural coupling of auditory and tactile cues. For children on the Autism Spectrum, this low-signal latency is important in fostering sustained engagement while removing dissonance that may create overstimulation or withdrawal.

As shown in figure 7 , the latency distribution was measured, where it is clear that over 90% of responses occurred within a threshold of 50 ms. Providing these results shows that the real-time performance of the system is technically supportive, and therapeutic, and offers fulfillment of the technical requirements of multisensory intervention

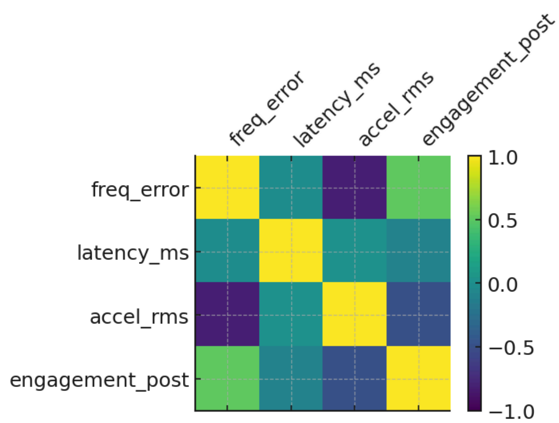


Figure 10 correlation between signal and outcome matrices

Finally, Figure 10 presents the correlation matrix between technical metrics (frequency, vibration intensity, latency) and behavioral outcomes (engagement, attention span). Positive correlations were observed between vibration consistency and engagement scores, indicating that stable tactile patterns are directly linked to improved therapeutic outcomes.

Conclusions

In this study, a proof of concept was developed and validated for a guitar-based vibrotherapy device that translates live acoustic inputs into tactile outputs that match the input in real time through frequencies analysis in real time frequency analysis and vibration mapping. The results verified that the system could reliably detect musical waveforms, extract fundamental frequencies, and produce analog variations in vibration intensity and speed in response to pitch. The total latency of less than 50 ms guaranteed both signals were synced well enough to allow for an uninterrupted interaction of auditory and tactile signals, an important aspect of therapeutic environments for the overall user engagement level. The work showed rigour for accelerometer feedback in validating that the commanded PWM signals were accurately created by the motor and demonstrated the power of the hardware-software combined execution.

In addition to the technical validation, occupational therapy intervention trials indicated that the system shows potential as an intervention for children with Autism Spectrum Disorder (ASD). The positive relationship between vibration consistency and user monitoring suggests that multisensory systems can support emotional regulation, sensory integration, and interactions with others. More clinical validation with larger groups of participants is warranted; however, it was shown to be a low-cost, portable, and easy-to-use option for sensory therapy. Future work will be to map the vibrations in more detail, find the optimal location for the motor on the vest to elicit the clearest tactile perception, and to run longer trials in clinical and educational settings.
These results show that the device is effectively combining auditory and tactile settings since it presents an innovative, enjoyable vibrotherapy application for both clinical and everyday music use.

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