

A Step towards Identifying the Sound Preferences of Children with Autism

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ABSTRACT

Music-based therapies are increasingly being used to support children with autism with promising clinical results. However, we have a little understanding of which are the most appropriate sounds to be used in music-based interventions for children with autism. In this paper, we describe a pilot study to understand the attention and emotions of children with autism when listening to different sounds. We measured participants' attention using a wearable brain-computer headband, and a psychologist scored their emotions through direct observation. We compared 15 sounds including three *natural* sounds, and a *melody* and a single note being played with cello, clarinet, and piano, in a low and high pitch. Our results show children with autism stay more focused when listening to a *melody* being played with a cello in a low pitch. Additionally, they were more distracted and felt more negative emotions when listening to *natural* sounds. We close discussing how our results could be a first step towards a potential understanding of what are the proper selection of sounds that could inform the design of pervasive healthcare applications for this population.

Author Keywords

Sounds feedback, autism, music-therapy, brain-computer interfaces.

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION

Autism is a neurological disorder associated with impairments in attention, communication, social interaction, and behavior [1]. Most children with autism exhibit significant sensory-motor problems [34]. There is evidence that indicates that children with autism enjoy musical

activities [12] and music can help them to deal with their behavioral, emotional, sensory, and motor problems [33].

Music-based therapies, such as auditory-motor mapping techniques [35], melodic intonation therapy [27], rhythm therapy [26], the Tomatis method [5], and improvisational [15] and neurologic music therapy [11], are increasingly being used to support children with autism having promising clinical results. These results are mainly related to improvements in facilitating communication and social skills [36], attention [13], expression of emotions [14] and sensorimotor regulation [2, 33].

Current therapeutic interventions, using musical experiences, involve activities like singing, playing musical instruments, and listening to different sounds [33]. In recent years, pervasive technology has proposed to assist children with autism during therapies involving musical activities [16]. For instance, previous research has shown that pervasive technology could support children with autism during music-therapy sessions [4] and the proper selection of sounds could have an impact on the therapy outcome [32].

As most children with autism have impairments in communication and do not express their emotions [1], it is difficult to gather their feedback to understand their preferences. Hence, we have a little understanding of which are the most appropriate sounds to be used during music-based therapies for children with autism.

Previous research has used brain-computer headbands, such as Mindwave¹ from Neurosky, to measure the attention span of children when attending to a particular task [20]. Mindwave is portable, flexible, and suitable to acquire mental data from children with autism [6]. However, to our knowledge, there are no studies using brain-computer headbands to understand the attention levels of children with autism when listening to different sounds.

In this paper, we hypothesize that the use of brain-computer headbands supplemented with direct observation could help us to understand the attention of children with autism when listening to different sounds. This knowledge could be used to inform what sounds could be more engaging and suitable

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to be used in music-based therapy interventions, in video games or pervasive healthcare systems designed for children with autism.

The main contributions of this paper are:

- We show that the Mindwave headband could be useful to conduct studies of sounds preferences with children with autism.
- We present empirical evidence revealing how the attention and emotions of children with autism vary when listening to different sounds being played with different musical instruments and in different pitches.

RELATED WORK

We first describe research quantifying users' attention placing especial focus on those solutions using a Brain-Computer Interfaces (BCI). We then describe research that has studied different musical structures and sounds when designing musical interfaces and interactive sonification solutions. This research is relevant to us to unveil the importance of understanding sound preferences when designing pervasive healthcare solutions, and identifying what we know about the sound preferences of different populations, especially those of children with autism.

Identifying and quantifying attention

A typical technique used by psychologists to measure attention is through direct observation [24]. Direct observation demands a researcher to collect data by observing users' behaviors during activities of interest. However, this solution is costly, highly interpreted, and demands a lot of manual labor. So, several research projects in pervasive healthcare have proposed solutions using sensors to more objectively measure attention and supplement the direct observation. The most widely used solution to measure attention is the use of eye gaze trackers [25]—as eye gaze and face orientations are the most common indicators used to quantify attention [18]. However, in recent years, the use of BCIs is considered more unbiased to recognize attention—as in contrast with eye gaze trackers BCIs solutions use the electrical activity signals of the brain to measure attention [19].

For example, Mindwave has been used to measure the attention of individuals with attention deficit hyperactivity disorder (ADHD) to improve their inattentive symptoms during therapeutic interventions [20]. Also, Mindwave has been used for selecting the music preferences of individuals based on their measured attention [21]. For instance, Liu *et al.* [21] designed a system that measures drivers' attention using Mindwave to select the appropriate music to help them stay alert.

Mindwave was also used to detect the mental activities of children with autism when playing games [6]. Five children (two with autism) played an exergame using a Kinect sensor and a Mindwave headband to capture all of their movements and mental data respectively. One teacher evaluated the

movements and children's engagement through direct observation. A classification framework proposed shows 95% of accuracy in detecting engagement and motion in children with autism.

This body of work shows the use of portable and low-cost BCIs, particularly the Mindwave headband, is feasible to measure the mental activity of young individuals, neurotypical children, and children with autism during therapeutic interventions and in their everyday activities (e.g., driving). However, to our knowledge, there are no studies to understand how the attention of children with autism varies when listening to different sounds.

Musical interfaces and interactive sonification

Previous research has proposed to use pervasive technology to support individuals with disabilities during music-based therapies [3, 4, 9], but little research has been done in supporting children with autism (the population of our interest) during music-based interventions. An effort in this direction has explored how to support children with autism during music therapy sessions [4]. This research project involves the development and evaluation of BendableSound [4], an elastic display encouraging children with autism to practice motor coordination movements when touching a fabric to play sounds. A deployment study with children with autism showed BendableSound is easy to use and could have potential therapeutic benefits. However, in BendableSound therapists need to select the song and the musical instrument according to each child's preferences from a predefined list of sounds. Unfortunately, most therapists have little knowledge about which are the most appropriate sounds to better encourage repetitive movements being practiced during therapies. This work shows that pervasive healthcare technology is useful to support music-based therapies of children with autism; however, there is no evidence of which kind of sounds children with autism prefer and which ones are better to be incorporated into musical interfaces for this population.

Beyond exploring interaction with songs in general, other projects have shown the use of sonification techniques to explore the relationship between movements and music [31, 32]. For example, the use of sonification techniques with wearable technologies has shown to be adequate to provide feedback to users about their movements during rehabilitation therapies [7, 32]. The sounds designed use anchor points to provide information about movements. Patients could choose between different sounds structures, two musical instruments, and *natural* sounds. Control studies with patients with chronic pain found that a simple sonification structure was more effective in enhancing body awareness than complex sounds.

Another example is the use of interactive sonification of spontaneous movement of children [7]. In this research, three different sounds structures, based on filtered noise, were

created and tested. The first sound structure produces a smooth, wind-like sound. The second one produces a more abrupt sound. The third one produces a very choppy and clicking sound. An evaluation study with eleven children (aged 5-6 years) found that the smoothest sounds encouraged participants to move more continuously [7]. This study shows that sounds might affect the characteristics of the body movements and that different sounds could provide a different outcome during therapies. However, there is no evidence of how such sounds could be used to support the therapies of children with autism.

Although this body of work has shown that music has been successfully integrated in pervasive healthcare technology to support therapies of children with autism, to our knowledge, there is no evidence of which type of sounds are more appropriate for children with autism. Also, there is evidence that BCIs could be used to measure attention during different tasks; but our literature review showed there are no studies exploring the use of BCIs to measure the attention of children with autism to identify their sounds preferences.

METHODS

We conducted a one-week pilot-study to understand the attention and emotions of children with autism when listening to different sounds. The design of the study was within-subjects.

Participants

We recruited nine children with autism from “Pasitos”, a school clinic specialized in the care of children with autism in Mexico. Participants² were between four and eleven years old, but with the same developmental age (Avg. age = 6.2; SD = 2.17). Participants were voluntarily enrolled in the study, and all parents consented to the study on behalf of their children. Most participants were not verbal and had attention problems. None of the participants in the study had taken music lessons. Also, three psychologists-teachers from Pasitos participated in the pilot study.

Sounds

We selected a set of sounds according to the structure used in [32], as these sound structures have been previously evaluated in rehabilitation and therapeutic context [32]. Each sound lasts 10 seconds. We particularly used:

- Three *natural* sounds including sounds of wind, water, and birds
- A *flat* sound consisting of 11 repetitions of the same note
- A *melody* sound consisting in the first 11 notes of a nursery rhyme similar to the *wave* sound proposed in

²For simplicity of reading, we will now refer to the children with autism participating in our evaluation study as participants

³We selected these three musical instruments as they are in the bass and midrange frequency. The three of them can play the selected pitches, and belong to different groups according to the western classification of musical instruments (wind, string, and key).



Figure 1. A child with autism hearing a sound and using the Mindwave headband during the study (left). Set-up of the study (right).

[32]. The *melody* sounds do neither include lyrics nor chords.

For the *flat* and the *melody* sounds, we designed six variations. Each sound was played using the timbre of three different musical instruments³ including cello, piano, and clarinet. Each instrument was played using both high and low pitch notes⁴, but not mixed. Overall, we designed 15 sounds, including the three *natural* sounds and the variations of the *melody* and the *flat* sounds.

Setting up and installation

The experimental procedure took place in a therapy room at Pasitos (Figure 1-left). During the experimental procedure, we used a PC with Windows 8.1, CPU 2.70 GHz, and 4 GB of memory with an application developed using Unity⁵ and Open Vibe⁶ to communicate and record the data from the Mindwave headband (Figure 1-right). We selected this headband from others commercially available (such as Emotive or Muse⁷) as its installation is relatively easy, its internal ThinkGear Chip already measures attention in the scale of 0 to 100 at a rate of 1 Hz, and has been previously used with children with autism [6]. The second author, who is trained in neurofeedback techniques, operated both the application and the Mindwave headband during the sessions.

We controlled the lighting and sounds condition of the room, and we removed all the visual stimuli from the room. Participants sat comfortably on a chair with enough distance (about 50 cm) from the screen display with integrated speakers (Figure 1-left).

Data collection

To measure the attention levels of the participants, we used the Mindwave headband. To reduce potential noise when recording data, participants were instructed to remain as still as possible and avoid abrupt movements (Figure 1-right). Although this could be challenging for some participants, the psychologist could provide a verbal or physical prompt to

⁴We selected the C3 note as a lower pitch and C5 note as higher pitch starting note

⁵<https://unity3d.com/>

⁶<http://openvibe.inria.fr/>

⁷EmotivEpic (<https://emotiv.com/>), Muse (<http://www.choosemuse.com/>)

ask them to remain sitting. Psychologists sat to the left side of the participants to observe their behaviors and score their emotions.

The psychologist answered a brief survey consisting of one question about the emotional state of the child according to the valence-arousal plane [28], where emotions are organized regarding affect and appraisal (positive-negative), and participants' physiological reaction (active-passive arousal). The valence-arousal plane has been widely used to classify individuals' perception of affects and musical features [38].

Procedure

As most of the participants were hypersensitive and did not easily accept to wear accessories on their heads [1, 34], we conducted a sensitization process previous to the pilot study. Then participants were asked to wear a traditional headband and clip-earrings to help them get used to wearing the Mindwave headband with a clip in their earlobe. They wore the clip-earrings for one week from 5 to 15 minutes, on a daily basis during their everyday activities at Pasitos.

Then, we conducted the pilot study, consisting of three stages, lasting for around 10 minutes per participant. To avoid losing the attention of participants, none activity was conducted before the calibration process.

Calibration: during the first stage, participants conducted a relaxation and an attention task for the auto-calibration of the headband. Auto-calibration is needed when using the Mindwave headband as its algorithms, to infer attention, use "slow adaptive" techniques that need to be adjusted to natural fluctuations and trends of each user –to avoid adding noise to the data these activities were not used as a control. Auto-calibration lasted 1.5 min per child. During the relaxation activity, participants watched an animation of bubbles randomly appearing in the display for around 30 seconds. During the attention activity, participants solved a visual discrimination task based on a continuous performance test widely used to measure attention [8]. For around 30 seconds, the test shows in the display two cards containing cartoons of different objects available in a farm. Cards randomly changed every 5 seconds. Participants must press the sidebar of the keyboard when the two cards match and show the cartoon of a tractor. None of these activities have sounds, and both have been widely used in the literature to quantify and measure when individuals are paying attention [8] or relaxing[22].

Listening to sounds: during the second stage, which is the experimental portion of our pilot study beginning just after the participants finished the attention task, participants had to listen to our 15 designed sounds completing 15 trials. A trial consists of the following ordered sequence of events (Figure 2):

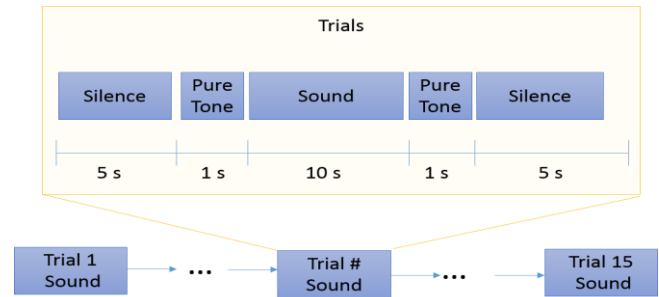


Figure 2. Trial structure adopted in the third and fourth stage of the pilot-study.

- 5 seconds of silence, serving as a neutral control condition for attention.
- 1 second of a pure tone (i.e., a tone with a sinusoidal waveform), as a sign of alert to ease the transition between silence and sound
- 10 seconds of a sound. Sounds were randomly selected from our database of 15 sounds to avoid the effect of transitions
- 1 second of a pure tone to signal the ending of the sound
- 5 seconds of silence, returning to the initial condition

Our trial mimics other trials' structure that has been used to recognize musical preferences with BCI [10]. The intervals of 10 seconds of sound, and 10 seconds of silence (5 seconds in the beginning, and 5 seconds at the end of the trial) fall into the range of inter-stimulus interval previously reported in related studies [10, 17, 29].

When listening to sounds, the display shows a fixed icon representing a musical note as a reference point to focus participants' sight on the screen. Participants received a star as a reward after completing three trials. The goal for each child was to collect five stars.

During the silence periods of the trials, psychologists were asked to score the emotion that better represented the emotional state each participant exhibited one each trial. Psychologists selected one emotion per trial if participants exhibited any.

Control sounds: finally, in the third stage, after completing the 15 trials and as a control task for emotions, participants heard an *annoying* and a *pleasant* sound for 30 seconds each. The *annoying* sound consisted of random sounds from a crowded place, as psychologists explained our participants dislike the sounds of crowds. The *pleasant* sound included the "Old MacDonald" song with both lyrics and chords that our participants found enjoyable.

According to psychologists, both sounds were familiar to participants. The sounds follow the same structure of a trial (Figure 2), but these sounds last 30 seconds instead of 10 seconds to allow participants recognize the sounds. As in the other trials, the psychologist scored participants' emotional state. Similar controls have been used previously to analyze sounds preferences using BCI [30].

Data analysis

Here, we describe the analysis we conducted with our attention and emotion data.

Attention

To analyze attention, we computed:

- each participant's average attention when listening to each sound
- each participants' average attention about the type of sound, musical instrument, and pitch being used to play the sound.
- the average attention of all participants for each type of sound, musical instrument, and pitch.

Since the attention could change due external factors during the experiment (e.g., time elapse, fatigue), we calculated how each sound differs from silence. We particularly computed the difference between attention of each sound and its previous silence interval as a control for attention. Also, to compare the behavior of the attention between the different sounds, we computed a linear regression analysis across time (10 s) for each type of sound, musical instrument, and pitch.

Emotion

To analyze the emotion data, we computed the total of emotions' instances that participants exhibited per trial. In total, we defined four types of emotions, according to the valence-arousal plane [28]: active-positive (e.g., happy, excited), passive-positive (e.g., relaxed, calm), active-negative (e.g., annoying, angry), and passive-negative (e.g., sad, boredom). Then, we calculated the average percent of emotions about the type of sound, musical instrument, and pitch being used to play the sounds. Thus, we present the average percent of the instances of positive and passive emotions that participants exhibited per trial. We focus on discussing positive and passive emotions as they are more related to engagement.

RESULTS

Overall, participants stayed more focused and exhibited more positive emotions when listening to *melody* sounds, and to those sounds being played with cello and low pitch.

Additionally, participants were more distracted and felt more negative emotions when listening to *natural* sounds.

Type of sound

Here, we describe the results of attention and emotions according to the three types of sounds: *flat*, *melody* and *natural*.

Attention

On average, participants' attention when listening to the *melody* sounds was a little bit higher (Avg. = 52.34) than when listening to the *flat* (Avg. = 48.9), and *natural* (Avg. = 48.72) sounds. Comparing participants' attention when listening to any of the sounds against its previous silence (our control); 88% of participants increased their attention level when listening to the *flat* sound, 66% when listening to the *melody* and 55% when listening to the *natural* sounds (Figure 3-left). On average, participants' attention differs more when listening to the *flat* sounds (Diff. = 4.75), in contrast, to the *melody* (Diff. = 2.99) and *natural* sounds (Diff. = 0.04). These results could be partially explained as the *melody*, and *flat* sounds have a more predictive pattern that could be more easily interpreted by children with autism [2].

Our linear regression analysis (Figure 3-center), revealed participants' attention is more likely to increase over time when listening to the *melody* sounds. In contrast, participants' attention is more likely to decrease over time when listening to the *flat* and *natural* sounds, as the behavior of the data has a negative trend. Participants' attention span when listening to the *melody* sounds seems to last for around 5 seconds; in contrast to the *flat* and *natural* sounds that last for around 3.5 seconds. These results may suggest that the *melody* sounds could be used to better catch and maintain the attention of children with autism over time.

Emotion

According to the psychologist's perceptions, on average, 66% of participants' emotions were positive (e.g., happy, relax) when listening to the *melody* sounds; in contrast, to the *flat* (Avg. = 53.7% of instances) and the *natural* sounds

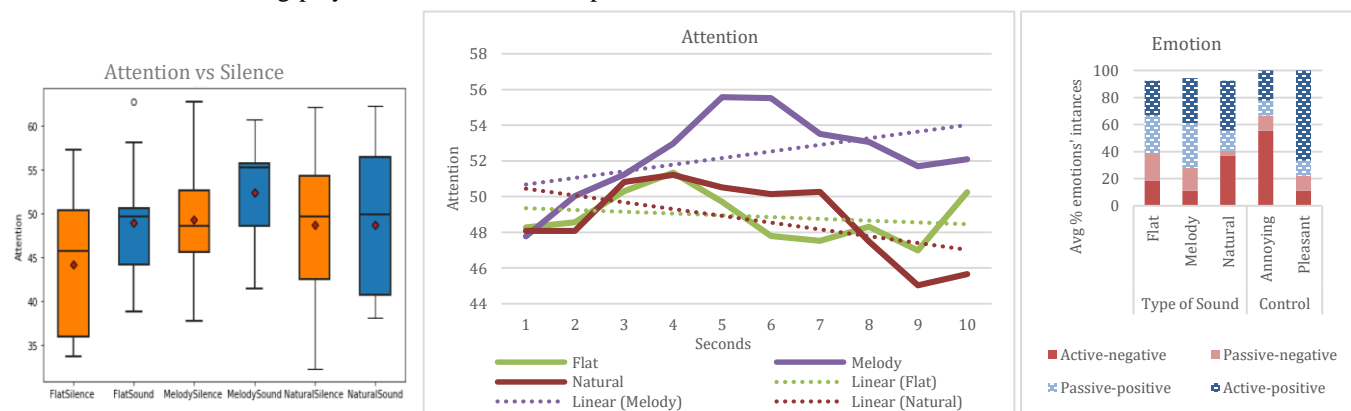


Figure 3. Attention and their previous silence per type of sound (left); Average of attention per seconds and their lineal trend (center) according to the Mindwave headband. Average percent of emotions' instances that children with autism exhibit when listening to different types of sounds and the control sounds (right).

(Avg. =51% of instances). When listening to both the *melody* and *flat* sounds, participants emotions were more passive (e.g., relax, sad) (Avg. = 48.14% of instances) than with the *natural* sounds (Avg. = 18.51% of instances; Figure 3-right). These results could be partially explained because most of the participants enjoyed listening to music from nursery rhymes. Also, the *natural* sounds could be found to be “too abstract” and could be more difficult to process for this population.

Comparing our emotion data to our control, according to the psychologist’s perceptions, our results indicate the *flat* and the *melody* sounds have more similar behavior to the emotions participants’ exhibited when listening to the “pleasant” sound (Figure 3-right). In contrast, participants’ exhibited emotions when listening to the *natural* sounds are similar to those emotions they exhibited when listening to the “annoying” sound. These results confirm that participants prefer *melodies* over the *natural* sounds.

Overall, our results may indicate, participants’ attention could increase and exhibit more positive emotions when listening to sounds with a predictive pattern like the *melody* and *flat* sounds. Our results show that is probable that the *natural* sounds tend to decrease participants’ attention over time, more similar to the effect caused during silence. Participants exhibited more negative emotions when listening to *natural* sounds as they may find them too abstract. Open questions remain to study if there is a correlation between participants’ emotion and attention when listening to different patterns of sounds; and perhaps, investigate other sounds with a different structure and patterns.

Musical instruments

In this section, we present the results of attention and emotions according to the musical instrument (cello, piano, clarinet) being used to play the *flat* and *melody* sounds.

Attention

Analyzing participants’ attention according to the musical instrument; we found out, on average, participants were a little bit more focused when listening to sounds being played with the cello (Avg. = 51.56) than when listening to those being played with the piano (Avg. = 49.88) and the clarinet (Avg. = 50.40). Similarly, our results indicate that, in comparison with the previous silence, 88% of participant’s attention increased when listening to the cello, 77% when listening to the clarinet, and 66% when listening to the piano sounds (Figure 4-left). Also, participants’ attention with the cello highly differs to their attention during silence (Diff. =6.51); in contrast, to the piano which is the closest (Diff. =1.21) and the clarinet laying in the middle (Diff. =3.84).

Our linear regression analysis (Figure 4-center), revealed participants’ attention is more likely to increase over time when participants listen to sounds being played with the cello and the clarinet. However, participants’ attention when listening to the sounds being played with the cello has a higher slope than the clarinet sounds. This could mean that when listening to sounds being played with the cello, the attention span could be maintained for a longer period (10 seconds). In contrast, participants’ attention is more likely to decrease slightly when listening to sounds being played with the piano (5 seconds) having a slightly negative trend.

This result could be partially explained as the sound of the cello instrument in contrast to the other two, has much more harmonics (i.e., produce sharper waves). These harmonics translates into more auditory variations in the sound that could be more engaging to the child.

Emotion

Participants exhibited almost the same instances of negative emotions independently to the musical instrument being used to play the sounds (Figure 4-right). However, they exhibited a little bit more instances of positive emotions when listening to sounds being played with the cello (Avg. = 63% of

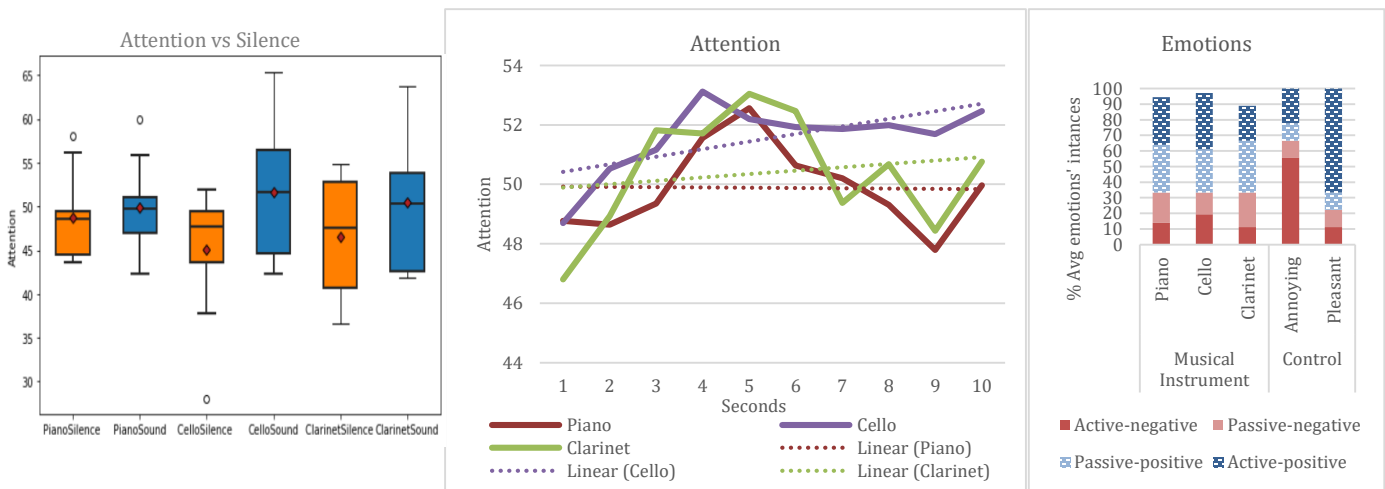


Figure 4. Attention and their previous silence per musical instrument (left); Average of attention per seconds and their lineal trend (center) according to Mindwave headband. Average percent of emotions’ instances that children with autism exhibit when listening to different musical instrument and the control sounds (right).

instances), than with those being played with the piano (Avg. = 61% of instances) and the clarinet (Avg. = 55% of instances). However, when listening to the clarinet participants exhibited more passive emotions (Avg. = 55% of instances) than with the piano (Avg. = 50% of instances) and the cello (Avg. = 41.65% of instances). This difference could be explained, as the timbre of string-based musical instruments have more harmonics that could make our participants feel a little bit happier. Similar results have been previously found with neurotypical adults, where the violin was scored as the “happier” musical instrument [37], compared with other string and wind musical instruments.

Comparing our emotion data to our control, according to the psychologist’s perceptions, our results indicate all the musical instruments have more similar behavior to the emotions participants’ exhibited when listening to the “pleasant” sound. As the cello has a little bit less difference with the pleasant sound, we could confirm that strings musical instrument timbres could be more pleasant for children with autism.

Our results suggest that participants were more focused and exhibited more positive emotions when listening to sounds being played with the cello than when listening to those sounds being played with the piano and the clarinet. Also, cello’s sounds differ more to silence, and better maintains the attention span of participants over time than the other two. In contrast, children’s are more distracted, when listening to sounds being played with the piano. With the clarinet, participants’ behavior is more passive. Open questions remain to study if timbres with the same classification (e.g., wind, string), produce the same attention and emotions as the cello, clarinet, and piano sounds.

Pitch

Here, we present the results of attention and emotions according to the pitch (low and high) being used to play the *flat* and *melody* sounds.

Attention

Our results indicate, participants’ attention is slightly higher when listening to low pitch notes (Avg. = 50.96) than high pitch notes (Avg. = 50.25). Comparing participants’ attention with our control, our results indicate that 77% of participants increase their attention when listening to the high pitch notes, and 44% when listening to the lower (Figure 5-left). Moreover, low pitch notes are slightly more similar to silence (Diff. =2.81) than high pitch notes (Diff. =4.92). However, our linear regression analysis (Figure 5-center), revealed participants’ attention is more likely to increase over time when listening to low pitch notes, as the behavior of the data has a positive trend. In contrast, with high pitch notes having a negative trend. These results might suggest that high pitch notes could be used to draw the attention of participants for a short period of time and mainly when wanting to decrease the occurrence of behavior as children will feel more negative towards sounds played in a high pitch. In contrast, low pitch notes could be used as a reinforcer to sustain their attention span.

Emotion

On average, participants were more positive when listening to low pitch notes (Avg. = 62.95% of instances) than high pitch notes (Avg. = 57.39% of instances; Figure 5-right), and more negative when listening to high pitch notes (Avg. = 38.88 % of instances), than lower notes (Avg. = 27.77 % of instances). On average, participants exhibited the same passive emotions when listening to sounds played either in low or high pitch. We attribute this result to the subtle variation between our high and low pitch notes. A stronger variation is desirable to better depict the differences between pitches.

Comparing our emotion data to our control, according to the psychologist’s perceptions, our results indicate the low pitch notes have more similar behavior to the emotions participants exhibited when listening to the “pleasant” sound. These results confirm that participants found more enjoyable lower tones.

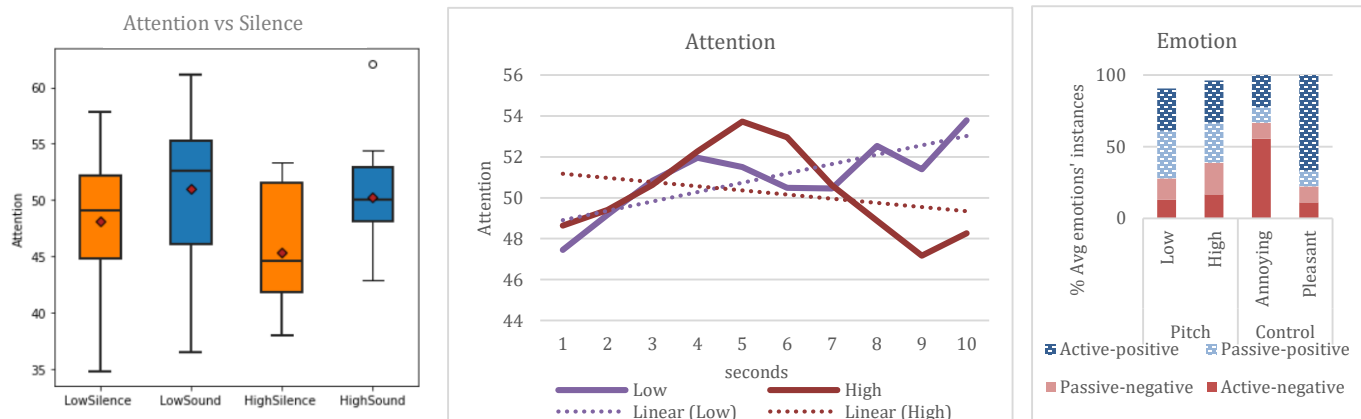


Figure 5. Attention and their previous silence per pitch (left); Average of attention per seconds and their linear trend (center) according to Mindwave headband. Average percent of emotions’ instances that children with autism exhibit when listening to different pitch and the control sounds (right).

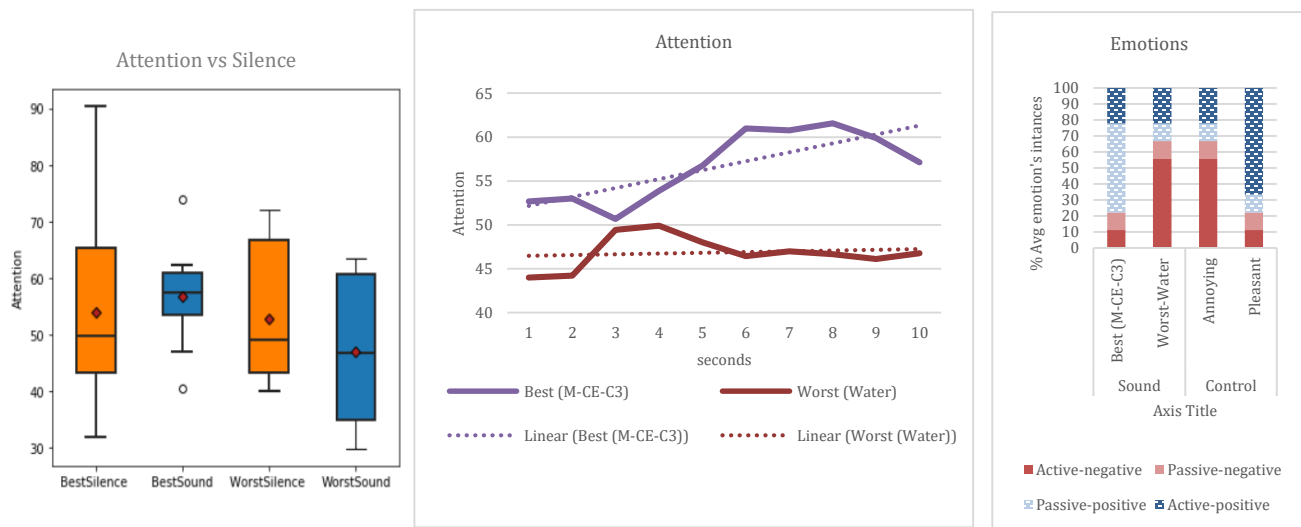


Figure 6. Attention and their previous silence of the best sound (i.e., Melody, cello, low pitch, and worst sound (i.e., water) (left); Average of attention per seconds and their lineal trend (center) according to Mindwave headband. Average percent of emotions' instances that children with autism exhibit when listening to the best and worst sound (right).

Overall, our results suggest that with low pitch notes participants maintain more time their attention and exhibit positive emotions, as lower sounds could be more pleasant. In contrast with high pitch notes, as sounds could annoy them, their attention tends to increase more, but for short periods of time, then, this sound could more easily help participants to “snap out of” those periods of distraction – like clapping or snapping your fingers in front of someone, but, it should be used as a brief sound, as participants attention span tends to decrease and they could exhibit slightly negative emotions.

Behavior of the best and worst sound

Overall, our results suggest that participants will stay more focused and may be more positive when listening to *melody* sounds played with the cello in a low pitch. In contrast, the worst sound to use with our population is the *natural* sounds, especially the sound of water.

We conducted a further analysis (Figure 6) to understand participants' attention and emotions when listening to a *melody* played with a cello in a low pitch (best case) against the natural sounds of the water (worst case). Our results indicate participants were more positive, stayed more time focused, and their attention span was higher and increased over time when listening to the melody played with the cello in a low pitch (Figure 6- left and center). On this condition, 66% of participants' attention increased and heavily differs to their attention during silence. Also, their emotional state is almost identical to their emotional state when listening to the pleasant sound (Figure 6-right).

In contrast, when listening to the sound of water, participants' were very distracted (Figure 6-left-center) to the point of being more focused during silence (Figure 6- left), as 44% of participants increased their attention in comparison with the previous silence. Their attention span heavily decreased over time (Figure 6 center). Moreover,

they were more negative; thus, their emotional state when listening to the water sounds looks very alike to the annoying sound (Figure 6-right). However, open questions remain to investigate if participants exhibit the same behaviors with other variations of *natural* sounds.

DISCUSSION

Our results could be used by researchers to identify what are the best “candidate sounds” to be used during music-based interventions. Then, we propose some scenarios where these “candidate sounds” might be useful. For example, taking, the design of motor-therapeutic interventions using sonification techniques. Interactive sonification has been recently gained a lot of attention in HCI and pervasive healthcare. Researchers have a null understanding of what sounds could be used to alter the body perception of movements of children with autism. This knowledge is needed to design the appropriate sound feedback that better guide the movements of children with autism.

In this direction, our results indicate that a *melody* sound played with the cello in a low pitch could be used to positively catch the attention of children with autism during the therapy. So, this sound could be used to provide patients with feedback about their movements. However, when patients disengage from the therapy, the *melody* sound in high pitch could be used to re-direct patients' attention to the correct movement. During breaks, therapists could play a *melody* sound using a clarinet to encourage the patient to relax and provide a more enjoyable experience between breaks and intense activity.

More broadly, a similar structure could be used to integrate sounds into multisensory environments or during neurofeedback therapies that involve transitions between activity and breaks. Even in real life situations, a high pitch note could be used to help children with autism to “snap out of” when being locked up.

Overall, pervasive healthcare applications, from mobile technology to exergames, use a wide range of auditory stimuli. The results of this study could be used to better inform how to combine different sound structures to control the attention and emotions of children with autism when appropriate. For example, low pitch notes could be used to reward users; whereas, high pitch notes could be used to penalize them. When working with children with autism selecting the appropriate reinforcements is paramount. Teachers are constantly looking into more positive ways to penalize the child when behaving poorly. Using auditory feedback could be a more subtle way to support behavior management.

LIMITATIONS

Although the research reached our goal, we observed some unavoidable limitations. The research was conducted only with nine children with autism, in one school-clinic in Mexico. This is a small sample size, therefore, it is impossible to generalize these results, and the reader should be advised that a longer study with more participants should be conducted to evaluate the significance of our results. Moreover, nowadays, there are few works about the use of Mindwave for children with autism [6], then, in this research, we assume that the headband provides reliable results about the attention of children with autism after the calibration process. However, it has been noted that mobile EEG headsets are notoriously prone to noise [23]. Thus, in our study, we took special care to avoid that some noise in the signals could influence our results, for example, the sensitization process before the pilot study and conducting real-time analysis of the data during the pilot study. After all, this study is one of the first steps in the direction of gaining a better understanding of the sound preferences of children with autism. As this is one of the first studies of this kind, the objective of this pilot study was not to generalize our findings; but to get preliminary insights of how to conduct such a study and preliminary results in the area in controlled settings.

CONCLUSIONS

This paper presents the results of a pilot study investigating the sounds preferences of children with autism. As children with autism have impairments in communication and do not express their emotions [1], in this study, we show that Mindwave headbands could be useful to quantify the attention of children with autism when listening to different sounds.

Our results indicate that children with autism stay more focused when listening to *melody* sounds being played with a cello in a low pitch. We also found out children were more distracted and felt more negative when listening to *natural* sounds.

The lessons we learned from this project might benefit other researchers interested in understanding which are the sounds preferences of children with autism, and how to conduct user studies using BCI with children with autism. Also, this study

could be replicated using a different BCI headband, but children with autism could require more time to get used to using a headband with more electrodes, as most of them are hypersensitive and could have problems with new experiences or get refuse to use new accessories.

As a future work, we need to decrease the number of sounds and increase the number of children in our study to understand their sound preferences better. Also, we could test the same sounds with neurotypical children to understand if there are differences between both populations. Moreover, it will be interesting to consider participatory design session, including music therapist, and psychologists to re-design the sound structures according to their expertise and the children with autism preference, which could help us to understand the long-term effect of hearing different types of sounds.

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