Towards Embodying Emotions in Play with Neurodivergent Children using Haptic Technologies

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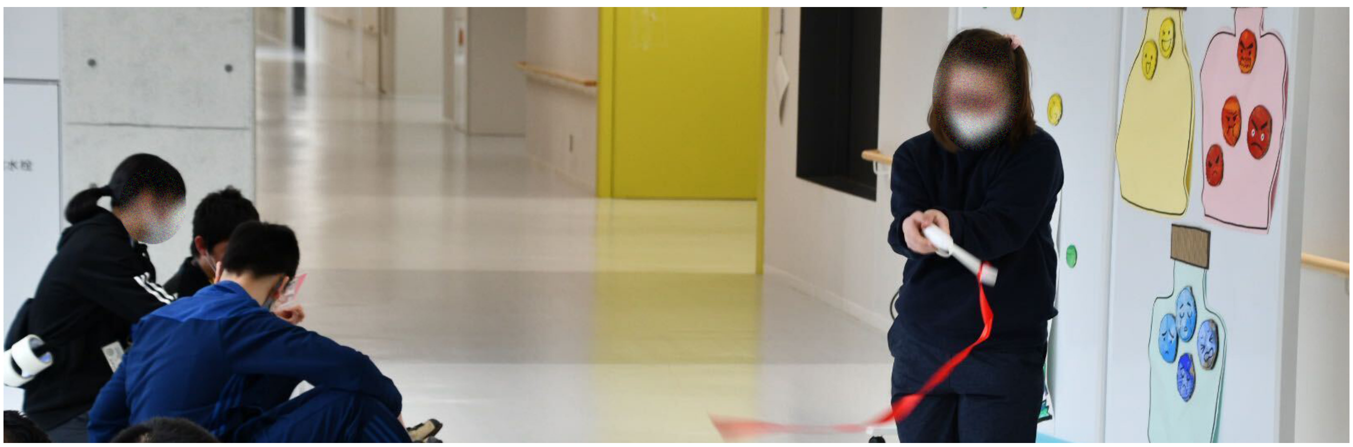

Figure 1: A photo of the workshop where a child is using the haptic device to convey an emotion to their peers.

ABSTRACT

As neurodivergent cases in children are steadily increasing, we are also seeing increased awareness regarding personalized neurological development and efforts towards social inclusion. Children struggling with these conditions should engage in education curricula custom-tailored and personalized for their individual needs. In this initial work, we describe the first steps of the development of an interactive system that created a multi-sensory environment embedded into a participatory performance to help neurodivergent children learn about emotions. We first report on the co-design process and research insights from our work integrating haptic technology and neurodivergent children's emotion learning activity. Then we report on a study in which 28 children were involved in testing the implementation of our system and share our insights that we gained about designing haptic interventions for neurodivergent children and the collaborative process with their instructors and other related parties.

CCS CONCEPTS

• **Human-centered computing → Accessibility design and evaluation methods**; *User studies.*

KEYWORDS

haptic, vibrotactile, emotion, neurodivergent, assistive technology, participatory performance

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1 INTRODUCTION

The most recent National Health Interview Survey, "Prevalence and Trends of Developmental Disabilities among Children in the

United States", reported a 9.5 percent increase in prevalence over the past decade [6, 7]. According to the Centers for Disease Control and Prevention (CDC), about one in six children aged 3 through 17 years in the United States have one or more developmental disabilities [7]. The CDC points out that these global increases are likely a consequence of improved child survival rates, especially those of children with high-risk factors such as preterm birth or brain trauma, increased awareness of neurodevelopment, and social inclusion of neurodivergent children [6].

Understanding and expressing affect is a vital part of social participation and communication [17]. Neurodivergent children, especially children with autism, struggle in this area, since one of the defining characteristics of autism is the "triad of impairments", broadly defined as social imagination, social communication, and social interaction [28]. As such, their development of social communication is very slow compared to neurotypical children who learn social cues with more ease while growing up [4, 11, 13]. It is crucial to recognize this difference in autistic perception and avoid pathologizing autism as something that requires a "cure" but rather is a "divergence". At the same time, however, it is important to recognize that autism is a condition that poses unique challenges; according to the CDC, autism is a condition that can pose significant behavioral and social challenges, with there being varying levels that require different levels of personal assistance [8, 9]. It is, therefore, becoming increasingly important to be able to provide neurodivergent children with "interventions" that are tailored to help compensate for the triad of impairments that they struggle with on a daily basis.

Past studies set out to achieve this by employing interactive multisensory theatre-based activities, employing mostly visual and auditory elements, with positive results [2, 11, 24, 26]. This study aims to adapt this interactive model to emotion learning and add tactile stimulation to help children learn emotions more intuitively. This initial study comprised of a ten-week user research period (eight-week ideation period and two-week fieldwork) and a four-week system development period, culminating in three workshop sessions that involved 28 children. The process led us to propose a co-learning system to support neurodivergent children in learning emotions by augmenting their natural abilities to recognize and express affect. Through this implementation process, we were able to gain insights into designing technological tools for a specialized demographic, working with collaborators in the field (such as instructors) who can provide contextual help when working with the said demographic, and the limitations and considerations that come with working with neurodivergent children.

2 RELATED WORK

Drama and interactive theatre have seen long and extensive use as therapeutic mediums. For neurodivergent children, puppets have proved to act as mediators between the child, the caretaker, and the external world [23, 26]. Since one of the defining characteristics of autism is the difficulty in understanding the concept of "otherness" [3], the fictional worlds of interactive theatre provide its participants the freedom and safety to perform roles as the "other"; for neurodivergent children, puppets along with the other objects that provide sensory stimuli in that environment act as predictable objects that they are free to imbue with mind, acting as a safe bridge to a less predictable world of other objects [26]. Building on this, Reynolds and Reason used drama activities where they created an immersive and interactive physical environment involving masks, puppetry, and digital media as a way to encourage emotional and cognitive engagement [19].

Existing haptic interventions for children with autism mainly focus on managing idiosyncratic behaviors that are associated with autism [25, 27, 29]. For example, Tang developed a tactile sleeve that would provide a virtual experience of being touched to help those with autism learn to manage hypersensitivity to human touch [25]. Vaucelle developed haptic interfaces to facilitate interventions between therapists and neurodivergent patients by providing relief via touch therapy [27]. Even in cases where tactile stimulation is used in systems designed as auxiliary means to help convey emotions, they often take the role of notification [18]. For example, a project called Affective Social Quotient [4] tried to improve the ability to recognize affective information in children with autism using haptic feedback by synthesizing social situations, but the haptics used in this system were only for capturing the child's attention. Another example is a fault-tolerant vibrotactile breathing pacer system called FAR [15] that aimed to assist children with autism with slow-paced breathing; however, the haptic functionalities were interpreted in ways they did not expect or were too complex to recognize clearly. While some work does exist that uses haptics directly to transmit emotional messages to children with autism [5], there are very few real-world applications that use this concept in a classroom or learning setting.

3 APPROACH AND DESIGN CONSIDERATION

To develop our concept and apply our technology in practice, we worked in collaboration with the Tokyo Metropolitan Rinkai District Special Support School[1] Miraikan (The National Museum of Emerging Science and Innovation)[2]. All participants in this study were students who possessed the Intellectual Disability Certificate (Ai-no-Techo) from Tokyo Metropolitan Rinkai District Special Support School. The Tokyo Metropolitan Government issues the "Ai-no-Techo" to those with an intellectual disability that causes considerable inconvenience in their daily lives and requires welfare considerations during their developmental period (under 18 years of age). Children diagnosed with only autism spectrum disorder will not be issued the "Ai-no-Techo." During their elementary school year, the school divides students into Group A and Group B for instruction according to their level of impairment. Students in Group A (ages 6-7) receive courses designed for severe multiple disabilities and intellectual disabilities. Students in Group B (ages 6-7) receive courses designed for ASD. For middle school students, all students are combined into one class and receive all three courses. For the purposes of this work, we will refer to them as Group C (ages 12-13).

Co-Design Process - We held regular meetings within the research team and conducted monthly discussions with our collaborators from early in the ideation stages. The team consisted of four researchers, three instructors from the school in charge of

[1]https://www.kyoiku.metro.tokyo.lg.jp/en/list/special_needs/intellectually_disabled.html
[2]https://www.miraikan.jst.go.jp/en/aboutus/

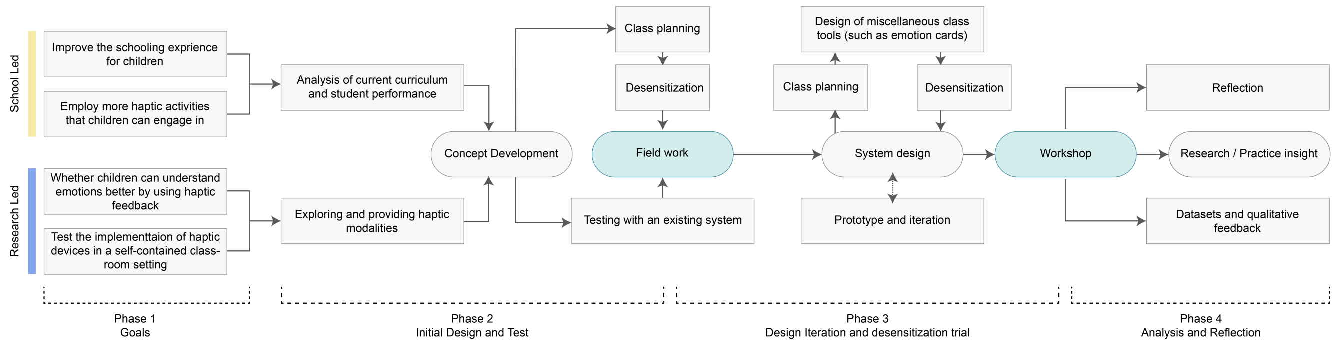

Figure 2: A graphical overview of the co-design process presented in this work. The four main elements of the process are shown in the center of the graph and the arrows show the dependencies between the tasks.

teaching, and four staff members from Miraikan to assist the study and facilitate communications between the research team and the school. Fig.2 depicts the overall co-design process that led to the insights presented in this work. As such, phase 1 involved aligning our goals, and we eventually settled on enriching tactile experiences and promoting social interactions.

As this project involved a highly specialized demographic, we were faced with multiple challenges. First, our participants included individuals with intellectual disabilities, autism, and physical impairments, meaning individuals are highly heterogeneous in their communication style and level. This made it challenging to conduct research activities in a group setting. Thus, it is fundamental to create a space that is predictable enough for the children to feel comfortable in, but flexible enough for the children to enter, leave and rejoin. Apart from that, we also needed to consider the restrictions caused by the pandemic, such as the extremely limited access to children and the need to consider reduced physical contact in interaction design [1]. Meanwhile, it took extra effort and time for the instructors to ensure that the research activities fit best with the children's learning schedule. With these challenges in mind, we started our first attempts to understand children's behavior in the field and help them adapt to haptic technology by integrating two existing tactile devices, "Kinder BURU BURU cushion" [22] and "Techtile Toolkit" [14] without straying too far from the regular teaching activities - storytelling. The initial results were reassuring as none of the participants showed abnormal behaviors such as panic or resistance towards engaging with the new devices. Meanwhile, we summarized the following design requirements based on our observations and feedback from instructors:

- The device needs to be portable for young children to use (but no wearable devices).
- The shape of the device could reference items that children are familiar with, such as a ribbon wand.
- Since visual sensations are dominant in the majority of children, it is preferable to use different colors in the design to assist children in distinguishing between emotions.
- Use simple inputs and outputs to lower the learning curve.
- The exterior design should take into account safety precautions and prevent inappropriate or potentially dangerous uses such as throwing the devices.

System description - Accommodating all the design requirements, we proposed a system to embody emotions for neurodivergent children (see Figure 3). This system consists of three parts: expressing emotions, sharing emotions, and identifying emotions. Considering that emotion recognition in children with ASD becomes more accessible when they use cartoons rather than photos of real faces [20], the system was implemented based on the content of a picture book - The Color Monster: A Story About Emotions (©Anna Llenas, Editorial Flamboyant, S. L.). Referencing and simplifying the concept of interactive theatre to blend it with the class, we guided children to perform roles as the "monster" from the book and learn about emotions. In light of the previous findings during fieldwork that children were unable to create precise vibration patterns with the "TECHTILE Toolkit," we encouraged them to use their body language to express emotions. We then captured and converted this motion data into audio waveforms in real time, then displayed it in the form of vibrations using the "BURU BURU cushion."

Hardware Design. - We used an inertial measurement unit (IMU), which includes both a 3-axis accelerometer and gyroscope, controlled by an ESP32 module to capture motion: the IMU provides data about acceleration and angular velocity, which can be used to provide information about the child's activity and movements. As illustrated in Figure 3(a) [3], the device was fitted with two IMUs, one in the handle and one on the other tip of the device. The IMUs were polled at 50HZ frequency and were sharing one I2C bus. After implementing and confirming that the system could capture and stream motion data, we redesigned the hardware to accommodate a rechargeable battery and make it more compact. PCB designs were done in Diptrace, and firmware was written using Arduino framework[4]. TouchDesigner was used to convert the motion data into audio. Communication between the device and TouchDesigner utilized the WiFi capabilities of the ESP module, and the vibrotactile sensation was shared from the PC to each cushion where the children sat using the wireless audio units (WA-TX-03 and WA-RX-03 from Circuit Design, Inc.).

[3] Schematic Diagram – ESP32 with MPU-6050 https://randomnerdtutorials.com/esp32-mpu-6050-accelerometer-gyroscope-arduino/
[4] Diptrace https://diptrace.com/

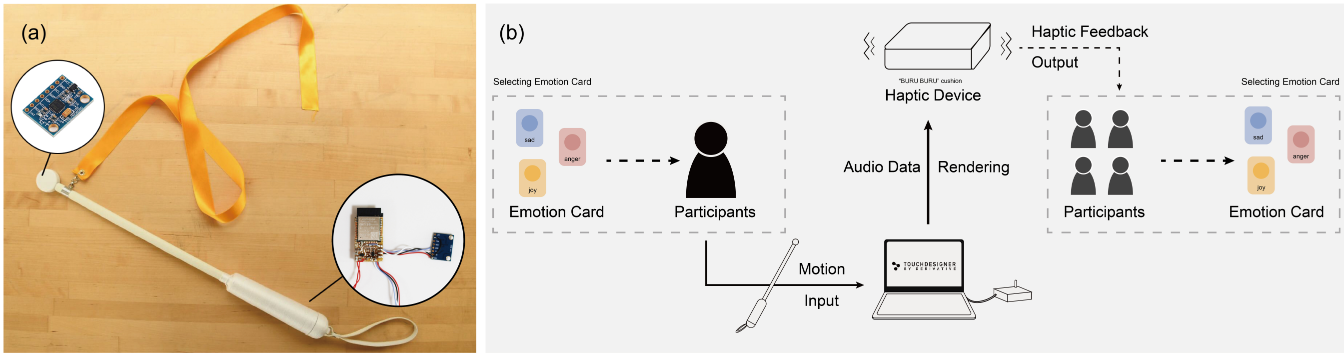

Figure 3: (a): Picture of the finished device with hardware locations highlighted. (b) Diagram illustrating the interaction between the device and processing software.

Haptic Design. - We used TouchDesigner[5] to hold text data that would later be parsed into numerical values and filter and normalize the data stream. In order to collect as much gesture data as possible in the early stages, we did not separate all the discrete gestures for haptic design. As the final output would be audio data, we used this processed motion data to render a neutral sound in real time. Referencing our previous work [10] that certain rhythmic characteristics of the emotional vibration recordings are associated with specific emotions, we matched the speed of the movement to both the frequency and volume of the audio output. Finally, the audio stream was fed out to an audio interface. All the processing was done within standard TouchDesigner functionalities.

Product Design. - From a design perspective, we followed two of the basic principles of designing for autism: simplicity and robustness [21]. According to the autistic-led theory [16], one defining trait of autism is a single-minded attention system, meaning they prefer to take in one information source at a time. Therefore, in order to avoid any interference it might cause to their ongoing tasks, we minimized the details in the design by choosing white as the main color of the product. As for the ribbon, we chose red, yellow, blue, and green as four colors representing different emotions to serve as a visual reminder to the children. For the shape, we referred to items that are commonly used in daily teaching exercises - the ribbon wand - as the ideal form factor, which also serves the role of hiding the hardware from being visible.

4 WORKSHOPS

As we were introducing new devices and contexts in the workshop, the school conducted two desensitization sessions for each group to get the children comfortable and accustomed to said devices and contexts. The desensitization training involved the same procedure and contexts as the final workshop but was carried out using regular ribbon wands that lacked any sensors and had a similar form factor to the hand-held device we provided.

Instructors and parents (including next of kin or guardians) were approached for written consent on behalf of child participants. Only workshops involving researchers were authorized for video recording with the explicit understanding that the collected footage was to be used for academic research purposes only. Three of the participants' video requests were not authorized and were scheduled to be out of the video camera's range during the workshop. One researcher was responsible for gathering data, which included video recording and field notes. Two video cameras were used to record the workshops. One was placed at the top of the screen, located at the front of the classroom. The other was placed at the back of the classroom.

Participants and Procedure. - The workshop was conducted once for each group (A, B, and C). The basic information of the workshops is shown in Table 1. The class's difficulty level was adjusted based on the feedback from the desensitization session. Group A used only two emotions (joy and anger), and groups B and C used three emotions (joy, anger, and sadness). In addition, the instructor prepared other teaching aids for fluency and comprehensibility: two whiteboards (one with mixed emotion cards and one with bottles corresponding to the emotions), a monitor (for visual presentation during storytelling), a monster-shaped hat as costume, and several emotion cards. The procedure of the workshop is shown below, and Fig.4 shows the flow of how children interact with our system :

(1) Introduction session (5 mins): the teaching assistants gathered all participants in the audiovisual room and guided them to sit on the "Kinder Buru Buru Cushion." To begin with, the instructor briefly introduced the workshop topic and flow to participants and then introduced study-related external parties (N = 7).
(2) Warm-up session (5 mins): the instructor guided participants to do some physical activities as a warm-up.
(3) Storytelling session (10 mins): the instructor read the picture book of the Color Monster to participants and helped them identify emotions through colors.
(4) Demonstration (5 mins): the instructor led the first five minutes and gave instructions and a demo.
   (a) Put on the "monster" hat and stand in front of the whiteboard, telling the class about which emotion you want to express.

[5]TouchDesigner https://derivative.ca

Table 1: Basic information of the workshop

Group	Location	Emotion	Subjects
A	audiovisual room	joy, anger	first-year students in primary school (N = 10)
B	audiovisual room	joy, anger, sadness	first-year students in primary school (N = 10)
C	hallway	joy, anger, sadness	first-year students in middle school (N = 8)

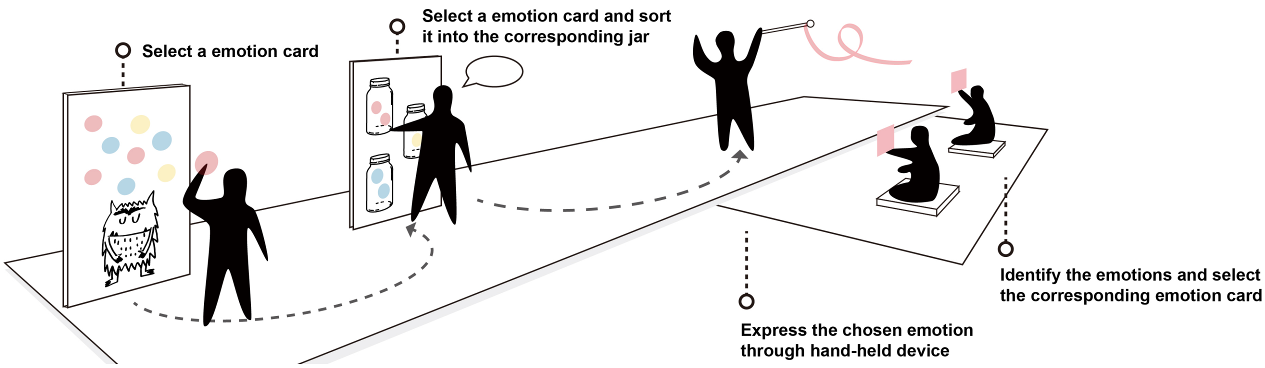

Figure 4: Flow of the workshop. Children would choose the emotion of their choice from a whiteboard and place it in the corresponding glass jar on another whiteboard. They would then use the device to convey the emotion to the children sitting on the cushions, who would try to identify which emotion was expressed.

   (b) Act like the monster in the story by picking up the corresponding emotion card from the whiteboard and sorting it into the glass jar on the whiteboard.
   (c) Stand in front of the whiteboard again and use the hand-held device to convey the chosen emotion.
   (d) Children (sitting on the cushion) identify expressed emotion and raise the corresponding emotion card.

(5) Directed activity (10 mins): participants were selected to present in front of the class. They were taught to imitate what the instructor did in the demonstration session and create vibration patterns.

(6) Free activity: participants were divided into two groups. The teaching assistants supported participants in using the hand-held device correctly and gave orders such as "it is your turn" and "try to wave it."

5 INITIAL OBSERVATIONS AND FEEDBACK

We started by analyzing video data using a free-form text annotation to capture children's overall performance during the class. After the initial analysis, we focused on the children's performance while using our device and their social interactions with each other. We provided an overview, viewing the children from the perspective of the "performer" and the "spectator." First, in the role of "performer," we found that all the children were capable of completing the task as per the instructions. Some of them could distinguish basic emotions and express them in different forms. For example, some children expressed the emotion of joy by waving the device in circles, with a large swing and relatively gentle speed, while for the emotion of anger, the children opted for a more rapid and intense wave of the device. It is also worth noting that when the children tried to express their feelings, not only did they move the device, but their body movements also became more abundant, such as bowing their heads or stamping their feet. Their facial expressions also become richer and more exaggerated to pretend they were the little monsters under the corresponding emotions. These behaviors implied that they were putting themselves in the character's shoes and engaging in role-play, which is an important step in empathizing with someone. As the "spectators," we found that they could correctly select the corresponding emotion card based on the information obtained, either through visual or tactile means. Moreover, we observed that they were able to respond differently to different emotions. In particular, when they felt the vibration that corresponded to anger, a few children showed signs of fear, while when they felt the vibration corresponding to joy, they responded by moving their bodies in accordance to the beat. It implies that the children developed empathic responses to some of the visual or tactile stimuli.

5.1 Focus Group

On the second day after the workshop, we, the researchers (referred to as R1, R2, R3, R4, N=4), used a focus group with the instructors (N=2), hereby referred to as I1 (Instructor of Group A and B) and I2 (Instructor of Group C) and staff members (N=2) from Miraikan to collect feedback, and then analyzed it following a thematic analysis method by Maguire and Delahunt [12]. The analysis was led by the first author, and the transcripts were read and re-read by the first author and the third author, respectively. After coding and organizing into themes by the first author, themes were reviewed and verified in discussion with the third author. In total, 183 data points were assigned to 66 codes, further refined to 12 codes, and finally, two themes were crafted.

Level of understanding of class content - This theme describes the extent to which children understand the topic of emotions, specifically in terms of expressing emotions and interpreting emotions. Starting from children using our system to express emotions, I1 and I2 mentioned that children were mostly imitating the instructor's or classmates' movements in the desensitization trials, while in the workshop where vibration feedback was added, children tended to interact based more on their own understanding. I2 pointed out that *"[...]there were many occasions where they were thinking and creating their own patterns, but on the other hand, I think there was less variation[...]Anger, in particular, was more indicative of children thinking by themselves instead of trying to imitate"*. On the other hand, I1 observed a different phenomenon: *"[...]children showed anger mainly through imitation, but when they expressed joy and sadness, there was more originality"*. Furthermore, I1 also observed that the children's facial expressions were richer and more diverse while playing the role of a color monster compared to desensitization sessions. Consistency between their facial expression and the selected emotion implied that the children were able to "put themselves in the shoes" of the characters. While observing the above reassuring results, we must also point out the individual differences in the comprehension of the content. *"Some children were having fun playing with the device as a toy[...]they had a happy look on their faces while trying expressing anger with their body movements"* (I1). This can also be taken as one evidence of a high level of satisfaction among children, along with other relatively positive feedback we received. I2 found that *"children became more involved with haptic feedback"*. Likewise, I1 mentioned that *"In the contact report, one message from a student said he was disappointed he didn't get the chance to try it"*.

Promoting social interactions - This theme captures instances in which children exhibited social-communication behaviors such as eye contact, joint attention, and initiating interaction. R1 mentioned that *"one child was looking around a lot and even made eye-contact with me as he interacted with the hand-held device."*. It was also mentioned that a child from Group C *"seemed to know that the message was conveyed and was slowly increasing the intensity of the wave to make me feel the vibration more."* (I2). These cases showed that children appeared to voluntarily observe others' feedback and try to promote further interactions. From the perspectives of the children receiving the vibrations, R2 noted increased shared attention, which *"some children alternated their gaze between the cushion and hand-held device when they felt the vibration."*. However, it also appeared that about half of the children were *"hyperfocused on the ribbon, or sound and vibration coming from the cushion"* (I1), which led to an *"inability to complete the requested tasks"* (I1). This led to a discussion about potential system improvements, which will be discussed later.

5.2 Implications for Co-design Process

Active communication with instructors - In this user needs-oriented research, a great amount of assistance from instructors is fundamental to integrating the research activities with the children's current learning activities. This applies not only at the key research stages, such as concept development and final implementation, but also during the entire design process; even with the smallest research tasks, such as collecting information, require extra effort and time to ensure a pleasant experience for the children and related parties during the process. It is worth mentioning that one of the focuses of this paper, participatory performance, was inspired by instructors. Based on their teaching experience, we integrated the theoretical knowledge of empathy to complete an adapted system design.

Empathic engagement with users - As our work progresses, we become increasingly aware that everyone has different difficulties and abilities, which cannot be reliably quantified into data. As researchers, an excessive focus on evaluating objective indicators may cause us to lose sight of the user experience. But as practitioners, we need to stay vigilant and remind ourselves that the primary requirement is to provide a better teaching and learning experience for neurodivergent children. Therefore, we need to engage empathically with the groups we work with. Secondly, our most reliable source of data was the instructors or parents who knew about the children's daily behavior and reactions and could provide us with additional context or significance of certain actions.

6 CONCLUSION

We proposed an interactive system that created a multi-sensory environment embedded into a participatory performance that utilizes vibrotactile feedback to assist neurodivergent children in their emotional development. Our early findings suggest that this system is well-received by neurodivergent children, which is a promising indication for future applications. Although we lacked objective indicators to show that children better understood emotions after the intervention, our system increased their desire to express themselves as well as initiate social interactions. We show the potential of utilizing haptics and provide an initial basis as an educational tool for neurodivergent children. There are some limitations. The sound generated by the cushion easily distracted children and led to feelings of discomfort. In addition, we lacked direct feedback from children. The subsequent behavioral impacts of the system on children need to be summarized in long-term observations and collaborations. Furthermore, it is worth considering refining the system by providing a bank of gestures that can be further analyzed in order to allow educators to understand neurodivergent children's emotions.

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