



HAL
open science

Haptic Music Players for Children with Profound and Multiple Learning Disabilities (PMLD): Exploring Different Modes of Interaction for Felt Sound

Emma Frid, Claudio Panariello

► **To cite this version:**

Emma Frid, Claudio Panariello. Haptic Music Players for Children with Profound and Multiple Learning Disabilities (PMLD): Exploring Different Modes of Interaction for Felt Sound: Exploring different modes of interaction for felt sound. International Congress on Acoustics (ICA), Oct 2022, Gyeongju, South Korea. hal-04029009

HAL Id: hal-04029009

<https://hal.science/hal-04029009>

Submitted on 14 Mar 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

ABS-0021

Haptic music players for children with profound and multiple learning disabilities (PMLD) – Exploring different modes of interaction for felt sound

Emma FRID^{1,2}; Claudio PANARIELLO³;

¹ EECS School of Electrical Engineering and Computer Science, KTH Royal Institute of Technology, Sweden;

² STMS–UMR9912 Sciences et Technologies de la Musique et du Son, IRCAM Institut de Recherche et
Coordination Acoustique/Musique, France

³ EECS School of Electrical Engineering and Computer Science, KTH Royal Institute of Technology, Sweden;

ABSTRACT

This paper presents a six-month exploratory case study on the evaluation of three Haptic Music Players (HMPs) with four pre-verbal children with Profound and Multiple Learning Disabilities (PMLD). The evaluated HMPs were 1) a commercially available haptic pillow, 2) a haptic device embedded in a modified plush-toy backpack, and 3) a custom-built plush toy with a built-in speaker and tactile shaker. We evaluated the HMPs through qualitative interviews with a teacher who served as a proxy for the preverbal children participating in the study; the teacher augmented the students' communication by reporting observations from each test session. The interviews explored functionality, accessibility, versus user experience aspects of respective HMP and revealed significant differences between devices. Our findings highlighted the influence of physical affordances provided by the HMP designs and the importance of a playful design in this context. Results suggested that sufficient time should be allocated to HMP familiarization prior to any evaluation procedure, since experiencing musical haptics through objects is a novel experience that might require some time to get used to. We discuss design considerations for Haptic Music Players and provide suggestions for future developments of multimodal systems dedicated to enhancing music listening in special education settings.

Keywords: tactile sound, haptics, accessibility

1. INTRODUCTION

Listening to music is a multisensory experience; musical experiences involve both perceiving airborne acoustic waves and vibratory cues conveyed through air and solid media (1). *Musical Haptics* is an emerging interdisciplinary field that focuses on investigating such experiences of touch and proprioception in music scenarios (1). Playing a musical instrument requires a complex set of skills that depend on the brain's ability to integrate information from multiple senses (2). Acoustic instruments intrinsically provide vibratory feedback during sound production and these vibrations are utilized for self-monitoring in acoustic performance, see e.g. (3). The haptic sense has been shown to play an important role in musical interactions with acoustic instruments such as the piano (4–6), the violin (7,8), and percussion (9). Research has also suggested that vibrations play a significant role in the perception in music; amplifying certain vibrations in a concert venue or music production system can improve the musical experience overall (10,11).

The current study focuses on Haptic Music Players (HMPs), i.e., devices that can process an audio signal to extract musical information and translate the information into a vibratory signal. HMPs can be considered *sensory substitution systems*, i.e., systems that translate sensory information that is normally available via one sense to another (12), in this case from hearing to touch. HMPs allow for enhancement of music listening experiences through simultaneous playback of haptic feedback; haptic signals passed through a HMP system are put in contact with a users' skin and body to enrich music

¹emmafrid@kth.se

³claudiop@kth.se

activities. A review of Haptic Music Player technology was recently published in (13). Examples of HMPs include fixed setups or installations such as haptic chairs (14) and platforms (15); wearable systems covering skin surface such as bracelets (16), gloves (17), belts (18), or whole-body suits (19); systems intended to be held in the hands (20); and more complex setups combining several of above mentioned mechanisms (21). Examples of commercially available HMPs include the *Ultrasonic Audio Syntac*⁴, the *SubPac*⁵ and the *Soundbox* and *MiniBox* from *Soundbeam*⁶. In the review of HMPs published in (13), the authors describe four main components that are necessary to provide vibrotactile rendering of musical elements in HMPs: audio signaling processing software, a digital to analog converter (DAC), amplifier(s), and actuator(s). Crossmodal mapping techniques, which involve identifying sound descriptors to be mapped to properties of vibrotactile feedback (22), can be used to translate elements of music into coherent haptic signals. Knowledge about the psychophysical similarities and differences of the auditory and tactile modality can help developing perceptually optimized algorithms for such music-related vibration generation (11). Examples of methods used for a haptic chair described in (11) were low-pass filtering, reduction to fundamental frequency, octave shifting, substitution of signals, and compression of dynamic range of an audio source. Results from an experiment revealed a general connection between vibrations and the perceived quality of the music reproduction, but that it might not be necessary to code all available auditory information into the tactile channel to improve the perceived quality of music.

In this paper we present a six-month study exploring different types of Haptic Music Players (HMPs) for pre-verbal children with Profound and Multiple Learning Disabilities (PMLD). Pre-verbal children do not yet have verbal communication skills. The term PMLD is commonly used to describe a person with severe learning disabilities who most likely has other complex disabilities and health conditions, although there is no single universally agreed definition of the term (23). Children with PMLD may express themselves through several different communication methods depending on what is most efficient for them at the time. Examples include bodily gestures, nonverbal sounds, pointing, and facial expressions. Previous research focused on the role of music for children with PMLD has emphasized the importance of music education (24) and musical play (25). A study exploring the role of music within the home-lives of young people with PMLD through parental perspectives was presented in (26). Findings outlined the positive role of music in contexts where music was used for enjoyment, to support mood-regulation, and to add structure to the lives of the children. As pointed out in (1), musical haptics could potentially facilitate access to music for persons affected by somatosensory, visual, and hearing impairments. The potential of multisensory experiences to enrich the lives of people with profound and multiple disabilities has been stressed (27). However, few studies have yet explored the role of haptic feedback for people with multiple disabilities, especially in the context of music (see e.g. 28,29).

The goal of the work presented in this paper was to allow for rich multisensory experiences and multiple modes of interaction for users with various abilities and needs, as suggested in (30). The work is part of a larger research project aimed to improve access to music-making through the development of novel accessible multimodal music interfaces, see (31). As suggested in (32), design of technology should make sure that users have control of, and not only are passive recipients of, developed technology. The disability rights movement motto "*Nothing about us without us*" (33) highlights that people with disabilities know what is best for them and their communities. In our research we have tried to include the children as informants in the design process using user-centered (34) and participatory (35) methods. Participatory development processes should enhance the voice of the participants, considering their ideas, desires, and needs (36). Existing co-design methods may need to be adapted to fully incorporate users with disability into user-centered design processes (37). Such adaptations are particularly important when including children with PMLD in design and evaluation processes since the communication between designers and the users can be affected. Alternative methods for augmented communication, such as *PODD (Pragmatic Organisation Dynamic Display)*⁷, a way of organizing word and symbol vocabulary in a communication book to support understanding (38), can be used to support design and evaluation processes with children with PMLD. In the study described in this paper, we used *Participatory Design with Proxies (PDwP)* (39)

⁴ <https://ultrasonic-audio.com/products/syntact-touch-the-sound/>

⁵ <https://subpac.com/>

⁶ <https://www.soundbeam.co.uk/vibroacoustics>

⁷ <https://novitatech.com.au/podd-communication-books/>

to enable inclusion of input from the pre-verbal students in the evaluation process. Since the students participating in the study are pre-verbal, we could not ask them directly about their haptic experiences. To get an understanding of how the HMPs were perceived, the responsible teacher and the teaching assistants at the school communicated directly with the students using alternative methods for augmented communication, such as *PODD* picture cards. In this way, the teachers acted as proxies, augmenting the direct input from the students taking part in the study.

In the following sections we describe a case study exploring how music can be presented not only in an audible form, but also as haptic sensations, through three different Haptic Music Players used in a special education setting. This paper contributes to the field of Musical Haptics by exploring how HMPs could be designed to be accessible to a group of pre-verbal children with multifunctional physical and intellectual challenges. To our knowledge, little prior work has explored design considerations for HMPs for pre-verbal children in special education settings.

2. METHODS

This paper describes a long-term collaboration with a teacher and a student group at the school Dibber Rullen⁸. Dibber Rullen is a special education school for students with intellectual challenges and multifunctional physical challenges. The study was carried out during the COVID-19 pandemic. This greatly affected the choice of methods, as well as the extent to which we could interact with the student group. Social-distancing measures were required to ensure the safety of the children, since they are a risk group. Since we could not meet the students physically, we adapted our methods to a distributed participatory design setting (40) in which the design team members were physically dispersed, and the HMPs were tested with the help from a teacher and teaching assistants at the school, *in the wild* (41). All research described in this paper was carried out as activities within the school's standard curriculum.

2.1 Aim

The purpose of this case study was to explore design considerations of Haptic Music Players for a group of children with PMLD. More specifically, the aim of the study was to allow for exploration of musical haptics using customized devices that could be tested by the students in a safe and familiar environment, without leaving the educational setting at the school⁹.

2.2 User Group

We collaborated with a student group consisting of four children (2F, 2M, age 9-15). The students are mostly pre-verbal, have multifunctional physical challenges, varying motor skills, use wheelchairs, and have moderate to severe intellectual challenges. A questionnaire was initially sent to the students' parents to get a better understanding of the children's challenges and musical background¹⁰. The parents of S1 (Student 1) reported that she is hard of hearing, has a visual impairment, a chromosome aberration, reduced mobility, a physical disability, and hypermobility in the joints. The parents of S2 reported that she has a visual impairment and that she can lift her arms and grab objects. It is unclear if she has a hearing impairment. The parents of S3 described that they didn't know if S3 is hard of hearing and has a visual impairment. He cannot walk but he can jump when sitting. The parents of S4 reported no hearing loss or visual impairment for S4. None of the parents reported that their child could play a musical instrument or sing. Only one of the students (S3) had tested electronic music-making tools or music technology. When asked to rate the level of musical interest (where 0 corresponded to strongly disagreeing, and 10 corresponded to strongly agreeing that the child was interested in music), the parents of S1 and S2 reported a level 4 interest, S3 a level 10, and S4 a level 8. Based on the questionnaire results we concluded that the students had very diverse taste in music overall, spanning across many different music genres.

2.3 Design Process

To inform the design of the HMPs and define a set of design constraints, we first organized a meeting with the teacher who worked with music and dance classes at the school. In this in-person

⁸ <https://dibber.se/skola/rullens-sarskola/>

⁹ Because of the COVID-19 pandemic, the students could not visit any external multisensory rooms/music installations.

¹⁰ The questionnaire is available as supplementary material: <https://doi.org/10.5281/zenodo.6977775>

meeting, we demonstrated the use of two haptic devices, the *HUMU Augmented Audio Cushion*¹¹ (see Figure 1) and the *Woojer Strap Edge*¹² (see Figure 2). The teacher got the chance to test the devices on different body parts (the Woojer Strap Edge is intended to be worn on the hips, chest, or cross-body). We played different music examples through the devices and discussed appropriateness of the tools for the specific user group. In particular, we focused on how the HMPs should be designed to best take the physical challenges of the students into account, and which modes of interaction (i.e., bodily locations) that might work well for them. The discussion was recorded and manually transcribed by author 1. Both authors analyzed the transcription, summarizing the findings into a set of design constraints, presented in Section 3.1.1. Conclusions from this analysis guided the design of two Haptic Music Players (HMP 2 and 3, see Section 3.1.3 versus 3.1.4 for detailed descriptions respective device). We concluded that the HUMU Augmented Audio Cushion (from this point referred to as HMP 1, see Section 3.1.2) could be used without any modification, since it to already fulfilled the defined design constraints. To summarise, the three final HMPs used in the study were HMP 1, the HUMU pillow; HMP 2, a haptic device embedded in a modified plush-toy backpack; and HMP 3: a custom-built plush toy with a built-in speaker and tactile shaker. The construction of HMP 3 took longest time since it was built completely from scratch. Once the HMPs were ready, we confirmed with the teacher that the visual appearance of the devices would work well for the students (i.e., that they would not scare the children). This was followed by the evaluation sessions discussed in Section 2.4. The evaluation sessions prompted a re-design of HMP 2. This HMP was thus tested in two different iterations. The teacher provided valuable suggestions regarding how HMP 2 could be improved in a follow-up meeting held after the first evaluation session.

2.4 Evaluation

Since we could not attend the HMP test sessions with the students in person, we asked the teacher to film the interactions taking place at the school. The teacher had six months to test out the HMPs with the students. Each HMP was tested a minimum of two times. Apart from the responsible teacher, teaching assistants were also present during the test sessions. To support the teacher and teaching assistants in their use of the HMPs, we provided instruction manuals with links to instructional videos for all devices. The responsible teacher decided which music that would be used during the evaluation sessions. To be sure that music with low frequency content was also tested, we provided a sound example with a broad frequency range¹³. The PODD tool was used to communicate with the students during the evaluation sessions. The teacher and teaching assistants used PODD to ask 1) if/what the students liked versus disliked about respective device, and 2) with which body they wanted to feel vibrations. The students had previously practiced using PODD picture cards focused on descriptions of musical haptics and haptic sensations in different body parts, within the scope of the larger study described in (42). When possible, the responsible teacher filmed the interactions taking place during the evaluation sessions using a mobile phone, and annotated observations. The authors watched these videos, taking notes of the interactions taking place, as well as the PODD discussions.

We carried out three semi-structured interviews with the responsible teacher to discuss what was observed during the evaluation sessions, using a video conferencing tool. The interviews started with general questions focusing on: the music used when testing; how many times the HMPs were used and the time spent exploring respective HMP; which HMP that worked best/worst, i.e. which HMP that was most/least preferred by the students; if the vibrations provided by the HMPs enhanced hearing (and if so, how); and the balance between the sounds that you could hear versus feel. This was followed by questions focusing on three different themes: *functionality*, *accessibility*, and *user experience*, broadly inspired by evaluation methods used in Human Computer Interaction (43,44) and Digital Musical Instrument research (45,46). The *functionality* theme focused on how well versus not well the HMPs worked, overall. This involved, for example, performance in terms of audio quality, reliability, durability, and if certain functions were lacking. The *accessibility* theme focused on achieving an identified goal in the identified context of use. More specifically, accessibility in this context was conceptualized as usability for a population with the widest range of user needs, characteristics, and capabilities, see ISO 9241-171:2008¹⁴, which fits within the *universal design* or

¹¹ <https://humu.fi/>

¹² <https://www.woojer.com/products/strap>

¹³ This sound file is available as supplementary material: <https://doi.org/10.5281/zenodo.6977775>

¹⁴ <https://www.iso.org/standard/39080.html>

*design for all*¹⁵ philosophies. This category focused on questions based on the seven design principles of universal design (47), i.e. equitable use, flexibility in use (e.g., the preferred bodily locations used for the three HMPs), simple and intuitive use, perceptible information (e.g., if the HMPs communicated musical information effectively, regardless of the sensory abilities of respective student), tolerance for error, low physical effort (if the use of the HMPs resulted in fatigue), and size and space for approach and use. Finally, the *user experience* theme focused on the overall experience of interacting with the HMPs and the emotional reactions of the students. For this category, questions were based on the User Experience Questionnaire¹⁶, focusing on concepts such as attractiveness (if the students liked the look and feel of the HMPs), perspicuity (if it was easy to get familiar with the HMPs and learn how to use them), efficiency (if the HMPs could be used in an efficient and pragmatic way), dependability (if the behaviors of the HMPs met the students expectations and if the students appeared to feel safe when using the HMPs), stimulation (if it was fun and motivating to use the HMPs, and if any emotions could be identified among the students), and novelty (if the HMPs caught the interest of the students and if they were creatively designed).

Two of the interviews were done when the HMPs had been tested for three months. The third interview was carried out after six months, when the teacher had had time to try out a new iteration of HMP 2. Mean interview duration was 50 minutes (min 33 min, max 79 min). All interviews were manually transcribed by author 1. Transcriptions were analyzed using content analysis (48) to identify different types of reactions to the HMPs across sessions. Themes were included if more than seven instances (quotes) were identified for a specific theme. All quotes were also subdivided into *accessibility*, *usability*, and *user experience* themes for respective HMP. The results are presented in Section 3.2.

2.5 Ethics Statement

This research was reviewed by the Swedish Ethical Review Authority (application No 2021-06307-01). The study was carried out in accordance with the declaration of Helsinki. In this work, we use people/person first language (PFL) when writing about disability, as opposed to identity-first language (IFL), see (49). The parents and the teacher gave written informed consent before participation and agreed to the data being collected as described in the consent form. The teacher and teaching assistants used PODD to make sure that all students gave consent to participate at all times. Management of datasets that include personal information of study participants was compliant with the General Data Protection Regulation (GDPR). Procedures for registration and storage of personal was reviewed and approved by KTH's data protection officer and KTH's research data team.

3. RESULTS

3.1 Design of Haptic Music Players

3.1.1 Design Considerations

Conclusions from the initial meeting with the teacher resulted in the definition of a set of design constraints for the HMPs to be used in the study. The discussions about the design of the Woojer Strap Edge versus the HUMU Augmented Audio Cushion provided important insights about how the HMPs could be designed to best fit the student's needs. We quickly realized that the HMPs must be *robust* and *durable*, since they might be thrown to the floor. Related to this, we discussed the *affordances* of the demonstrated haptic devices. For example, the teacher mentioned that the Woojer strap looked a bit like a ball, which might also invite the students to throw it. We therefore discussed embedding the Woojer strap into a plush toy or similar. An approach in which the vibrating unit could be attached to something wooden, which in turn would be embedded into a fluffy material, would both *invite to touch* while simultaneously enable transmission of vibrations. Such a design would also allow the students to throw the device to the floor, without any risk of damaging the haptic actuators. Regarding *bodily locations*, we discussed that the Woojer Strap Edge, which is supposed to be worn as a belt on the body, might not be suitable for all students since it is not so easy to take off if you do not like it. As a result of the above-mentioned discussions, our design process largely focused on finding solutions that would enable us to embed the hardware in soft protective padding, and on hiding the cables of the hardware (since visible cables might invite the students to pull them out). The final design of the

¹⁵ <https://dfaeurope.eu/what-is-dfa/dfa-documents/the-eidd-stockholm-declaration-2004/>

¹⁶ <https://www.ueq-online.org/>

devices is described below and displayed in Figure 1. The three HMPs differ in terms of affordances: HMP 1 (a haptic pillow) encourages the user to lay the head down on it, HMP 2 (a plush toy backpack) is intended to be worn on the back/belly, and HMP 3 (a custom-built plush toy reminiscent of the Star Wars character Chewbacca) can be placed on the lap and explored using your hands.

3.1.2 Haptic Music Player 1

HMP 1, the HUMU Augmented Audio Cushion, is displayed in Figure 1. The HUMU pillow has an embedded vibrating sound board assembly, with a sound and vibration frequency response of 20-20 000 Hz. It plays music in stereo. We connected the HUMU pillow using Bluetooth, but it also has a 3.5mm jack connection. Based on the meeting described in Section 3.1.1, we concluded that the cushion might not need to be modified to fit the needs of the students. There was no need for an additional layer of padded protection for this device since it did not break when we threw it to the floor for testing purposes.



Figure 1 – The Haptic Music Players (HMPs) used in the study: HMP 1) a haptic pillow, HMP 2) a plush toy backpack with an embedded haptic strap, and HMP 3) a custom-built plush toy with embedded tactile transducer and full-range speaker¹⁷

3.1.3 Haptic Music Player 2

HMP 2 was designed as a plush toy teddy bear backpack with an embedded Woojer Strap Edge (see Figure 1). The Woojer Strap Edge consists of a haptic device that looks like a black disc, which is put in contact with the skin of the user by strapping on a textile tape around the body, see Figure 2. The device uses an Osci™ transducer¹⁸ which delivers polyphonic vibrations that can reproduce frequencies up to 200Hz, including subsonic frequencies below the threshold of human hearing in the range 1-20Hz. The device connects through Bluetooth, but also supports 3.5mm cable input/output. The Woojer Strap Edge has independent volume control for audio versus vibrations, and two different presets for vibrations: a broad mode with frequencies up to 200Hz and a focused mode with frequencies up to 100Hz. It should be noted that embedding the Woojer into the plush toy backpack may attenuate certain frequencies, thereby affecting the overall haptic experience. However, our tests suggested that the haptic experience was still of adequate quality in terms of the feedback provided. In the first version of HMP 2, the Woojer was connected to headphones using a cable. The Woojer was placed in a pocket located on the back of the backpack and surrounded by soft padding material. Conclusions from the feedback collected from evaluation session (see Section 3.2) prompted us to re-design HMP 2 to make it easier to debug. In the second iteration of this device, we connected a mini speaker (frequency response 50-18 000Hz) directly to the Woojer device. The speaker was taped to the Woojer using duct tape. We also sewed the protective padding into the backpack, so that the Woojer was the only thing visible in the pocket. The final version of HMP 2 is displayed in Figure 2.

¹⁷ Author 1 and 2 are the copyright owners of all pictures used in this manuscript

¹⁸ <https://www.woojer.com/pages/technology>

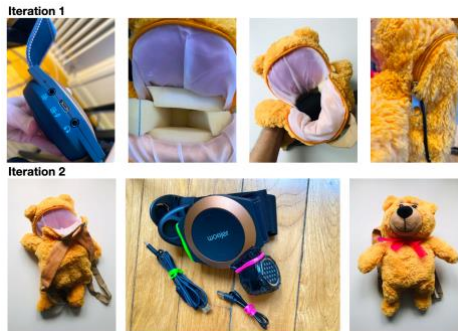


Figure 2 – HMP 2 in first iteration (upper), versus second iteration (lower pictures). The Woojer Strap Edge is shown in the leftmost image (upper) and middle image (lower)

3.1.4 Haptic Music Player 3

HMP 3 was designed as a custom-built plush toy with an embedded full-range speaker (Visaton FRS 8 - 8 Ohm¹⁹, frequency response 200-20 000Hz) and tactile transducer (TT25-8 PUCK Tactile Transducer Mini Bass Shaker²⁰, frequency response 20-80Hz). This HMP was inspired by the character Chewbacca from Star Wars. An overview of the design process is displayed in Figure 3. The HMP was built from a small wooden napkin box which was embedded in multiple layers of protective foam. This structure was covered in textile fake-fur material. To give the device a more animalistic character, we decorated the HMP with glass eyes and a round speaker cover that would symbolize a mouth. The HMP is constructed in such a way that it can easily be opened if cables or soldering would need to be mended or upgraded. Female 3.5mm jack outputs are glued to the wooden structure so that all cables can be easily pulled out by the students. Pulling the cable only results in the audio being unplugged; it doesn't break the device or the soldering inside of the wooden structure. HMP 3 was connected to a DTA-2.1BT2 100W 2.1 Class D Bluetooth amplifier²¹ using two 5-meter-long cables. This allowed the device to be moved freely in the room while at the same time keeping the amplifier (with all its cables and buttons) further away from the students. The amplifier has an adjustable crossover frequency (50-120Hz) for the subwoofer output. The sonic signal has a frequency response of 20-20 000Hz.

3.2 Evaluation

Transcripts from the three interviews are available as supplementary material. The evaluation interviews revealed that the students managed to successfully explore musical haptics using HMP 1, HMP 3, and the second iteration of HMP 2. The devices were primarily tested during lessons, but HMP 2 had also been used during free play time at the school. The average time spent exploring the HMPs was 10 minutes. The teacher described that it was a bit difficult to say which HMP that worked best: *"I would say that [...] either the Chewbacca or the [teddy]bear were most reliable. At the same time, I know that in the [free playing time] they used mostly the pillow. So comparing to how many times it is used...maybe the pillow [...] I would say that the most engagement from the students I felt [...] so far maybe from the Chewbacca."* A range of different sounds were used when testing: the music that we had sent to the teacher, children's music, other music that the teacher knew that the students liked, instrumental sounds (drums and electric guitar), and animal sounds (bear and whale singing). The students managed to actively engage with the HMPs using different modes of listening, both individually and as a group. When interacting as a group, the devices were usually placed on a wooden table, and passed around. This also enabled you to feel the vibrations through the table surface. Common themes that were identified through content analysis for all HMPs related to 1) *different strategies for exploration of the HMPs* (18 quotes), 2) *the novelty of musical haptics* (8 quotes), and 3) *elements of play* (7 quotes). Regarding theme 1 (strategies for exploration), the most common strategy was to use the hands for haptic exploration. The teacher described that this strategy also made it easy to withdraw from the interaction by removing the hand, if you did not like how it felt. The different interaction strategies are discussed in detail below, for respective HMP. Concerning theme 2

¹⁹ <https://www.visaton.de/en/products/drivers/fullrange-systems/frs-8-8-ohm>

²⁰ <https://www.daytonaudio.com/product/1104/tt25-8-puck-tactile-transducer-mini-bass-shaker>

²¹ <https://www.daytonaudio.com/product/1604/dta-2-1bt2-100w-2-1-class-d-bluetooth-amplifier-with-sub-frequency-adjustment>

(novelty of musical haptics), it was clear that regardless of which HMP that was used, the students were not interested at their first encounter with the devices. The novelty of the vibrating experience, or the functionality of the devices in general, clearly resulted in skepticism upon first use. This was communicated by pushing away the devices the first times they were presented. The teacher described: *“We usually just listen to music and dance so it is another experience for them that there is something that vibrates to music.”* However, the HMPs were indeed accepted, and appreciated, in subsequent test sessions (although some devices were more popular than others). Finally, regarding theme 3 (elements of play), certain aspects of the HMPs naturally invited to play. For example, it appeared to be particularly interesting and fun for the students to play with the hair of HMP 3, and its cables.

3.2.1 Haptic Music Player 1

When it comes to the *functionality* of the pillow, the teacher mentioned that it was quick to set up and reliable. It was good that it only had one button. However, there were instances where there had been some issues; the sound had been cut off at times and it was a bit tricky to set up the Bluetooth for the first time. The pillow had not been thrown but it once fell to the floor, and it did not break. In terms of interactions, the students had used their hands, hugged, clapped/petted it, laid their head on it, and used their feet, and mouth, to explore it. Regarding *accessibility*, the teacher described that *“The cool thing about the pillow was that it could be used by two persons at the same time. For example we could put [it] on the table [...] and the students who were sitting in front of each other, could both feel it with their hands or with their faces”*. In other words, the fact that the pillow was long enough to be accessed by two students at the same time was a positive feature. The pillow was described as somewhat less intuitive to use compared to HMP 3; the teacher needed to demonstrate to the students how it should be used for them to understand it. Regarding the *user experience*, one student had described that he liked HMP 1 (and also HMP 3), using PODD. The teacher described that she got the impression that the students were quite interested in HMP 1, overall. However, in terms of visual and tactile experience, the object was not as interesting as HMP 3, since it has a beige color and the textile was quite smooth.



Figure 3 – HMP 3 at different stages of the development process

3.2.2 Haptic Music Player 2

In terms of *functionality*, the first version of HMP 2 had problems related to the headphones: it was difficult to debug the system and to know if it was working or not. The new iteration of the HMP included an embedded loudspeaker, which made it easier to use and more reliable. In particular, the spoken prompts about the Bluetooth connectivity were immediately transmitted through the speaker. The teacher described that she had to carefully read the instructions about Bluetooth pairing to successfully set up the device. She also mentioned that in a school setting a speaker might be more appropriate, since it allows more students to listen to music simultaneously in a group setting (compared to headphones). She described that since the speaker was embedded in padding the sound was a bit muffled, but this was not something that significantly affected the overall experience. Regarding durability, the zip locker on the backpack unfortunately broke rather quickly. When it comes to *accessibility*, as opposed to HMP 3 (which also had an animalistic character), HMP 2 was not as intuitive for the students. The teacher described: *“It looked like it was confusing that it’s a teddy bear, and it’s something that sounds also at the same time.”* We discussed whether this confusion could be caused by the fact that the sound was always on; the teddy bear was just making sounds without any interaction (as opposed to standard interactive plush toys, which require you to, for example, squeeze them). The teacher also mentioned that providing a “button feature” perhaps could have resolved this issue. She compared the design of HMP 2 with HMP 3, mentioning that HMP 3 had

a mouth that the audio was coming from, and that the black circular shape of its mouth reminded a bit of a button. In terms of bodily locations used when interacting with HMP 2, the students mostly used their hands. The teacher did not try to put the backpack on the students' bodies, since she wanted to allow them to test out the device using their hands, first. The teacher described: *"But it's hard to say if they pushed it away because of the vibration or they pushed it away because of the unusuality of the sounding plush toy."* Overall, regarding the *user experience*, the students appeared to be mildly impressed; only one student played a little bit with HMP 2, before pushing it away.

3.2.3 Haptic Music Player 3

Regarding the *functionality* of HMP 3, it took a little longer to set it up, compared to HMP 1. However, it was still easy for the teacher to use, despite having a somewhat more complex configuration, involving an amplifier. The audio quality was reportedly good and the filter knob for the subwoofer frequencies resulted in perceptual differences. Regarding this feature, the teacher described one instance in which: *"it was such a wonderful time and [...] it seemed like the students were so calm and happy, so I felt that maybe I won't change [the knob] now because it felt really good, with the vibration and everything."* One student had tried to pull the cables from HMP 3 and the teacher was impressed that the HMP did not break. A comment made by the teacher was that the combination of HMP 1 and HMP 3 would have been ideal, i.e., to have one button to set up the system while maintaining the playful properties of HMP 3. Regarding *accessibility*, it seemed like HMP 3 worked equally well for different users. It was somewhat more intuitive to use than HMP 1. The teacher described that for HMP 1: *"[...] I was showing them more that oh, you can put your hand on it, or you can lie down on it. You can put it in your lap"*. She contrasted this to HMP 3: *"[...] with Chewbacca I hadn't done this kind of showing. I just presented the Chewbacca [...] so maybe because the Chewbacca was more playful, it was more intuitive also for the students."* The teacher not only explored music but also animal sounds with HMP 3, since Chewbacca looked a bit like a bear. Apparently, bear sounds were well received by the students. As described by the teacher, the students reacted as though they thought: *"Okay it's a bear and it sounds like a bear."* She had also tried using whale sounds, but the students were more engaged for the bear sounds. Regarding how HMP 3 was used, it had - similarly to HMP 1 - been put on the table and mostly been explored using the hands. The students also tested it in their lap and put their chins and faces onto it. One student had communicated using PODD that she wanted to feel the vibrations from HMP 3 on her feet. The teacher described that a positive aspect about HMP 3 was that it was smaller than HMP 1. As such, it was easier to put it on the stomach or the feet. Although the strategies used for interacting with HMP 1 versus HMP 3 were not that different, some aspects related to the *user experience* appeared to be. For example, the teacher described: *"The big difference for Chewbacca [was that]...the student that is really interested in hair, felt of course more with their hand, on the Chewbacca. Because, it was, it was also a play."* The fact that HMP 3 encouraged and invited to play distinguished it from the other HMPs. The teacher also commented: *"Chewbacca has also strong colors, fur [...] I would guess that the texture and the color makes it more interesting than the pillow"*.

4. DISCUSSION

Based on the evaluation of *functionality*, *accessibility*, and *user experience*, it appears as the most successful HMP overall was HMP 3. HMP 1 also worked well, but it did not invite to play in the same way as HMP 3 did. Moreover, based on the evaluation sessions, we can conclude that the affordances of the physical objects are important in this context. The appearance of HMP 2 led to some confusion, perhaps since its design created certain expectations that were not met. HMP 3 also looked somewhat like a plush toy, but not exactly like one. Perhaps it did not as strongly afford that it would work like a standard plush animal. Interestingly, HMP 3 was the device that was most interesting in terms of its tactile experience overall, since it had fake fur and a hair-like texture that invited to active haptic exploration, even if the vibrations were turned off.

If the types of devices described in this paper should work effectively in a school setting, they need to be effortless to set up. One reason why HMP 2 did not work well, apart from the fact that it had headphones as opposed to a built-in speaker, was perhaps that we had not demonstrated its setup procedure in person (HMP 1 was connected to the teacher's iPad during the initial meeting, but we never paired the teachers' iPad to the Woojer device; HMP 3 had also been demonstrated in person at another occasion). As mentioned by the teacher, having only one single button to setup the device would be ideal. Because of its ease of use, HMP 1 was used most times, even if HMP 3 was perhaps

the object that resulted in most engagement from the students. The interviews with the teacher also clearly highlighted the need for adequate time to get used to the HMPs; all devices were met with skepticism upon first use.

Assessing complex multisensory phenomena with users who are pre-verbal is a challenging task. In the current work, we could not directly ask the students what they perceived and thought, since they are pre-verbal. In addition, we could not meet the students physically, so the study had to be conducted in a remote setting. To get an idea of how the students perceived musical haptics through the different HMPs, we used an observation by proxies methodology. In other words, we focused on what was observed by the teacher, i.e., PODD conversations and observations of nonverbal expressions, to judge if the vibration enhanced the musical listening experience. Of course, this approach introduces a level of uncertainty and possible bias in the evaluation process. One of the main weaknesses of the current work is that the evaluation relies on the observation of a single teacher. It is also difficult to generalize from the reported results since only four students were involved in the study. What is reported in this paper should therefore be seen as results from a first exploratory case study; there is a need for more controlled long-term studies with a larger group of participants. Moreover, much of what was discussed during the evaluation interviews focused on the usability of the devices from the teacher's perspective. This is important, but it would be good to explore the haptic experiences of the children more in detail in future work. More objective methods of evaluation could be explored in future studies. For example, the time spent with respective HMP could be used as a measurement in this context. Because of the restrictions due to the COVID-19 pandemic, we could unfortunately not attend the evaluation sessions in person. As such, it was difficult to collect such measures. Nevertheless, we believe that the teachers' observations provide useful insights regarding what worked well versus did not work well for respective HMP, and that these design considerations could be considered in future work. Finally, it should be noted that we did not perform any accelerometer measurements or analysis of the frequency responses of the HMPs. This is another aspect that could be further explored in future studies.

5. CONCLUSIONS

In this paper we present a six-month exploratory study on the qualitative evaluation of three Haptic Music Players (HMPs) with four pre-verbal children with Profound and Multiple Learning Disabilities (PMLD). The HMPs encouraged exploration of haptic music through different means of interaction. Findings from the evaluation sessions revealed that the students managed to actively engage with the HMPs using different modes of listening, both individually and as a group. The students communicated to the teacher and teaching assistants if they liked versus disliked the haptic sensations and which body parts they wanted to use when feeling the vibrations. The dominating strategy when interacting with the HMPs was to explore the devices using the hands. This allowed the children to easily remove the point of contact, or to push away the HMPs, if they did not like the haptic sensations. The three HMPs greatly differed in terms of their functionality, accessibility, and user experience. Our findings highlighted the need for extra time to get used to HMPs since this type of musical interaction can be completely new for many children. The physical affordances and touch and feel of the objects are important in this context since they might influence how well the HMPs are received. The design of HMPs for children should ideally invite to touch and play. For experimentation with HMPs in school settings, it might be good to provide several devices of different sizes which can be used both in single and collaborative settings. An example of a design solution that allows for multiple users to perceive vibrations is a haptic table, or a haptic device that could be attached to such furniture. Finally, it is crucial that HMPs used *in the wild* are easy to setup, have proper documentation involving troubleshooting sections, and that the HMPs used in special education settings are demonstrated in person before first use.

ACKNOWLEDGEMENTS

The authors would like to thank the students, the teacher, and the teaching assistants at Digger Rullen, who kindly participated in the study. We would like to especially extend our thanks to Eszter Trautmann. This research was funded by the Swedish Research Council (Vetenskapsrådet) grant number 2020-00343, and a Bernadotte scholarship from the Royal Swedish Academy of Music (Kungliga Musikaliska Akademien).

REFERENCES

1. Papetti S, Saitis C. Musical Haptics: Introduction. In: *Musical Haptics*. Springer Nature; 2018.
2. Zimmerman E, Lahav A. The Multisensory Brain and its Ability to Learn Music. *Ann N Y Acad Sci*. 2012;1252(1):179–84.
3. O’Modhrain MS. *Playing by Feel: Incorporating Haptic Feedback into Computer-Based Musical Instruments* [PhD Thesis]. Stanford University. 2001.
4. Galembo A, Askenfelt A. Quality Assessment of Musical Instruments-Effects of Multimodality. In: *Proceedings of the 5th Triennial Conference of the European Society for the Cognitive Sciences of Music (ESCOM5)*, Hannover, Germany. 2003. p. 8–13.
5. Fontana F, Avanzini F, Jarvelainen H, Papetti S, Klauer G, Malavolta L. Rendering and Subjective Evaluation of Real vs. Synthetic Vibrotactile Cues on a Digital Piano Keyboard. In: *International Conference on Sound and Music Computing (SMC2015)*. SMC; 2015. p. 161–7.
6. Fontana F, Papetti S, Civolani M, dal Bello V, Bank B. An Exploration on the Influence of Vibrotactile Cues During Digital Piano Playing. In: *Proceedings of the International Conference on Sound Music Computing (SMC2011)*, Padua, Italy. 2011. p. 273–8.
7. Saitis C, Fritz C, Scavone GP, Guastavino C, Dubois D. Perceptual Evaluation of Violins: A Psycholinguistic Analysis of Preference Verbal Descriptions by Experienced Musicians. *J Acoust Soc Am*. 2017;141(4):2746–57.
8. Wollman I, Fritz C, Poitevineau J. Influence of Vibrotactile Feedback on Some Perceptual Features of Violins. *J Acoust Soc Am*. 2014;136(2):910–21.
9. Giordano B, Avanzini F, Wanderley M, McAdams S. Multisensory Integration in Percussion Performance. In: *10ème Congrès Français d’Acoustique*. 2010.
10. Merchel S, Altinsoy ME. Auditory-Tactile Music Perception. In: *Proceedings of Meetings on Acoustics ICA2013*. Acoustical Society of America; 2013. p. 015030.
11. Merchel S, Altinsoy ME. Auditory-Tactile Experience of Music. In: *Musical Haptics*. Springer, Cham; 2018. p. 123–48.
12. Visell Y. Tactile Sensory Substitution: Models for Enaction in HCI. *Interact Comput*. 2009 Jan;21(1–2):38–53.
13. Remache-Vinueza B, Trujillo-León A, Zapata M, Sarmiento-Ortiz F, Vidal-Verdú F. Audio-Tactile Rendering: A Review on Technology and Methods to Convey Musical Information Through the Sense of Touch. *Sensors*. 2021;21(19):6575.
14. Nanayakkara S, Taylor E, Wyse L, Ong SH. An Enhanced Musical Experience for the Deaf: Design and Evaluation of a Music Display and a Haptic Chair. In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. Boston MA USA: ACM; 2009. p. 337–46.
15. Frid E, Lindetorp H, Falkenberg Hansen K, Elblaus L, Bresin R. Sound Forest: Evaluation of an Accessible Multisensory Music Installation. In: *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. 2019. p. 1–12.
16. Petry B, Illandara T, Elvitigala DS, Nanayakkara S. Supporting Rhythm Activities of Deaf Children Using Music-Sensory-Substitution Systems. In: *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. Montreal QC Canada: ACM; 2018. p. 1–10.
17. Mazzoni A, Bryan-Kinns N. Mood Glove: A Haptic wearable Prototype System to Enhance Mood Music in Film. *Entertain Comput*. 2016 Nov;17:9–17.
18. Yamazaki Y, Mitake H, Takekoshi M, Tsukamoto Y, Baba T, Hasegawa S. Hapbeat: Tension-Based Wearable Vibroacoustic Device. In: Hasegawa S, Konyo M, Kyung KU, Nojima T, Kajimoto H, editors. *Haptic Interaction*. Singapore: Springer Singapore; 2018. p. 387–92. (Lecture Notes in Electrical Engineering; vol. 432).
19. Giordano M, Hattwick I, Franco I, Egloff D, Frid E, Lamontagne V, TeZ C, Salter C, Wanderley MM. Design and Implementation of a Whole-Body Haptic Suit for “Ilinx”, a Multisensory Art Installation. In: *Proceedings of the International Conference on Sound Music Computing (SMC2015)*; 2015. p. 169–175.
20. Yoo Y, Hwang I, Choi S. Consonance of Vibrotactile Chords. *IEEE Trans Haptics*. 2014 Jan;7(1):3–13.
21. Petry B, Huber J, Nanayakkara S. Scaffolding the Music Listening and Music Making Experience for the Deaf. In: *Assistive Augmentation*. Springer; 2018. p. 23–48.
22. Giordano M, Sullivan J, Wanderley MM. Design of Vibrotactile Feedback and Stimulation for Music Performance. In: Papetti S, Saitis C, editors. *Musical Haptics*. Cham: Springer International Publishing; 2018. p. 193–214. (Springer Series on Touch and Haptic Systems).
23. Bellamy G, Croot L, Bush A, Berry H, Smith A. A Study to Define: Profound and Multiple Learning Disabilities (PMLD). *J Intellect Disabil*. 2010;14(3):221–35.

24. Ockelford A, Welch G, Zimmermann S. Focus of Practice: Music Education for Pupils with Severe or Profound and Multiple Difficulties—Current Provision and Future Need. *Br J Spec Educ.* 2002;29(4):178–82.
25. Rushton R, Kossyvaki L. Using Musical Play with Children with Profound and Multiple Learning Disabilities at School. *Br J Spec Educ.* 2020;47(4):489–509.
26. Rushton R, Kossyvaki L. The Role of Music Within the Home-Lives of Young People with Profound and Multiple Learning Disabilities: Parental Perspectives. *Br J Learn Disabil.* 2022;50(1):29–40.
27. Fowler S. *Multisensory Rooms and Environments: Controlled Sensory Experiences for People with Profound and Multiple Disabilities.* Jessica Kingsley Publishers; 2008.
28. McLinden M. Hands On: Haptic Exploratory Strategies in Children Who Are Blind with Multiple Disabilities. *Br J Vis Impair.* 1999;17(1):23–9.
29. Argyropoulos V, Papazafiri M. Investigating Tactile Exploratory Procedures of Students with Multiple Disabilities and Visual Impairment: Current Trends in Education. *Spec Educ.* 2017;8:9.
30. Frid E. *Diverse Sounds: Enabling Inclusive Sonic Interaction [PhD Thesis].* KTH Royal Institute of Technology; 2019.
31. Frid E. Accessible Digital Musical Instruments – A Review of Musical Interfaces in Inclusive Music Practice. *Multimodal Technol Interact.* 2019;3(3):57.
32. Ladner RE. Design for User Empowerment. *Interactions.* 2015;22(2):24–9.
33. Charlton JI. *Nothing About Us Without Us.* University of California Press; 1998.
34. Abras C, Maloney-Krichmar D, Preece J, et al. *User-Centered Design.* Bainbridge W *Encycl Hum-Comput Interact* Thousand Oaks Sage Publ. 2004;37(4):445–56.
35. van der Velden M, Mörtberg C. Participatory Design and Design for Values. In: *Handbook of Ethics, Values, and Technological Design: Sources, Theory, Values and Application Domains.* Dordrecht: Springer Netherlands; 2021. p. 1–22.
36. Quintero C. A Review: Accessible Technology Through Participatory Design. *Disabil Rehabil Assist Technol.* 2020;1–7.
37. Spencer González H, Vega Córdova V, Exss Cid K, Jarpa Azagra M, Álvarez-Aguado I. Including Intellectual Disability in Participatory Design Processes: Methodological Adaptations and Supports. In: *Proceedings of the 16th Participatory Design Conference 2020-Participation (s) Otherwise-Volume 1.* 2020. p. 55–63.
38. Porter G, Cafiero JM. Pragmatic Organization Dynamic Display (PODD) Communication Books: A Promising Practice for Individuals with Autism Spectrum Disorders. *Perspect Augment Altern Commun.* 2009;18(4):121–9.
39. Hamidi F, Baljko M, Gómez I. Using Participatory Design with Proxies with Children with Limited Communication. In: *Proceedings of the 19th International ACM SIGACCESS Conference on Computers and Accessibility.* 2017. p. 250–9.
40. Constantin A, Alexandru C, Korte J, Wilson C, Fails JA, Sim G, et al. Distributing Participation in Design: Addressing Challenges of a Global Pandemic. *Int J Child-Comput Interact.* 2021;28:100255.
41. Rogers Y. Interaction Design Gone Wild: Striving for Wild Theory. *Interactions.* 2011 Jul;18(4):58–62.
42. Frid, E. and Panariello, C. and Núñez-Pacheco, C. Customizing and Evaluating Accessible Multisensory Music Experiences with Non-Vocal Children - A Case Study on the Perception of Musical Haptics Using Participatory Design with Proxies. *Multimodal Technologies and Interaction.*
43. McNamara N, Kirakowski J. Functionality, Usability, and User Experience: Three Areas of Concern. *Interactions.* 2006 Nov;13(6):26–8.
44. Petrie, Helen and Bevan, Nigel C. The Evaluation of Accessibility, Usability and User experience. In: *The Universal Access Handbook.* Boca Raton: CRC Press; 2009.
45. Young GW, Murphy D. HCI Models for Digital Musical Instruments: Methodologies for Rigorous Testing of Digital Musical Instruments [Internet]. *arXiv*; 2020 [cited 2022 Jul 8]. Available from: <http://arxiv.org/abs/2010.01328>
46. Young, Gareth W. *Human-Computer Interaction Methodologies Applied in the Evaluation of Haptic Digital Musical Instruments.* University College Cork; 2016.
47. Connell, BR, Jones M, Mace R, Mueller J, Mullick A, Ostroff E, Sanford J, Steinfeld ED, Story M, and Vanderheiden G. *The Principles of Universal Design.* 1997.
48. Downe-Wamboldt B. Content Analysis: Method, Applications, and Issues. *Health Care Women Int.* 1992;13(3):313–21.
49. Ferrigon P, Tucker K. Person-First Language vs. Identity-First Language: An Examination of the Gains and Drawbacks of Disability Language in Society. *J Teach Disabil Stud.* 2019;