CHIMELIGHT: Augmenting Instruments in Interactive Music Therapy for Children with Neurodevelopmental Disorders

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ABSTRACT
In this paper, we propose a new mobile system to support therapists for teaching and tracking socio-communicative behaviors in children with neurodevelopmental disorders during music therapy sessions. The CHIMELIGHT system was designed to deal with the current issues in conventional therapies, such as the difficulty in both evaluating the performance and maintaining engagement of these children during therapeutic activities. The system evaluated movements made by a child with neurodevelopmental disorders playing a musical instrument while delivering contingent visual feedback based on real-time motion analysis. A set of metrics was implemented to evaluate the performance during the therapy activity and quantify specific target behaviors. An evaluation study performed during music therapy group sessions showed that the CHIMELIGHT-delivered visual feedback increased the engagement of children in the activity and decreased targeted negative behaviors. In some participants, we observed potential changes in their positive behaviors. Interviews and questionnaires provided to therapists showed that the developed system was effective for supporting evidence-based music therapy. Accordingly, our research enables new methods for both interactive therapy and mediation of the interaction between therapists and children with neurodevelopmental disorders.

Author Keywords
Assistive Technology; Socio-communicative Behaviors; Interactive Therapy; IoT; Music Therapy; Neurodevelopmental Disorders; Social Playware;

CSS Concepts
Human-centered computing~Interaction design; Ubiquitous and mobile computing; Children.

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INTRODUCTION
Children with a neurodevelopmental disorder (NDD) show disruptions in learning, attention, and socio-communicative behaviors. NDDs includes sub-disorders such as autism spectrum disorder (ASD), attention deficit hyperactivity disorder (ADHD), and intellectual disability (ID). NDD children have been subjected to different types of therapy, such as applied behavior analysis (ABA)-based therapies, speech therapy, and music therapy, for the promotion of the acquisition of communication skills and development of social behaviors. Nevertheless, progress during therapy can be slow, and it is difficult to keep children motivated during long-term therapy sessions. Current therapies present other limitations because they lack a standardized objective assessment and require intensive sessions with trained professionals who are not typically available. In addition, generally, such sessions require interaction with another person as the primary model of teaching, which might possess some degree of built-in difficulty and cause anxiety to some NDD children [8].

Technology-based solutions may have the potential to minimize the above-mentioned anxiety and deal with some of the current limitations of conventional therapies. Children with NDD need to be empowered in their interactions with therapists as well as in the process of both learning communicative behaviors and increasing attention. Interactive therapies can be developed around feedback delivery, behavior change models, behavior reinforcement rewards, interactivity, and technology-mediated play. We believe that these concepts can be applied to different types of therapeutic activities targeting socio-communicative skills in people with an NDD. The tools to support interactive therapy should be easy to use, attractive, and employ multi-sensory stimuli to facilitate communication between a therapist and client.

In this research, we developed a tool for supporting interactive music therapy. This tool intended to increase the attention of and facilitate teaching socio-communicative behaviors to children with an NDD. This paper describes the design, implementation, and evaluation of CHIMELIGHT, our mobile system for engagement and assessment during music therapy practice. Our approach introduced real-time sensing and device-delivered contingent feedback as new methods to facilitate both therapy assessment and compliance. Herewith, this research contributed to new methods for the mediation of a child–therapist interaction and behavior tracking during group music therapy sessions. We expect that our work will enable a wider adoption of interactive therapy, bringing together the fields of design, engineering, and therapy.

BACKGROUND

Music Therapy for Neurodevelopmental Disorders

Music has been proved as an effective tool for the development of a wide range of skills, including language and non-verbal communication [13]. Because musical patterns are not only engaging but also predictable and structured, music therapy is an emerging multisensory support therapy. It can be defined as the clinical and evidence-based use of music or rhythmic activities to address non-music therapeutic goals. Over the last two decades, music therapy practice and research have grown significantly, strongly focusing on those with an NDD, namely ASDs [5,23]. It has been demonstrated that careful manipulation of specific musical elements helps facilitating attention and communication in children with ASDs [11]. Furthermore, music therapy and ABA-based approaches can be combined for obtaining better outcomes for learning communicative behaviors and promoting behavior adoption [14].

Studying Behavior in Music Therapy

Music therapy can promote communicative behaviors by coordinating the interactions during its activities. In general, these interactions have been categorized into coherence, synchronization, and reciprocity [29]. Coherence interactions relate to the ability of producing melody and exerting a control over the played notes, volume, and rhythm. Synchronization refers to the ability of a client to imitate or being in synchrony with their therapist. Reciprocity relates to the ability of communicating by play, and it includes events such as turn-taking or non-verbal cues. This behavior has to occur with communicative intention to achieve reciprocity. The study of coherence, synchronization, and reciprocity behaviors during music therapy has been mainly focused on one-to-one therapy sessions and activities concerning music improvisation [29].

Technology in Music Therapy

Digital technology has been used in music therapy since the 1990s, either for assessment, treatment, training, or research [18]. Studies have reported that the percentage of therapists using technology in their music therapy practice has been increasing [7]. The assessment of the performance in music therapy using technology has been mainly conducted by computer software analyzing the recordings of music therapy improvisations [12], by databases of information from sessions [4], or programs to describe music therapy events qualitatively [6]. Several interactive music interfaces can be found in the form of rhythm games (e.g., Guitar Hero and piano game apps), augmented musical instruments, or movement-to-music systems. Nevertheless, studies regarding the impact of smart, mobile, or IoT technologies for supporting music therapy sessions for children with an NDD have not been sufficiently explored.

Technology-mediated Play

Previous works [21,24] have showed that technology-mediated play can enable learning in children with ASD. These methods can be integrated as social playware, i.e., the use of intelligent hardware and software to create playful experiences while encouraging learning processes and interactions between several users [17]. By providing technological methods of interactive play, it may be possible to promote basic social skills for children with an NDD. A few existing music-related assistive technologies and tangible user interfaces, such as Reactable [28] or Skoog [26], have been showed to promote social interaction and play in people with ASDs. Similarly, ubiquitous technology has the potential to promote the understanding of social interactions in a fun manner.

Feedback Delivery and Interactive Therapy

The role of feedback in any type of therapy is to enhance learning and self-awareness while promoting active participation during the therapeutic activity [22]. People with an NDD have sensory impairments and difficulty in cause–effect associations. Therefore, therapists use different types of feedback when working with children with NDDs. Verbal, visual, and haptic feedback can be provided to these children under different feedback modalities. Therapists can present feedback as a contingent response (typically a verbal praise or comment dependent on the performance of the child) or as a contingent imitation (where the same behavior is immediately returned by the therapist). Studies have shown that contingent imitation, for example, can promote verbal interactions in children with ASDs [10]. Computer-generated feedback (auditory and/or visual) has also been hypothesized to encourage communication in children with ASD. Particularly for music therapy, augmenting its natural auditory modality with real-time visual feedback may be an effective approach for strengthening the sense of causality in the therapy [20]. Related studies have focused on computer-based visualizations of vocal or music expressions, either in real-time or as a contingent feedback/imitation. Examples include IBMSpeechViewer*,* suggesting that visual feedback on sound productions is promising for non-verbal autistic children [1], or VocSyl [9], a software that provides real-time visual feedback as representations of the vocal pitch, loudness, duration, and syllables. CymaSense generates real-time three-dimensional visual stimuli as an interactive multimodal interface to improve the communication and self-esteem of people with ASDs [20]. Besides CymaSense and BendableSound [3], a few prototypes explore multisensory environments to target therapeutic goals. Interactive multimodal systems suggest that the ability to experience tactile, auditory, and visual feedback provide an additional sense of agency and independence to the client of the therapy. Nonetheless, the major limitation of these approaches is related either to the lack of portability or lack of a strong group-play component, relying significantly on abstract visualizations.

DESIGN PROCCESS

Observation of Therapy Sessions

The initial challenge in creating a new technological tool for interactive music therapy was the identification of the needs of the target user and system requirements. The first step toward this was to observe first-hand how music therapy activities unfold and how target users behave on the setting of therapy sessions. We selected group sessions occurring at a center for child development and psychosomatic medicine. We observed four sessions, one per month, of a certain therapy group. A team of six music therapists and a medical doctor worked together with children with NDDs and their parents in one-hour monthly therapy sessions. The participating children were divided into groups of 7–10 according to the severity of their NDD diagnosis. Mainly between 6 and 15 years of age, they were diagnosed with ASD, ADHD, and/or ID. In these sessions, the therapists employed ABA methodologies in music therapy and focused on generating good group dynamics. Each child participated in several musical activities, responding on his/her own timing to the cues provided by the therapists. The objective was for the children to learn and practice good socio-communicative behaviors in an engaging manner. During these sessions, we observed that it was difficult to make these children to sit still and comply during all the activities. The observed negative behaviors of children during the sessions included, for example (see Figure 1), throwing away or mishandling of musical instruments, poor engagement in the given tasks, not facing nor looking at the therapist, not paying attention to nor imitating what the therapist is doing for them, incorrect sitting position, suddenly getting up and walking across the room, and repetitive behaviors such as balancing in the chair, shaking the head, or moving hands continuously. These negative behaviors are behaviors that therapists wanted to reduce, while trying to replace them by positive socio-communicative behaviors. These positive behaviors included looking at the face of the therapist, respecting the silence, and respecting playing turns of other participants.

The Handchime Activity

After observing a few therapy sessions, the 'Handchime Activity' was selected as the main focus of this work. Handchimes are squared tubular musical instruments made of lightweight aluminum and with an external clapper mechanism. Handchimes of different lengths and widths are available for producing different musical tones. For the Handchime Activity, the children sat on their own chairs, were placed in a semicircle, and held a handchime. Each child had a different musical tone. The lead therapist sat on the opposite side of the semicircle (see Figure 2) and guided the group through the activity segments: ensemble-play (synchronized group play of the handchimes, where all the children imitate the lead therapist play) or free-play (improvisation section). The activity was accompanied with a background song. Each Handchime Activity could be 4–10-minutes long, depending on the developmental level and progress of the participants. During this activity, the main target behaviors for the children are: paying attention to and responding to the lead therapist cues, respecting the silence and pauses, listening to others when not playing, and playing the handchime correctly and in sync with the therapist.

User Needs and Requirements

We designed the system by a user centered design methodology. Based on the evidence and feedback collected from the observation of therapy sessions, informal interviews to therapists, and a literature review, we identified a set of needs and requirements for two types of users (therapists and children with NDD).

Figure 1. Examples of negative behaviors of children with NDDs observed during music therapy group sessions. From left to right: standing and jumping during activities, not participating in the activity, repetitive negative behaviors, screaming, and mishandling music instruments.

Figure 2. Photo during the Handchime Activity during the observed music therapy group sessions.

The observations highlighted the importance of promoting desired behavior changes during therapy: decreasing negative behaviors and increasing positive behaviors of children with NDDs. As the main focus of the Handchime Activity were attention, imitation, and synchronization, the support technology designed should preferably make a child 1) more attentive to the activity tasks, 2) imitate the therapy voluntarily and follow all the provided cues, and 3) play with the right timing and correctly. During the sessions, the children were not typically aware that they were being evaluated by the therapist. Even in the case they were conscious of it, the excitement during the musical activities and will to play, sing, or dance, made them forget about the anxiety and stress of being among healthcare professionals and unfamiliar people. Herewith, with our system, the child must not realize that the device is a tool to serve the goals of the therapist. This also relates to the recommendations of the design of playware devices [15].

In the interviews after each of the observed sessions, the therapists stated that recording and evaluating pauses, silence, and stillness are as important as evaluating active plays and actions. They considered that the ability to hear others and patiently respect the turns of others were important to teach to these children who lack socio-communicative skills. It was also agreed that integration with familiar objects already used during therapy would be preferable, as for example musical instruments or toys.

Based on [15], feedback as a reward for the desired behavior modification can be provided for positive reinforcement. Light-based visual feedback has been considered as a method to rapidly capture the attention of a child, and as such, is used as an additional engaging factor during music therapy. Furthermore, we expect to deal with some of the current issues of music therapy by providing a practical approach to mediate and assess a therapy activity for children with NDDs. For mediating the therapist–children interaction, we support that offering simple and casual interactions will facilitate the interaction and engagement of the users. Regarding the assessment of music therapy, we investigated and discussed with therapists several metrics that could evaluate the performance during the Handchime Activity.

Therefore, we designed CHIMELIGHT, an IoT music therapy tool to be used by children and their lead therapist during the Handchime Activity, for simultaneous assessment and intervention during the therapy. With the objective of supporting behavior modification in children with NDDs, the following two main functions of the system were defined: measuring performance (by sensing motion of the handchimes) and rewarding positive behaviors (by delivering contingent visual feedback). The system aimed to augment the natural auditory modality of the handchime play with real-time visual feedback. We hypothesized that this might strengthen the sense of causality between positive behaviors and feedback rewards in children with NDDs.

THE CHIMELIGHT SYSTEM

IoT Device

For children to receive therapeutic benefits while having fun, we augmented a typical handchime musical instrument with the CHIMELIGHT device. Each device contained a microcontroller, Bluetooth low-energy (BLE) module, 4x8 RGB LED matrix, multi-environmental sensors board (with a 3D accelerometer, 3D gyroscope, and three-axis magnetometer), and lithium battery; all accommodated within a 3D-printed enclosure. The final prototype used a black opaque circular shaped box with a white translucent section on the top on the section of the LED array. The device was wireless, portable, and could be fixed to the top of one handchime, with the LED white area facing the player, as shown in Figure 3. The CHIMELIGHT device was built to be attached to a handchime without disturbing the acoustic sound produced by the musical instrument and while being firmly fixed. Devices could be attached and detached from the handchime surface as desired, allowing the therapists to rapidly change a device between handchimes of different lengths and musical tones.

Mobile Application

CHIMELIGHT devices operate while connected via BLE to a dedicated Android application. Multiple devices can be connected simultaneously. The CHIMELIGHT app works as a control and data management platform for all the devices being used and registered for one session. A therapist can use this app to connect and pair devices, control simultaneous start/stop of all the connected devices, change between sensing-only or sensing with feedback modes, and store and visualize the recorded data. Some examples can be seen in Figure 4. The CHIMELIGHT app is responsible for most of the necessary data processing. While the device is connected, data from the accelerometer, gyroscope, and magnetometer are retrieved and processed in real-time on a smartphone. This is achieved by a sensor fusion, a sliding window peak-finding algorithm, and other calculations to identify the basic handchime motions or motion states.

Figure 3. One standalone CHIMELIGHT device and another attached to a handchime.

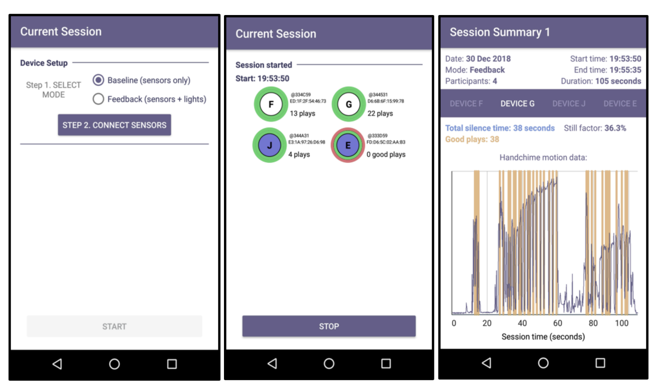

Figure 4. Screenshots of the CHIMELIGHT mobile application: mode selection screen for starting a new session (left), ongoing session screen (middle), and past session summary data screen (right).

How It Works

The CHIMELIGHT system records and evaluates the handchime motion states in real-time. Three key states can be identified: still, random movement, and good handchime play. Visual feedback can be provided according to the state detected. When a random movement is detected, no feedback is given, and the LEDs are turned off. Otherwise, CHIMELIGHT can deliver two types of visual light-based feedback: 'static blue' and 'filling yellow'. 'Static blue' corresponds to the still state and is activated when the child does not move the handchime for some seconds. This blue light feedback aims to reward good waiting and silence behaviors. 'Filling yellow' corresponds to a good handchime play state and is activated after the child performs a good handchime play movement. A good handchime play movement is defined by the therapists as a clear 'slow_up-fast_down-brief_stop' movement sequence that has sufficient acceleration to produce the expected tone sound. The yellow feedback lasts for 2 seconds and is animated: a yellow light gradually fills the device matrix in the direction of the play. We select the color blue to represent a relaxed state when a child waits for his/her turn to play while listening to the music, and the color yellow to relate to the energy and excitement of something good and rewarding.

This method of interactive therapy creates situations that reward the target behavior, so we can influence the user to perform this behavior more frequently and effectively. CHIMELIGHT promotes socio-communicative behaviors such as turn-taking, listening to others, respecting silence and stillness, and good handchime play behavior. The main technical challenges that had to be overcome included maintaining robust multiple BLE connections and data synchronization across devices.

Metrics for Evaluation of the Performance of a Child

We explored a set of suitable features or metrics to evaluate the performance of a child during the Handchime Activity. In this paper, we discuss the following metrics:

% imitative-play. The percentage of notes when the child is attempting to imitate the therapist. An imitative play is considered as a play that is in sync with the therapist or is delayed or ahead in time but still has the intention of imitating the therapist play.

% synchronized-play. The percentage of notes played simultaneously with the therapist within a defined threshold of 250 milliseconds (average reaction time to a visual stimulus [19]). It relates to positive behaviors, and thus, is to be promoted.

% non-imitative-play. The percentage of notes when the child is not attempting to imitate the therapist. Extra plays or missed plays are considered as having no associated imitation intention and are categorized as non-imitative plays. It relates to negative behaviors, and thus, is to be reduced.

Still factor. The proportion of long pauses (instances when not playing or moving) in the entire activity. Long pauses are defined as silences of more than 2 seconds. This metric is a variation of the silence factor in [16].

Number of good plays. The number of times a handchime is played while satisfying the defined characteristics of a good play. It relates to positive behaviors.

% plays looking at therapist. The percentage of plays performed by the child while simultaneously looking at the handchime, eyes, or face of the therapist. It relates to positive behaviors.

% plays looking at chime. The percentage of plays performed by the child while simultaneously looking at the handchime or device attached to it.

% plays looking away. The percentage of plays performed by the child while looking neither at the handchime, device, nor therapist. It relates to negative behaviors.

The first three metrics evaluated the skills of imitation and synchronization. They were computed in relation to the play of the lead therapist. The still factor and the number of good plays were calculated independently of the play of the therapist. However, for the analysis of the session outcomes, they could be compared to the metrics of the lead therapist as a reference. The last three features aimed to quantify the number of gaze-related communicative cues occurring during the activity and their relation to performance of the play. Only these features were obtained by video coding in the post-analysis of the sessions.

EVALUATION METHODS

Experimental Design

We conducted a case study to evaluate the use of the CHIMELIGHT system during real therapy sessions and the effect of the introduction and removal of visual feedback on the behavior changes in children with NDDs. The objective was to assess the impact of the device on the negative and positive behaviors over multiple sessions. For this study, we used a single subject design with a small group of children with NDDs over a period of six months (with one session per month) under one of two conditions: baseline or feedback. In both the conditions, one CHIMELIGHT device was attached to the handchime of each participant. In baseline condition A, the device did not provide any visual feedback, and only the motion sensing mode worked. In feedback condition B, both the sensing and visual feedback modes were working. All the six experimental sessions followed condition sequence ABBAAB. We did not remove the device between the conditions to maintain the weights and shape of the handchimes. The difference between the conditions was only in the light feedback mode being on/off. If we had removed the device, it would have been an extra variable affecting the behaviors of the children. The impact of the "novelty factor" could also have been higher at each change of condition. Initially, we planned to provide the children no explanation on how the device worked. However, after the first feedback condition, a simple explanation of how the device worked was provided at the start of the activity. We obtained data from the CHIMELIGHT device motion sensors, and the metrics were estimated using the mobile app for post-session analysis. The metrics obtained by the app included % imitative-play, % synchronized-play, % non-imitative-play, still factor, and number of good plays. In addition, the sessions were video-recorded by two cameras at different angles as well as a 360° camera. Playing timings and gaze direction during plays were manually coded and extracted from video data to obtain the remaining metrics.

Participants

A group of nine children with NDDs and four music therapists participated in this case study with the CHIMELIGHT system regarding the Handchime Activity performed in music therapy. However, we will present the results of three participants in this analysis because the remaining ones were not present in all the six evaluated sessions. The three evaluated children are diagnosed with ASD and ADHD, as listed in Table 1.

Participant	Age	Gender	Education	Diagnosis
P1	9	Female	Elementary School	ASD, ADHD
P2	8	Male		
P3	7	Male		

Table 1. Demographics of the children participating in the CHIMELIGHT evaluation study.

System Evaluation by Therapists

After the final case study session, the four therapists were asked to participate in a 40-minute debriefing. The objective of this debriefing was to obtain feedback about the CHIMELIGHT system from them. The aim was to assess the system under the following categories: (a) usability and learnability, (b) perceived impact and usefulness, and (c) subjective quality of the system (including engagement, aesthetics, information quality and quantity, and willingness to pay for or recommend the system). We also intended to identify potential improvements and recommendations. During this debriefing, the therapists were aging provided the opportunity to freely use both the mobile app and device. They were asked to fill four short questionnaires about how they felt about the system. We selected the relevant statements from different standard IT or mobile health assessment questionnaires. The first questionnaire was a standard system usability scale questionnaire (SUS) (ten statements with a Likert-type scale) to evaluate the usability and learnability of the system [2]. The second was a compact version of the health information technology usability evaluation scale questionnaire (Health-ITUES) with three sections (sixteen statements with a Likert-type scale) [25]. The third questionnaire was an adaption of the user mobile application rating scale questionnaire (uMARS) (six multiple choice questions and eight statements with a Likert-type scale related to the system engagement, aesthetics, information quantity and quality, and subjective quality) [27]. From uMARS, a perceived impact section was used and tailored to this study to investigate the perceived influence of the system (device and app) on the therapists and music therapy practice. Finally, the therapists filled a brief demographics and IT knowledge form regarding their basic information and daily usage of technology. After finishing all the questionnaires, a semi-structured interview was conducted. The therapists were asked about their overall opinion of CHIMELIGHT, what they liked the most and least, what they felt it was missing or should be improved, the light feedback, and the design of the device. Additionally, the therapists were asked to describe the CHIMELIGHT system in a sentence to a colleague. This interview was video recorded. Quantitative analysis of the debriefing consisted of the computation of the average scores, standard deviations, medians, and range values for the three main questionnaire scores (SUS, Health-ITUES, and adapted uMARS). The SUS score and its sub-scores for usability and learnability were computed for each participant following standard scoring methodology [2]. The Health-ITUES statements were scored per section following standard procedures [25]. Statements from uMARS were also scored per group of statements: engagement, aesthetics, and information [27]. For each interview, the relevant statements were transcribed and grouped under each major question prepared in the interview guide. A qualitative analysis was performed after discussion and interpretation of the individual interview records.

RESULTS

Attention to Feedback

Figure 5 shows the percentage of plays in which the children are looking at the handchime. This feature can relate to the attention the participants pay to the CHIMELIGHT device attached to the handchime. For the sessions with feedback condition (S2, S3, S6), participants P1 and P2 clearly look more at the handchime than under all the baseline conditions in which the CHIMELIGHT device is attached to the handchime but no light feedback is provided. The feedback seems to make the children look more at the handchime in expectation of seeing if a light reward is given or not. This also indicates that participants P1 and P2 are effectively paying attention to the feedback. Participant P3 looks more at the handchime under all the feedback conditions, but only in comparison to two of the baseline sessions (S1, S5). In session S4, participant P3 shows the same percentage of plays looking at the handchime as in the previous feedback session. It is possible that after removing the feedback in S4, he is still expecting for feedback and looking at the handchime to verify if the device will light up or not.

Impact on Negative Behaviors

Two of the metrics for negative behaviors during the Handchime Activity are shown in Figure 6. The upper graphic shows a decrease in the number of non-imitative plays for all the participants during feedback conditions S2 and S3 in comparison to the first baseline condition, S1. The reduced non-imitative play behaviors seem to maintain after the feedback removal in S4 and S5 for participants P1 and P2. Participant P3 shows a peak in the non-imitative plays in baseline S4. The negative behavior of the percentage of plays looking away seems to decrease with the first and second feedback conditions for all the participants. Except for participant P1, this decrease is maintained even after removing the feedback in session S4 and S5. In summary, a decrease in these two negative behaviors is observed.

Impact on Positive Behaviors

Two metrics of positive behaviors during the Handchime Activity are shown in Figure 7. There seems to be less variation among the three participants in the percentages of synchronized-play in comparison to that in the previous results. There is a slight decrease in the synchronization with the therapist under feedback condition S3, after the "novelty factor" in session S2 (when the feedback is first introduced). In the second baseline segment (S4–S5), there is a slight increase in the synchronization, mainly in two participants. No other trends can be clearly observed regarding how the feedback might impact the synchronized-play values. The positive behavior of looking at the therapist while playing increases under the feedback conditions for participant P3. However, it decreases for participant P1. Participant P2 looks more at the therapist in the first set of feedback conditions

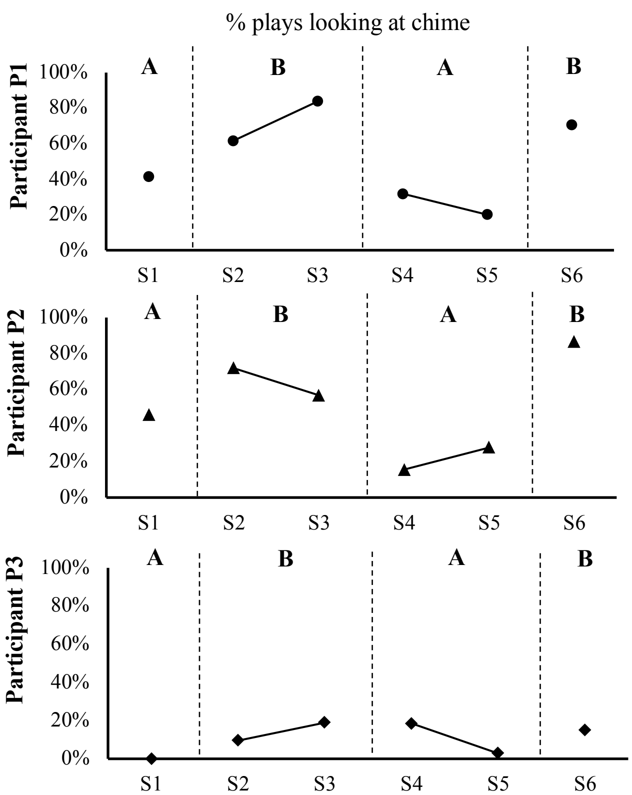

Figure 5. Attention to feedback given by the percentage of plays where each child is looking at the handchime while playing. Values are shown per session (s = 6) for both baseline (A) and feedback (B) conditions for each participant (n = 3).

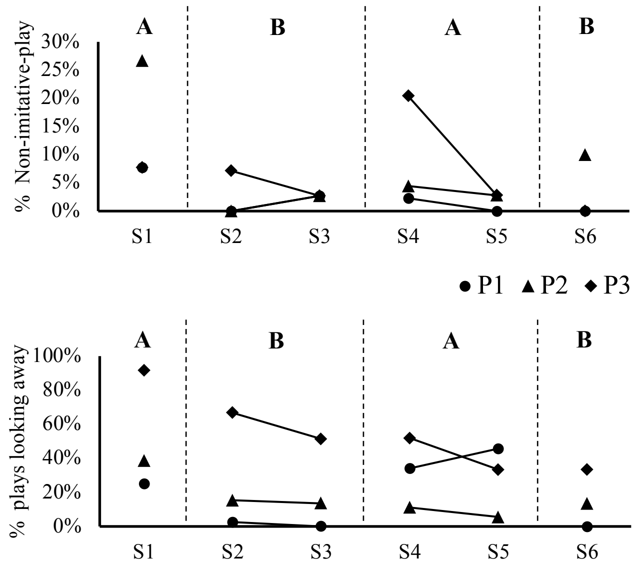

Figure 6. Negative behaviors across the six-session CHIMELIGHT evaluation study. Percentages of non-imitative plays (top) and percentages of plays looking away (bottom) are shown per session (s = 6) for both baseline (A) and feedback (B) conditions for each participant (n = 3).

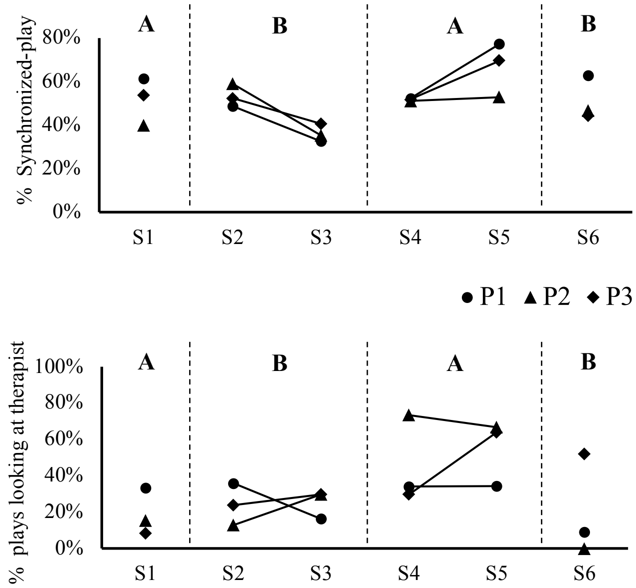

Figure 7. Positive behaviors across the six-session CHIMELIGHT evaluation study. Percentages of synchronized plays (top) and percentages of plays looking at the therapist (bottom) are shown per session (s = 6) for both baseline (A) and feedback (B) conditions for each participant (n = 3).

but does not look at all at the therapist in the last feedback session. His highest value for this metric is in the session of feedback removal.

Observations

With the assistance of the therapists, it was possible to introduce a unique technology such as CHIMELIGHT in the routine of children with NDDs and their therapy sessions.

Within the complete group of children, some would throw the device on the floor at the beginning, whereas others tried to open or bite it. Gradually, they came to understand how they should handle it, and learned to take good care of it. It was also part of the process of the behavior change. In addition, music therapists were satisfied that researchers from different fields, such as engineering and design, came to work on a device that could be integrated in their current activities. They stated that what they learned from the CHIMELIGHT experience could be used for their work as inspiration for new therapy activities and new methods of validating their practice. Regarding the three case study participants, we observed that the children looked more at the handchime when there was feedback. They frequently focused their attention on the light feedback. Some children vocalized their admiration when the device lighted up, particularly participant P3. When the feedback was removed in sessions S4 and S5, the children realized it was missing and promptly asked "*where are the lights?*" or "*will it light up next time?*". Participant P1 was shy and not very energetic during the sessions. Aside from the initial curiosity, we did not observe a strong facial reaction to the changes in the conditions. Participant P2 was highly energetic. He sometimes balanced on the chair while playing, and even stood up during the activity without being supposed to. He was the child most curious about the device, asking the therapist several times "*what is this for?*" during the first session. He was smiling a lot during the feedback conditions while looking at the device lights. In session S4, he was talking significantly and complaining about the device not having lights that day and asking why it was that way. Participant P3 vocalized frequently when playing during all the sessions. He was the only one singing along with the music and therapists while playing. He was less energetic than participant P2, but he spoke extensively during the activity and was lively. Sometimes he balanced and placed his legs on the chair during the activity. He showed interest in the device, although he did not focus his visual attention as strongly on the device as participants P1 and P2.

System Evaluation by Therapists

Quantitative Analysis

The CHIMELIGHT system achieved an average SUS score of 57.5 (SD5.0). This placed the system between 25%–30% percentile, classifying it as 'ok' and below average (50%, SUS score of 68) in terms of usability, with improvements needed (see Table 2). The learnability score component (25.0, SD17.6) was much lower than the usability score component (65.6, SD5.7). The results from the remaining questionnaire sections are summarized in Table 3. Regarding the Health-ITUES section, a third of the responses (33%) scored the maximum on the impact sub-scale, and 14% scored the maximum on the perceived usefulness sub-scale. No participants scored the lowest possible score on any of the Health-ITUES sub-scales. The average impact score was 4.0 (SD 0.9) out of 5.0. This was the highest value, followed by perceived usefulness with a mean score of 3.6 (SD 0.8). The perceived ease of the used sub-score had a slightly low value but was still above the middle value (3.0). For the adapted uMARS section, the highest mean sub-scores were for the engagement and perceived impact, both scoring 3.8 (SD 0.5) out of 5.0. Aesthetics scored the lowest with 3.0 (SD 0.8). No participants scored the lowest possible score on any of the uMARS sub-scales, and 13% of the responses scored the maximum on the information sub-scale. In summary, the Health-ITUES questionnaire scores were high for the engagement and perceived impact of the CHIMELIGHT system. The uMARS score for the impact of the system was also high. The worst components of CHIMELIGHT were identified as its aesthetics and learnability aspects.

	SUS score	Learnability	Usability
Average (SD)	57.5 (5.0)	25.0 (17.6)	65.6 (5.7)

Table 2. Average scores for the SUS questionnaire (n = 4).

		Average (SD)	Median (range)	Floor, %	Ceiling, %	No. items
Health-ITUES	*Impact*	4.0 (0.9)	4.0 (3.3-4.8)	0%	33%	3
	Perceived usefulness	3.6 (0.8)	4.0 (2.8-4.3)	0%	14%	9
	Perceived ease of use	3.4 (0.7)	3.0 (2.5-4.0)	0%	0%	5
uMARS	*Engagement*	3.8 (0.5)	4.0 (3.3-4.0)	0%	0%	3
	Aesthetics	3.0 (0.8)	3.0 (2.5-3.5)	0%	0%	2
	Information	3.6 (0.7)	3.5 (3.3-4.0)	0%	13%	2
	Perceived impact	3.8 (0.5)	4.0 (3.3-4.0)	0%	0%	6
	Would you pay	3.3 (0.5)	3.0 (3.0-4.0)	0%	0%	1
	Would you recommend	3.5 (0.6)	3.5 (3.0-4.0)	0%	0%	1

Table 3. Average scores for each of the Health-ITUES and uMARS sub-scales, with the respective median, floor, and ceiling information (n = 4).

Qualitative Analysis

The terms more frequently mentioned during the interviews regarding the CHIMELIGHT device were 'interesting' and 'new'. When asked what they liked the best, three out of four therapists mentioned the different modes of visual feedback as well as its colors, patterns, and brightness. They particularly mentioned the animation of the yellow feedback. Another therapist stated that what she liked the most was that the device made children focus more on playing the handchime. The transcribed statements included:

"… was totally new and fresh for me. Originally therapists provide feedback as words (…) but feedback from the object is really novel. It provides an experience and sensation people had not before."

"Contingency is important: you play, it lights - you stop the play and it goes off."

"Color, intensity, and brightness of feedback were good. Not too bright nor too low. Easy to see."

"I liked the progressive effect of the yellow light. The progressive motion increases eagerness of kids."

Regarding the design concerns, the most negative point mentioned by the therapists was that the device size was large and stood out. This could be a good point because children can be more engaged and attracted to the feedback. However, the therapists were mostly concerned that the children may be tempted to grab the device and try to remove it. During the case study, this was observed essentially during the first session. One therapist was also concerned about the fragility of the selected material, and suggested enclosure shapes that would be more interesting to children. Another participant liked the design and commented that it was good that it could be attached to other musical instruments. Regarding the light feedback, all the therapists stated that its impact on the children was highly satisfactory. They stated that the visual feedback was good as a practice reinforcement for learning how to use the handchime. A therapist mentioned that even though for children with high severity of an NDD it may be more difficult to understand the difference between the yellow and blue modes, it would be typically challenging and capture their attention. The therapists commented that the current system was good for learning how to play a handchime and measuring their performance. Most of the therapists mentioned that the system had a positive impact on the children, particularly regarding increasing engagement, concentration, and making the children challenge themselves. It also compelled the children to be more interested in the handchime as a musical instrument. All the therapists presented some concerns about the feedback being a distraction to the natural human–human interaction between the children and therapists. One therapist questioned if it could make children enjoy the music less. The transcribed statements included:

"Children tried to match handchime play with the light; children's motivation and concentration was maintained."

"While making the device light up, it may be difficult to pay attention to the music or to the partner (…) difficult to promote human–human behavior."

"Device may distract interaction. But the lights make children interested in the music instrument [handchime] and pay more attention to it."

"The device motivates them [the children] for playing the musical instrument [handchime]. Children concentrated on the light (...) but they may lose the opportunity to look at therapist, to interact, or to enjoy the music."

Therapists had some difficulty when asked how they would define the CHIMELIGHT system to a colleague. They mainly mentioned the device capability of attracting the attention of children with NDDs and enabling the evaluation of their play.

"New interesting device that will shine if played to attract attention of children."; "Interesting device for manipulation, sounds, and light. And to easily keep child attention."; "Tool to help raising motivation of kids and for enabling therapy research."

The therapists stated that in the future they would use CHIMELIGHT, or a similar device, if some improvements were introduced, particularly a reduced device size and more allowed individualization of its settings. They were particularly interested in testing the device with different musical instruments and for different musical activities. A therapist suggested a distinct light feedback mode at the end of the activity as a final significant reward as well as the capability of setting colors and animation patterns to change from session to session. All the therapists agreed that the next step of this work should be implementing more synchronization-dependent feedback according to the play timings between the group and therapist.

One therapist considered that the app would be difficult to use for non-specialists and be challenging for only one therapist to use during a group session. According to her, multiple therapists would be required to control the system and lead the activity simultaneously. Another interesting point brought by two therapists was related to the device possibly changing the identity of the handchime musical instrument and the children not wanting to use the standalone instrument anymore.

DISCUSSION

The quantitative results and observations showed that the device-delivered visual feedback during the Handchime Activity was engaging and facilitated the children to reduce negative behaviors while using the CHIMELIGHT system. Thus, we demonstrated that changes in socio-communicative behaviors were possible by augmenting music therapy with visual feedback, in agreement with other studies [3,9,20]. Similar to these other studies, we also presented a multimodal interactive interface that enhanced non-verbal methods of communication for those with NDDs. We also verified that augmenting the therapist–child communication channel communication increased their engagement. However, our design differed from others because CHIMELIGHT focused on portability and augmentation of familiar objects already being used in therapy while being based on the techniques of ABA-based therapeutic interventions. Our major advantage is the easy incorporation of our system into existing practices. Additionally, our system contributed to tools for evidence-based therapy and real-time assessment of performance. We provided therapists an interface for feedback control and data analysis in the form of the CHIMELIGHT app.

The participating therapists acknowledged the impact, engagement, and usefulness of the system. They reported that the feedback system had a strong impact on the children and allowed them to be more motivated for playing the handchime and participating in the therapeutic activity. The questionnaire results were in accordance with the statements of the therapists in their interviews. The system scored below average usability, and we identified several potential improvements. The reasons for this result may be the low learnability score and low aesthetics sub-scores. The therapists felt the need to improve the design of the device enclosure, particularly its shape and size. Nevertheless, we observed changes in the behaviors of the participants while using the current device, showing that this IoT device may be effective as a tool for therapy support.

In summary, the contributions of this research included 1) an augmented instrument with visual feedback and tracking of the behavior of the users during group music therapy (detected behaviors can be monitored on the mobile app); 2) the effect of mediation of the child–therapist interaction was verified in group music therapy for children with ASD (in particular, the engagement of the children in the activity increased, whereas the negative behaviors decreased.); 3) the feasibility of the developed system was confirmed by a case study in which no major problems nor disturbances to the therapy were reported. The technological contributions focused on a new IoT device as well as methods for data collection and metric extraction during group music therapy. The methods used to quantify the performance and engagement of children with NDDs may help to accelerate similar studies.

Integrating the users from the beginning in the design and testing processes proved to be extremely important, particularly as music therapy is a highly diverse field. Its practice depends significantly on the type of client, therapy settings, and experience of the therapist. The approach chosen for this research was tailored to the ABA-based music therapy group collaborating in this study. In addition, among the children with NDDs, we observed a broad range of behaviors, developmental levels, needs, and responses. Thus, it was challenging to classify or compare them. The unpredictable disruptive behaviors of children constrained this research to a specific music therapy activity, the Handchime Activity, and to a limited set of target behaviors. The results observed were positive, but this did not ensure that CHIMELIGHT fitted the needs of all the children with NDDs participating in other music therapy activities.

Another drawback of the reduced generalizability of the results relates to the inherent limitations in single-subject designs and small sample sizes. In this work, we aimed to address both quantitative and qualitative data. We introduced quantitative metrics as an initial step toward a methodology for the quantitative assessment of group music therapy. Additionally, we recognized that the “novelty effect” might have biased the results. The behavior and response of children with NDDs to novelty can be unpredictable, and significantly differ per child. Longitudinal studies with more participants are still required to extend the research findings, completely eliminate the “novelty factor”, verify the quantitative results, and further validate the applied metrics. Nevertheless, the purpose of the current study was not to generalize our findings but to obtain an overview of the impact and feasibility of CHIMELIGHT in a particular use case. The presented results are valuable for other studies in the fields of interactive therapy and interactive technologies for children with NDDs.

CONCLUSION

In this work, we have described the design, implementation, and evaluation of a system for supporting interactive music therapy for groups of children with NDDs. By using this interactive system, CHIMELIGHT, therapists attempted to persuade children with NDDs to learn positive communicative behaviors. For these children, the system delivered feedback rewards, provided behavior training experiences, and taught cause–effect (behavior–reward) associations. For the therapists, CHIMELIGHT made it easier to track therapy performance and to motivate children, increasing their capability during the sessions.

This work initiated the integration of social playware and mobile sensing technologies in music therapy for children with NDDs, more specifically for group ensemble activities. It contributed to new technological tools for performance assessment and behavior change evaluation in group music therapy. We brought additional insights to the field of interactive therapy, particularly on how to integrate portable interactive technologies for supporting traditional therapy practices and empowering children with NDDs.

The CHIMELIGHT system could promote engagement and reduce negative behaviors in children with NDDs during a music therapy activity. Both quantitative and qualitative results allowed an understanding of the feasibility, impact, and usability of the system. We also identified potential improvements that could make this system to be adopted to support music therapy practices and new interactions in therapy sessions. As future work, we may address the identified recommendations and further explore synchronization modes or features. Together with long-term intervention studies, the adaptation of CHIMELIGHT to other musical instruments and activities is also being considered.

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