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LONG PAPER

Non-formal therapy and learning potentials through human gesture synchronised to robotic gesture

E. Petersson · A. Brooks

Abstract Children with severe physical disabilities have limited possibilities for joyful experiences and interactive play. Physical training and therapy to improve such opportunities for these children is often enduring, tedious and boring through repetition—and this is often the case for both patient and the facilitator or therapist. The aim of the study reported in this paper was to explore how children with a severe physical disability could use an easily accessible robotic device that enabled control of projected images towards achieving joyful experiences and interactive play, so as to give opportunities for use as a supplement to traditional rehabilitation therapy sessions. The process involves the capturing of gesture data through an intuitive non-intrusive interface. The interface is invisible to the naked eye and offers a direct and immediate association between the child's physical feed-forward gesture and the physical reaction (feedback) of the robotic device. Results from multiple sessions with four children with severe physical disability suggest that the potential of non-intrusive interaction with a multimedia robotic device that is capable of giving synchronized physical response offers additional opportunities, and motivated non-formal potentials in therapy and learning to supplement the field.

Keywords Synchronous-human–robotic-gesture interaction · Motivated-play · Control-memory · Non-intrusive-sensors · Non-formal learning

1 Introduction

This paper reports on a non-formal therapeutic approach towards encouraging children with severe disability to "play" by utilizing their physical gesticulations, which were mapped to control synchronous robotic physical movement. The mapping also resulted in multimedia feedback in the form of visuals (light patterns/colors) emitted from the robotic device head, accompanied by an audible feedback (musical tones). In this context, *non-formal therapy* is intended as inherent physiological learning that emerges from an engaged play situation offering resources for joyful experiences and expressive interaction. This engagement is considered central in research towards developing a new conceptual platform to develop tools for supplementing traditional forms of human therapy. This platform has been coined SoundScapes/ArtAbilitation.

1.1 Non-formal therapy

The conducted investigation focused upon linking, via a local wireless network, a child's available natural 3D movement and the movement of a robotic device. The corresponding physical movements were synchronous. In this way, the child was empowered to control his own multimedia feedback stimuli.

A cyclic stimulus–response (S–R) chain [25] is created through feedforward gesture and multimedia-feedback iteration. This can also be compared to an afferent–efferent neural loop closure as shown Fig. 1, and is related to earlier research findings of the authors on implementing robotic units synchronized to human gesture.

The situated empowerment became apparent from the child's learned control of the robotic device that was

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Fig. 1 Afferent efferent loop closure

synchronized to physical gestures without encumbrance from worn body attachments or wires. Coding was focused on the actions involved in the interaction, i.e., the initiating physical gesture of the child, the corresponding movement response of the robotic device, and the child's facial expression resulting from the stimulation. The sensor based system can be thought of as a tool that targets implementation in therapy training. Fagan [12] suggests that 'using a tool' exemplifies such affective transformation. Accordingly, this paper focuses on the use of an interactive robotic device as a "tool" for therapists to utilize towards the yielding of beneficial effects in their training sessions.

2 Background

This section presents the background of the study. Section 2.1 offers a background to the research including selected related studies, fields of application, and the purposeful use of robotic devices reported in enquiries of human well-being. Section 2.2 informs of the interactive play inherent to the conducted study, and of the achieved understanding regarding its relationship to the development of a child. Section 2.3 reports on the intervention strategies implemented by the facilitator in the investigation, and their significance in regards to design issues of the created interactive environments for the sessions.

2.1 Robotic devices in rehabilitation, therapy and learning

In the last decade, robotic devices have been created specifically for applications involving human interaction where motivation, behavior and human well-being were the targeted goals [27, 35]. Robotic devices have been used with children and elderly in wards at hospitals, as well as senior-citizens homes as companion entities [11, 13], as a robotic pet for preschool children [16, 34], and as automated home-helpers [14, 21]. Hogan [15] details the therapeutic training of a damaged arm of a person with acquired brain damage (stroke) who is interacting with a robotic arm. Social and interactive communication issues with a robot are also subject of extensive research [17, 20]. Differences in response are evident in children when there is responsive direct movement from a robotic device [28] as a result of their input, and associated learning potentials are suggested from a study involving children with severe disability operating a robotic arm device [9].

2.2 Interactive play

For a child with severe disabilities, play situations could be more or less impossible and attached with frustration, due to limited access to suitable tools for expression. This affects the learning and fun potential for the child. Most research addresses the role of play in children's cognitive development, and focuses on solitary play [24]. However, the totality of what is going on in situations of interactive play is seldom taken into account. The approach to play presented in this paper is activity driven and based on what has been termed *Aesthetic Resonance* [5, 8], i.e., special moments that are experienced as control with intent within a responsive environment where a direct association between body movement and audiovisual feedback content acts as a stimulus that evokes joyful discovery, intense exploration, and expressive creativity that results in, and from, optimized and motivated ludic engagement. This phenomenon is such that the response to the intent is so immediate and aesthetically pleasing as to make one forget the physical movement (and often effort) involved in the conveying of the intention. This approach is such that it encourages the child to disassociate toward incremental higher order engagement and the inherent motivation of the play. This disassociation could for example be from pain that may otherwise be present as a result of the physical movement involved in the conveying of intention in interacting with the system. The aesthetic resonance paradigm can offer a potential in training where physical functionality limitations may be exceeded through motivated play.

In related work, play in the form of intrinsic motivated exploration is considered as an important resource for nonformal learning [1, 4, 22, 23]. This is similar to what Csikszentmihalyi [10] names autotelic activity, which is characterized as an endeavor carried out for its own sake by inner goals generating a state of *flow*. The robotic system used in achieving play experiences may be viewed as a support to increment the child's current level of development [32].

An adjusted support for the child is offered by the interaction with the robotic system, which challenges the child to reach a level of mastery. Rogoff [24] refers to this as the process of support including a "transfer of responsibility" (p. 201). Inherent is the balance between challenge and sensibility that provokes an opportunity for change. This, in turn, can result in an experience of self-agency and gained competence. Two simultaneous processes characterize this, involving on the one hand the use of technical tools and on the other hand the mediation of psychological tools [33]. Hence, in the adopted approach, there is a constant transformation of existing interactions and a constant making and re-making of new interactions in an on-going process between the robotic device, the child, and the facilitator, all guided by the child's and the facilitator's individual interest. Non-formal learning is contextually affected by the intervention strategies involved in the designed session participation. This aspect is outlined in the next section, discussing the intervention strategies involved in evaluating the children's interaction with the robotic device.

2.3 Intervention strategies toward an evaluation methodology

When working with severely disabled children, idiosyncratic attributes must be addressed so as to account for variance of abilities, needs and preferences. It is expected that the facilitator will have the ability to improvise and optimize the situation within the session through knowledgeable and timely intervention, as well as a trained competency in predicting the effect of system parameter change on the participant. In this way, conditions encouraging creativity and control become central for use in therapy, as well as for learning. Such conditions include a context where the situation promotes investigation of the individual's learning potentials within the personalized interactive play environment. Intervention strategies by the facilitator are inherent in designing the interactive responsive environment where the interaction with the robotic system takes place. Previous work emphasizes the facilitator's role relative to participatory and recursive analysis of session data [6]. Informed input from care-givers and helpers as to the child's possible preferences increments the developing personal profile and assists the facilitator in understanding the child's engagement with the robotic system. This supports the facilitator's reflection *in* action (i.e., decisions taken in the session) and, afterwards, the research team's post session reflections *on* actions (which includes all aspects of the session from a participant's perspective as well as from the facilitator's perspective—who also reflects on his or her *in* session decisions) [26].

In this way, session data is used to assess the optimal configuration of the system matched to the specific user profile, which is established initially as a result of information from the child's helpers and care-givers and built up over time through a process of session-to-session reflection and refinement towards a systematic evaluation method. The sequence of steps involved in a session is (1) preparation, (2) action, (3) observation, (4) reflection, and (5) refinement. This becomes a temporal cycle when relating to a series of sessions and provides a qualitative action research methodology which acknowledges facilitator intervention and desire for change. The change in this case is constituted by increased opportunities for the segment of the community where physical impairment is so high as to be severely limiting quality of life.

The facilitator intervention strategy makes a significant impact by manually optimizing the therapy situation. Thereby, the child and the facilitator develop means for an inter-subjective and joyful learning experience, which supports the child's creative achievements. Optimally, this results in a masterful performance encouraging explorations without immediate goals as in play [3], which are characteristics of a non-formal approach to therapy rather than more traditional forms [7, 8].

3 Method

The aim of this research has been stated as exploratory and centered on achieving an understanding of learning potentials of interactive play situations. This aim was approached through using Martin MiniMac moving head robotic light devices[1] that generated projected images (gobos) that are controlled through movement with the SoundScapes system. Supporting this direct and dynamic association of the synchronous robotic device to a child's head gesture was auditory feedback. The understanding of the potentials was approached from using a qualitative research methodology. This section exemplifies the adopted approach that has inductively evolved through prior research. The qualitative study thus involved using observation strategies with children with severe disabilities who were interacting with the three robotic devices. Semi-structured interviews with each of the child's carers were conducted. The aim of these interviews was to help define characteristics of the robotic device and the concept of use from a care-givers perspective of application in rehabilitation and habilitation. These

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[1] http://www.martin.com/product/product.asp?product=minimacprofile.

characteristics are embodied within the multimodal layered environment model, which has at the top-most level a user-perceived interactive “play” aspect and lower levels that relate to evaluation and analysis which are transparent to the child. These lower levels constitute the therapist/researcher tools towards refinement. All levels are personalized according to each child’s personal profile, with inclusive participation as an element of the methodology.

3.1 Inclusive participation

The context of this study included children with severe disabilities, including limited abilities to communicate their own wishes and desires. The carers became key persons when it came to the understanding of the specific child’s needs, and were inclusively involved in the study in order to optimize the understanding through their tacit knowledge about the child. The carers were asked to contribute with opinions, appraisals and interpretations of the specific session situation and of the collected data. Each child’s personal carer was present at each session to ensure well-being and to acknowledge cessation. This also allowed a strengthening of the validity of the study by decreasing mistakes such as making rash and naïve conclusions, as well as uninformed simplified interpretations. This approach can be considered as related to participatory research [30]. Carers gave their knowledgeable input, but did not influence the research process as a whole. Rather, they influenced the interpretation of the data and partly also the concrete planning of the sessions. However, the inclusive participation approach used in this study was intended to involve the carers actively in the creation of specific user knowledge, rather than only being informed or consulted.

Implicitly, this approach has a divergent nature [31] and, thereby, a situated character of understanding and communication. This means that the understanding is defined relative to actional contexts, not to researcher-self-contained structures [18]. By this, the creation of knowledge is participative and mediated by the differences of perspective among the researchers and the carers.

3.2 Subjects

The institute involved was asked to volunteer children who were all able to see and hear. Four children between 4 and 6 years of age were selected and included in this qualitative study. The children were from the community that is classified in Scandinavia as Profound Multiple Disabled (PMD). All of the children were receiving regular physical therapy. These children were selected as they have low functional ability and limitations that often prevent their play activities.

3.3 Equipment

An eight channel moving light controller (Elektralite CP10) capable of translation of MIDI (Musical Instrument Digital Interface—a standard digital communication protocol) to DMX 512 (robotic device control protocol) was central to the system. The graphical programming software Max[2] was used for the DSP (digital signal) mappings. The robotic devices chosen were the moving head MiniMAC Profile intelligent lighting units manufactured by Martin Light of Denmark. The units project multi-colored light patterns of high contrast from a projection lens head capable of up to 540° of pan and 270° of tilt. Three MiniMAC units were used in the study. The child’s gesture is captured by a sensor and mapped such that a direct correspondence to the movement of the robotic head was apparent, e.g., lateral child head movement is matched by lateral robotic head movement and light pattern change on the facing wall.

3.4 Process

Each participant was involved in three sessions that took place at the Center for Advanced Visualization and Interactivity (CAVI) in Aarhus, Denmark. The set up of the sessions was in a large empty room approximately 25 m 25 m × 6 m high with white painted walls. At the start of the sessions, the children were shown how the robotic device mirrored their movements. During the sessions, trials with the auditory feedback and no auditory feedback were experimented. It was observed that the children focused on the robot and light patterns rather than the auditory feedback.

Most of the sessions lasted around 30 min, with the shortest at 11 min and the longest at 46 min. Information regarding the interventions that the children were engaged in during regular physical therapy was collected from the carer of the child. A basic assessment coding scale for each session was established by asking the carer as to abilities, needs, preferences and other characteristics of each child. In this way the sessions could be optimised regarding specific considerations for gesture capture and sensor position. Furthermore, notes were taken as to (1) how the child was perceived at the start of every session, (2) how the child was perceived during the session, and (3) how the child was perceived following the return to the institute.

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[2] http://www.cycling74.com.

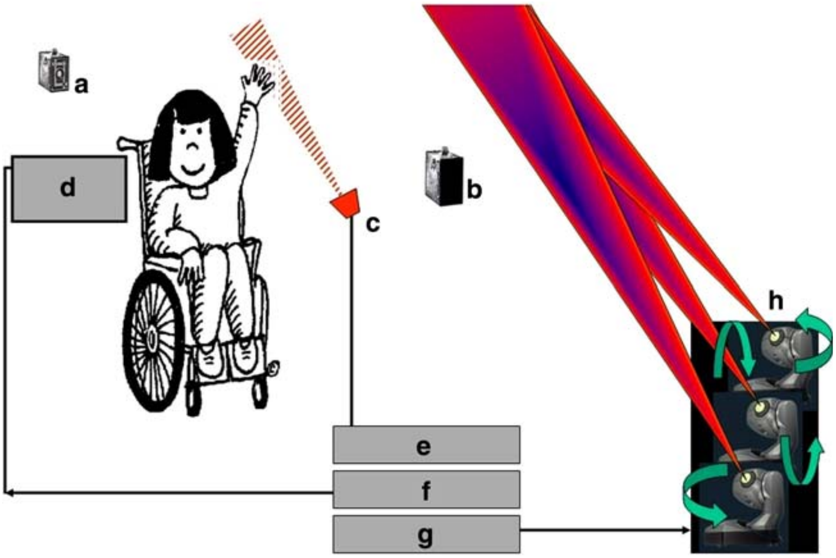

Fig. 2 Session set up

These details are important when assessing session results and decisions taken that maybe pertinent to the child's state on the day, as well as the short and long-term results. Such results define iterative strategies and refinements of the system and method.

Sensor selection and set up was logged in the user profiles. The white-walled large empty room enabled the authors to program the full range of the robotic moving heads to extend beyond the users peripheral field of view. This strategy is to evoke the child's head movement to its maximum extent so as to be able to observe the moving light image change projected by the robotic device onto the three white walls facing the child.

As shown in Fig. 2, the user was positioned near the center of the room with a camera behind to capture the scene. A second camera was positioned in front to capture facial expression and upper torso (including arms and hands) gesticulation. The sensor was set up according to the user's ability of movement. 3D infrared volumetric sensors that were created for the study were used alongside commercially available ultrasound[3] sensors. The set up used in the study may potentially be further improved, especially regarding the sensors' location for gesture capture from the human user. The sensor should be remotely controlled from a distance, so as not to interfere with the user, and also wireless. This has been addressed in the latest generation of infrared sensors with the implementation of Bluetooth technology. The use of night vision facility on the front observation camera resulted in corruption that was due to infrared impingement on the subject that was sensed as noise subsequently causing data change by the movement infrared sensor receiver. This has been addressed through the use of an infrared 'black' filter with a high sensitivity monochrome camera. There was no corruption with using the ultrasound Soundbeam sensor.

3.5 Data collection

Total observation time for each participant was approximately 90 min. Each session timeline involved dynamic interaction and response showing a recurring pattern. The resolution and sensitivity of gesture to the resulting feedback was totally programmable to accommodate the children's variance and limited only by the physical constraints of the hardware and room location.

Four topics guided the observation process: (1) the child's perception of the interactive play environment, (2) specific interests (3) (self)guidance, and (4) achievements. Field notes were generated after every session noting important information, including possible questions to ask of the carer/care-giver, the observation environment, and the intervention strategies. After every session, the carer was involved in the reviewing of the collected raw video data. This approach is in line with related research where we have developed a methodology named *participative involvement through recursive reflections* [6]; see also Sect. 3.1 in this paper concerning inclusive participation.

3.6 Analysis method

Video annotation using a proprietary software package (Anvil) was central to the analysis. The transcribed observations were coded separately by the two authors and then checked for validity and edited by the two authors

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[3] http://www.soundbeam.co.uk.

together. The coding system was based upon each child's interaction, set up and response to the feedback. As previously stated, the coding system was created with assistance from the carer who was familiar with the child's various responses. The data was analyzed using an explorative, inductive method [2]. The authors conducted an independent coding of the video material, followed by inter-coding comparison to establish the credibility of the analysis to assess the appropriateness of the coding. Notes on thoughts of the authors from the coding process, the development of themes, and other information that was important to the research were maintained in a notebook [29]. The results of the analysis were shown to the four carers separately for their review and opinions regarding the results. The carers were in agreement with the generated themes.

Common expressions among the children were generalized to the best possible extent, accounting for each child having individual abilities and limitations. Typically, facial expression related to head and limb gestures, (e.g., a smile, a mouth opening, a quieting, an eye focus, a frown, or hand gesture as well as lower torso movement) were noted and reflected upon to understand meaning.

A parallel research with children in virtual environments [7] used a camera based software algorithm to analyze quantity and segmentation of movement and pauses conducted post sessions. However, in the study reported here this related strategy was found unusable, due to (1) the excessive dynamic light change in the dark room, (2) insufficient background segregation (i.e., personnel movement in camera's field of vision) and (3) the use of infrared night vision hardware that unknowingly caused corruption to sensor infrared data. A reflection on the study is that the Soundbeam ultrasound sensor device was optimal for control.

3.7 Ethics

Parents and responsible staff at the institution were approached about the study, informed of the goals, and were asked to give their permission on behalf of their children beforehand. Consistently with earlier research, at all sessions there was a knowledgeable carer to ensure no discomfort for the child. The carers were informed of their option/right to interrupt the session whenever they considered it necessary. At all instances, the researchers tried to be aware of biases that could affect the understanding of the session situations and of the collected data. Such attention to possible bias supplements the approach inherent to the authors' body of research in following a strict ethical code due to the sensitive nature of context and participant identity. Any research that involves individuals inherently includes sensitivity and integrity issues of those investigating due to their role as primary instrument of data collection and analysis [19]. This fact has its advantages, but also limitations. Throughout this study, an inclusive participation approach was used, so as to decrease the limitations of relying on the researchers' own instincts and skills involved in the understanding of the observed interactions between the child and the system.

4 Results

The results are based on the analysis of three "robotic light interaction" sessions with each of the four children involved in the study and the analysis of semi-structured interviews in the form of questionnaires answered by the children's four carers. The child's facial expressions associated to the head and limb gesticulations that afforded the interaction with the system were the basic unit of analysis. The findings confirmed that it was useful to apply an inclusive participative analysis of the video material to understand critical emerging elements in the children's actions and interactions. Two main themes emerged from the data that were related to the child's interaction with the robotic light. These themes were: (1) Doing as sensation (Sect. 4.1), and (2) I am in control here (Sect. 4.2).

The results pointed to learning potentials from Human Robotic Interaction (HRI) within a Virtual Environment (VE). The choice of the MiniMac profile robotic intelligent light devices came out to be wise, due to the device ability to generate variance of multimedia feedback and to project the stimuli across a required range of physical wall space. The 'physicalness' of the units, i.e., being robustly real and touchable with inherent machine noise, also seemed to offer a conduit that the children liked according to the carers.

The units responded with a latency of around half a second that was acceptable for this explorative study but not optimal. Various gobos (patterns) and colors were tested, but could not be ascertained if the child had any preferences.

4.1 Doing as sensation

The children in this study showed engagement in every session through an observed concentration and consciousness of intent. The 12-picture sheet in Fig. 3 illustrates various moments from the sessions where engagement was apparent. These pictures alone cannot tell the whole story, but only hint at the explorations and experiences gained.

The carers stated that the children were tired following the return to the institute after the sessions, and that the

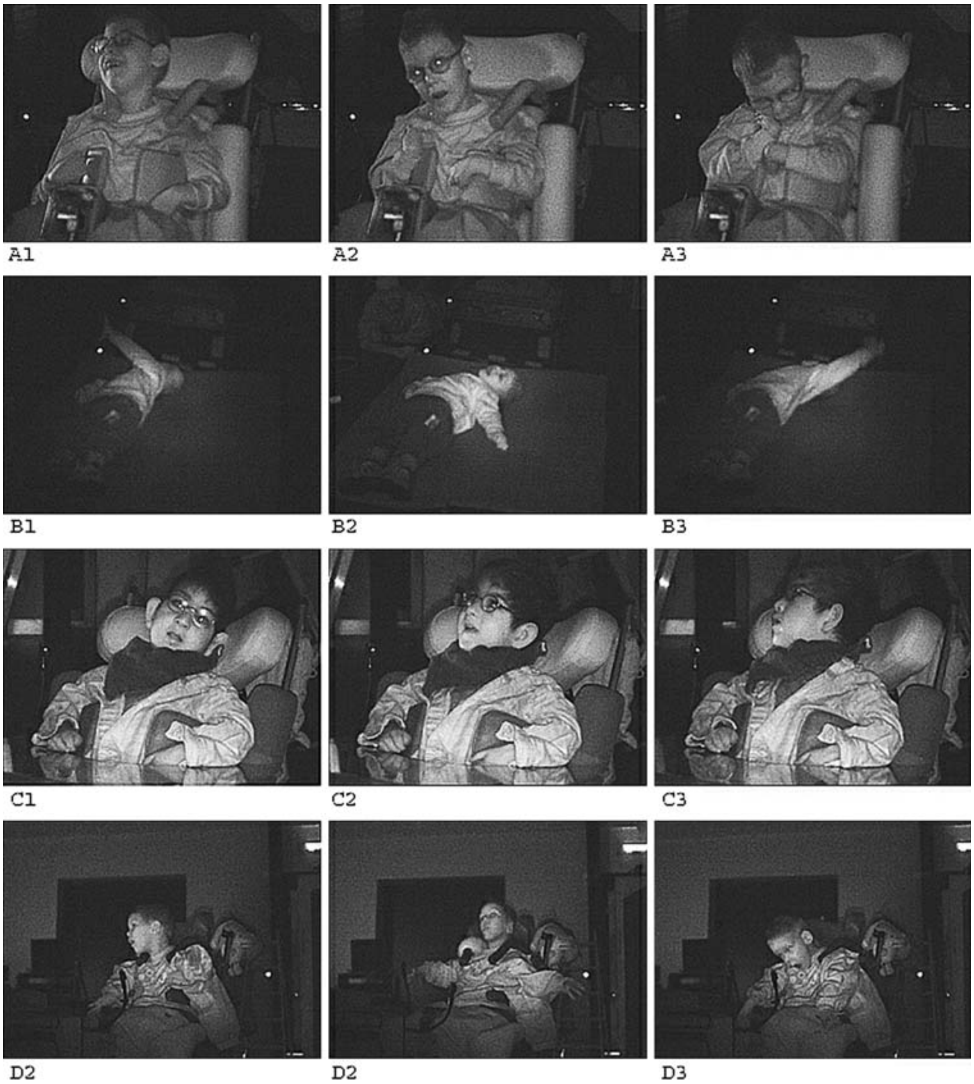

Fig. 3 Twelve session shots of children

physical exercise from whatever limited abilities they had was a positive way to energize their available skills. It was observed that the children were generally more content and happier after the session. One of the carers stressed that the child's engagement with the robotic device had an impact on the child's personal life, as the child learned new ways to play, train, and enjoy through this activity. Normally, it was difficult for the children to fully participate in play activities due to their limited abilities. To varying degree, the carers reported that the difficulties in having play experiences possible affected the children's development in general.

The children's expression of *doing as sensation* was analyzed in terms of the dynamic interaction between the child, the activity and the robotic lights. In terms of the dynamic interaction, facial expressions associated to head and limb gesticulations showed concentrated efforts in relation to the new experience this interactive play provided. The children's exploration of the virtual interactive space pointed towards awareness and enjoyment, as the interaction empowered them to manipulate the robotic device. The physical relationship of synchronized child movement to robot movement reinforced the activity of the child. The carers emphasized that the interactive play with the robotic lights was a form of therapy and that, noticeably, the recognized utterances from the children gave positive meaning to the interaction. Furthermore, one of the carers underlined that the interactive play was better than traditional physical therapy, as it added the fun factor to the therapy, which enabled the child to have motivating experiences instead of becoming bored.

Two of the carers noted that the interactive play enabled the children to develop skills and supported them to incrementally push their movement limits. Furthermore, three of the carers noted that following the end of the series of sessions the children were noticed to be aware of social contact at a slightly higher level and three of the four children showed indications of improved eye to hand coordination and concentration.

4.2 I am in control here

The children's possibility to experience a sense of control within the interactive play was an important aspect that was emphasized by the carers. For example, the children had the opportunity to choose if they wanted to interact or to "rest" within the "silent" space, which was available, that is to say "no interaction". Another factor that was mentioned by the carers was the easiness of the interaction and the child's ability to maneuver and control the interactive play almost immediately following a short exploratory learning curve. One child however was not comfortable in his chair due to his back problem, so his position was accommodated by placing him on a floor mat that was adjusted so that he was able to see his control of the light patterns. Input for this strategy was through the child's carer. One child was asleep upon entering the Virtual Interactive Space (VIS), i.e., the sensor space—a termed coined for the invisible interface space [5]—during one session. Slowly he awoke and explored with playful head movements that were mapped to the control of the device. Accordingly, the children exhibited a swift understanding of how to best control their movements and gestures in order to meet the challenge. The carers noted that the children enjoyed this challenge as they developed skills in their physical manipulation of the robotic device. The children were dynamically exploring what was happening under their control, and discovered the interactive space further through varying the range, the speed and direction of their gestures. Two of the children especially indicated an early awareness of a direct correspondence and control to the physical movement of the robot head and the subsequent movement of the lights. Such self-achievement is a rare commodity for such children, and was afforded by the simplicity of the system and set up which enabled the desired short learning curve exhibited.

The sessions followed a recurring pattern, often observed in children's play, where exploration is followed by playing and emphasis moves from "what does this object do?" to "what can I do with this object. The study showed that, along similar lines, the sequence was extended from "when I move—the light patterns move", to "when I move—I hear sounds", " when I stop moving I hear neither sounds or see the light patterns moving!", and finally "Hey I'm in control here- and its fun!". Observations further suggested that this positive feeling was extended to "well nobody told what I should do, or for how long, so I will just have more fun with what I have learnt I can do with this object!" Sessions were ongoing until the child signified cessation through reduced engagement. This was confirmed by the child's care-giver, who was observing a monitor showing the child's facial expression throughout the session.

5 Discussion

This section discusses key components that are required for self-agency and autotelic experience relating to individuals engaging in play with robotic devices and multimedia feedback, as well as the implications of therapeutic use of robotic tools.

5.1 Interactive play and self-agency

Through play in interactive environments a child could acquire new abilities, interactions, expressions and emotions, enabling a mastering of tasks and practicing of skills. As such, the interactive play situations indicated an enhancement of the quality of play and learning, which, in turn, facilitated engaging explorations that were utilized in the therapy. This is to say that play had a motivational potential achieved from the interactive virtual environment. The children's concentration when interacting with the robotic system furthermore emphasized the autotelic quality of the play. The virtual interactive environment had the potential to evoke the child's interest in practicing otherwise limited skills.

However, the carers emphasized the children's limited opportunities for play experiences in their everyday life. Thereby, the children had limited chances to challenge their skills and to develop new skills, which is vital in facilitating an optimal experience. If the child is limited in expressing him or herself and is unable to test his or her skills, this will limit his or her interest in trying. Rogoff [24] underlines that interest has a motivating character that channels the child's choices involved in 'doing'. After the children's engagement in the interactive play activity, the carers observed improved awareness, eye-to-hand coordination, and concentration. Thus, it may be concluded that through practicing of skills the child experienced a sense of control and, thereby, mastery and consciousness of the therapy situation. Furthermore, the interest and the novelty involved in the therapy situation was influencing the child's development of competencies in a positive way.

The above show that non-formal therapy has an opportunity to expand the child's learning experiences, as learning is so closely related to play and intrinsic motivation.

Additionally, the empowered activity resulted in achievement of control for the child, whereby the success factor, often unattainable from children with such severe disabilities, was contributing to their emotional self-esteem.

5.2 Facilitating the autotelic experience

The approach was rich in promoting collaboration between child and facilitator, as well as between researcher and facilitator. Overall, collaboration motivated the participants to achieve more than they would be able to individually. Hence, it can be concluded that intervention strategies have the potential to support the emergence of new and improved forms of actions and interactions in design of therapy. Thereby, the facilitator facilitates the child's optimal experience of the interactive play through the adaptation of the interactive space. This situation empowers the child to meet the challenge. Thus, in interactive play there is a fit between the skill level of the child and the challenge offered by the interactive application. Interactive play facilitated by facilitator intervention offered a play experience where the children were able to experience an autotelic state that facilitated mastery and growth.

The children were observed enjoying the interactive play experience. The carers described the enjoyment as rewarding and observed that the interactive play with the robotic tool was an alternative to traditional therapy. The child's enjoyment was related to the facilitator's personalization (adaptation) of the multimedia feedback while the child was engaged in the interactive play. The children demonstrated consciousness and concentration as they were in control over the interactive space, choosing the movement they wanted to produce or if they wanted to rest in the 'silent' space.

5.3 Implications for non-formal therapy through robotics

The following design issues might be generalized from this study to other interactive non-formal approached therapy designed as remedial play environments for children with severe disabilities:

5.3.1 Controlled and joyful play environment

Children with severe disabilities have a huge range of different skills, needs, and desires. Each child therefore needs to be addressed specifically, and the interactive play environment needs to account for individual needs. Interactive environments can be designed as spaces for play and learning [9]; for rehabilitation and therapy [17]; and exhibits a great potential for use with children with severe disabilities [7, 8]. In such tailored environments the feed-forward action from the child can be monitored and feedback can be controlled. Successive therapy sessions can be evaluated in order to monitor progress of rehabilitation objectives, controlled by the facilitator. The interactive environment can be adapted and personalized to account for individual differences. Children can be guided through the play experience and explore actions themselves. Such environments can provide a space with as much or as little intervention that is needed in the specific situation by the facilitator. This kind of environment can partially replace routine therapy sessions. Such environments should be created in a novel, playful, and exploratory context where the children can use the environment in a creative way, thus contributing to enjoyment and increased quality of life.

5.3.2 Embodied and engaged interaction

The non-intrusive design of the interactive play environment supported interactions involving the whole body in set ups where the children were free to move. The children were not required to wear special devices on their bodies and by this their movements were not constrained in any way. An interactive play environment of this kind can explore new therapy practices based on a non-formal therapy approach, where the children and the facilitator can explore and play, involving physical movements. These aspects are important prerequisites for the sense and experience of being engaged. In contrast to traditional therapy approaches, robotic and other interactive play environments are intuitive, as they offer the child a direct contact with the content feedback. In other words, the embodied interaction can therefore provide features that augment traditional therapy practice. This is where the embodied interaction itself acts as a direct feedback (thus as an assessment tool) for both the participant (whether conscious or unconscious), and for the facilitator. According to the result of this interaction, facilitator decisions are taken on whether an optimization is present according to the desired goals and the motivation of the participant towards those goals.

6 Conclusions

In this study the goal was to explore the feasibility of a non-formal approach to therapy using robotics. The results clearly showed that there is a potential for the concept as such. Remarks were made to the simplicity of the concept, which transcended many existing methods. Physical movement of the robotic device was synchronously manipulated from sourced data movement information from each child. The data was sourced through invisible volumetric and linear non-invasive sensor technology. Mapping algorithms were used to ‘tailor’ match the range of sourced data—limited through dysfunction—to the full range of the robotic device movement. The results highlighted the positive effect of physical robot control by those with physical dysfunction and conclude at the potential of the concept as a supplement to traditional therapy techniques. Furthermore, the results highlighted the intervention strategy with the facilitator as a key person as a prerequisite for engagement and for joyful experiences.

6.1 Future research

One of the limitations of this study was the small sample size. Although the results were sufficient to ensure that the main issues were elicited, it may not have been representative of all children engaging in interactive environments with robotics if given the opportunity. However, this study met the exploratory needs of investigating the children’s individual perceptions when participating in a new kind of therapy. A second limitation of this study was the short-term design of the study. Upon subsequent contact with the institute approximately 1 month after the end of the sessions, the carers stated that the children showed no significant long-term improvement compared to their condition prior to the limited numbers of sessions. The initial elevated happiness had returned to the level prior to the study. These facts indicate the need for a long-term study in order to study the potential of using robotics for children with severe disabilities, as well as to develop models of application. ‘In session’ real-time intervention by the facilitator through remotely adapting sensor sensitivity and content feedback is optimal in order to match the challenge of the interaction to the ability and motivation of the participant. Furthermore, the need should be emphasized to develop appropriate techniques, means of measurements, and instruments that are suitable to assess results and impact of the research.

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References

1. Aderklou, C., Fritzdorf, L., Petersson, E.: Pl@yground: Pedagogical Innovation and Play Products Created to Expand Self-development through Child Collaboration through Computer-Mediated-Communication (CMC). Socrates, Leonardo & Youth, Halmstad University, Halmstad (2001)
2. Atkinson, P., Delamont, S.: Analytic perspectives. In: Denzin, N.K., Lincoln, Y.S. (eds.) The Sage Handbook of Qualitative Research, 3rd edn. SAGE, Thousand Oaks (2005)
3. Berg, L.E.: The Playing Human (Swe). Studentlitteratur, Lund (1992)
4. Bigün, J., Petersson, E., Dahiya, R.: Multimodal interfaces—Designing digital artifacts together with children. In: Seventh International Conference on Learning and Educational Media. Bratislava (2003)
5. Brooks, A., Hasselblad, S.: CAREHERE—creating aestetically resonant environments for the handicapped, elderly and rehabilitation: Sweden. In: International Conference on disability, virtual reality, and associated technologies. Oxford, pp. 191–198 (2004)
6. Brooks, A., Petersson, E.: Recursive reflection and learning in raw data video analysis of interactive ‘play’ environments for special needs health care. In: Seventh International Workshop on Enterprise Networking and Computing in Healthcare Industry, pp. 83–87 (2005)
7. Brooks, A., Petersson, E.: Raw emotional signalling via expressive behavior. In: International Conference Artificial Reality and Telexistence, pp. 133–141 (2005)
8. Brooks, A., Petersson, E.: Play therapy utilizing Sony EyeToy®. In: Slater, M. (ed.) Eighth International Workshop on Presence, pp. 303–310 (2005)
9. Cook, A.M., Meng, M.Q.H., Gu, J.J., Howery, K.: Development of a robotic device for facilitating learning by children who have severe disabilities. Trans. Neural Rehab. Eng. **10**(3): 178–187 (2002)
10. Csikszentmihalyi, M.: Flow: The psychology of optimal experience. Natur & Kultur, Stockholm (1992)
11. Dautenhahn, K., Woods, S., Kaouri, C., Michael, L.W., Kheng, L.K., Werry, I.: What is a robot companion—friend, assistant or Butler? In: International Conference on Intelligent Robots and System, pp. 788–795 (2005)
12. Fagan, R.: Animal Play Behavior. Oxford University Press, New York (1981)
13. Fujita, Y.: Personal robot PaPeRo and its application as childcare robot. In: ROBOCASA, pp. 36–42 (2005)
14. Harmo, P., Taipalus, T., Knuuttila, J., Valet, J., Halme, A.: Needs and solution—home automation and service robots for the elderly and disabled. In: International Conference on Intelligent Robots and Systems, pp. 145–152 (2005)
15. Hogan, N.: MIT-Manus robot aids physical therapy of stroke victims. MIT, Boston (2000)
16. Kahn, P., Friedman, B., Perez-Granados, D., Freier, N.: Robotic pets in the lives of preschool children. In: Conference on Human Factors in Computing Systems, pp. 1449–1452 (2004)
17. Kozima, H., Nakagawa, C., Yano, H.: Using robots for the study of human social development. In: AAAI Spring Symposium, pp. 111–114 (2005)
18. Lave, J., Wenger, E.: Situated Learning. Legitimate Peripheral Participation. Cambridge University Press, New York (1991)
19. Merriam, S.B.: Qualitative Research and Case Study Applications in Education. Jossey-Bass, SF (1998)
20. Nabe, S., Kanda, T., Hiraki, K., Ishigurio, H., Hagita, N.: Human friendship estimation model for communication robots. In: International Conference on Humanoid Robots, pp. 196–201 (2005)
21. Nakauchi, Y., Fukuda, T., Noguchi, K., Matsubara, T: Intelligent kitchen: cooking support system by LCD and mobile robot with IC-labeled objects. In: International Conference on Intelligent Robots and Systems, pp. 76–84 (2005)
22. Petersson, E.: Innovative play products—development of toys for children’s play and rehabilitation. In: SNAFA Conference Proceedings. Halmstad University, Halmstad (Abstract) (2000)

23. Petersson, E.: Using and developing new learning technologies by integrating physical and virtual toy systems. Socrates, Leonardo & Youth, Halmstad University, Halmstad (2004)
24. Rogoff, B.: Apprenticeship in Thinking. Cognitive Development in Social Context. Oxford University, New York (1990)
25. Scherer, K.: Emotion. In: Hewstone, M., Stoebe, W. (eds.) Introduction to Social Psychology: A European Perspective, 3rd edn. pp. 151–191, Blackwell, Oxford (2000)
26. Schön, D.: Educating the Reflective Practitioner: Toward a New Design for Teaching and Learning in the Professions. Jossey-Bass, San Fransisco (1987)
27. Shibata, T., Irie, R.: Artificial Emotional Creature for Human–Robot Interaction—A New Direction for Intelligent System. In: International Conference on Adv Intelligent Mechatronics, paper 47 (1997)
28. Simo, A., Kitamura, K., Nishida, Y.: Behavior based Children Accidents' Simulation and Visualization: Planning the Emergent Situations. In: Fourth International Conference on Computational Intelligence, pp. 487–157 (2005)
29. Stake, R.E.: Qualitative case studies. In: Denzin, N.K., Lincoln, Y.S. (eds.) The Sage Handbook of Qualitative Research, 3rd edn. SAGE, Thousand Oaks (2005)
30. Starrin, B.: Participatory research—to create knowledge together (Swe). In: Holmer, J., Starrin, B. (eds.) Participatory oriented research (Swe). Studentlitteratur, Lund (1993)
31. Starrin, B.: Applied social research (Swe). In: Holmer, J., Starrin, B. (eds.) Participatory oriented research (Swe). Studentlitteratur, Lund (1993)
32. Vygotsky, L.S.: Mind in Society. Harvard University, Cambridge (1978)
33. Vygotsky, L.S.: The collected works of L. S. Vygotsky: Vol. 1. Problems of general psychology. Plenum, New York (1987)
34. Woods, S., Dautenhahn, K., Schulz, J.: The design space of robots: Investigating children's perspective. In: International Workshop on Robot and Human Interactive Communication, pp. 237–243 (2004)
35. Yamamoto, D., Doi, M., Matsushira, N., Ueda, H., Kidode, M.: Familiar behaviors evaluation for a robotic interface of practicality and familiarity. In: International Conference on Development and Learning, pp. 149–154 (2005)