A Tangible Tabletop Game Supporting Therapy of Children with Cerebral Palsy

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Abstract. This paper presents the design of a table-top game supporting the treatment of children with Cerebral Palsy. The game was developed through a participatory design process involving therapists and children from the target user group. The game is implemented on top of a platform that supports the implementation of tangible user interfaces using sensing technology. We argue that physical interaction, motivated and constrained by the design of tangible interfaces, offers enormous potential for occupational and physical therapy where patients need to practice specific and repetitive movements.

Keywords: Tangible interfaces, table-top, children, cerebral palsy, therapy, serious games.

1 Introduction

In recent years, research in interactive table-top surfaces has shifted beyond its original scope of office applications explored in the early days of this field (see for example [6]), to explore the potential of supporting leisure and gaming activities (see for example, [2]). The potential of table-top interactive surfaces for supporting entertainment is enormous; they combine the advantages and flexibility of traditional screen displays with the physical and social implications of allowing people around the surface to have shared access and to interact through interactive artefacts presented as virtual or physical entities on the tabletop. This paper discusses an exploration into how table-top interactive surfaces can support therapy of children with Cerebral Palsy. This investigation is part of a broad assessment of the scope of potential applications of these technologies and specifically the opportunities they offer to support therapeutic applications.

The research reported builds on top of the technology platform ESP, a hardware and software system designed to facilitate the creation of applications that are based on tangible interaction. This platform provides a high level programming interface allowing designers, without programming skills, to specify the interaction with the

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tangible artefacts, while making transparent to them the operation of hardware sensors used for input (wireless sensors and tabletop positioning technology), and output device drivers e.g., e.g., for audio output, LED lights, etc.

The ESP technology has been used before to implement games for children, e.g., [4] and [7]. The emphasis of this paper is on interaction design aiming to assess its suitability for the domain of therapy and to explore related opportunities for the development and deployment of tangible interfaces combined with interactive tabletop surfaces.

The remainder of this paper describes first the target user group and more specifically how Cerebral Palsy is currently treated. Then the participatory design process through which the therapeutic game was developed is described, concluding with the evaluation of the game with children. Finally, reflections on the lessons learnt from this study are discussed and links are drawn to related research.

2 Children and Cerebral Palsy

The term Cerebral Palsy refers to any one of a number of neurological disorders that appear in infancy or early childhood and affect body movements and coordination permanently, though they do not worsen over time [3]. These disorders are caused by abnormalities in parts of the brain that control muscle movements.

Besides surgery and medication, physical therapy and occupational therapy are the main forms of treatment for children with Cerebral Palsy. Cerebral Palsy can not be cured, but such therapy can improve a child's abilities and self-confidence.

The problems that affected children have can be summarized as follows [5]:

- Muscle tightness or spasms because of which patients take abnormal postures.
- Poorly coordinated movements.
- Involuntary movement which is not under control of the brain.
- Difficulty with gross motor skills such as walking, running and stabilizing.
- Difficulty with fine motor skills such as writing, grasping/releasing objects and two hands coordination for task like cutting a paper.
- Difficulty in perception, especially in depth.

3 Current Therapy Practice for Children

The design effort focused on assisting fine motor skill training for children with Cerebral Palsy. Fine motor skills are instrumental for daily living activities such as dressing and eating. The design process started with an analysis of current therapy approaches for children with Cerebral Palsy. Figure 1 illustrates some movements that affected children typically need to train.

Contextual interviews and observations of therapy sessions were carried out in two therapy centers in our region to find out how therapists go about training children currently, how children experience these sessions and which problems they encounter that interactive technology could help tackle.

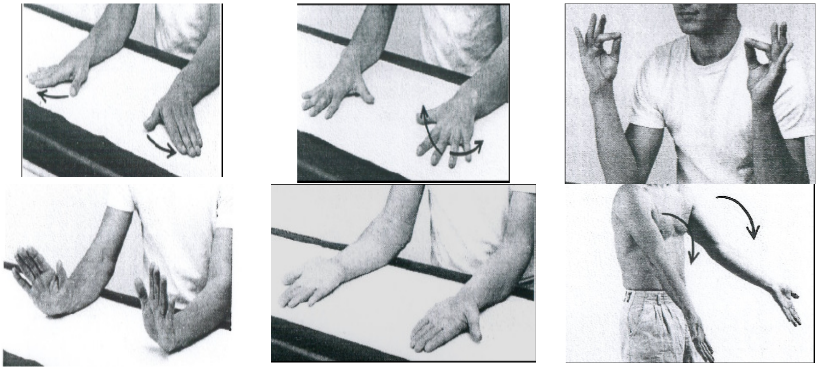


Fig. 1. Functions that children with Cerebral Palsy need to train; Source: [1]. Top Row from left to right: Finger abduction (curling and straightening), Finger Extension, Pincer Grasp. Bottom row from left to right: Extension of wrist, Supination, Extension of Elbow.

Therapists use various toys in playful training sessions that they carry out one-on-one, often in a small room. Training is very personalized. Examples of exercises are:

- For finger extension training, the children are asked to "wear" finger-puppets on their fingers (children have to extend and move their fingers to play) or they are asked to make stamp-prints of their hands on a paper. During the observation, "wearing" toys did not appear very appealing to the children however they seemed to enjoy thoroughly the stamping exercise.
- For pincer grasp training, therapists ask children to do some beading tasks, to slide coins into a box, or to move paper-clips from one side of a card to the other.
- To practice elbow extension children are asked to crouch on a small pulley and crawl around pushing their hands and arms against the ground. Other exercises include drawing on a blackboard, a fishing game and a puzzle game.
- For wrist extension a special rubber object was used that the therapist presses against the table surface to make it stick by suction. The children are asked to pull it off.
- To practice supination. card playing exercises are used, or opening water bottles, screwing/unscrewing screws, etc.

Some example of exercises with the occupational therapists are shown in figure 2.

Problems were noted during the contextual interviews regarding current training methods, focusing on the effectiveness of the method and how children experience it.

- Compensation: Children seem to always find a way to compensate for the movement they have problems with and need to practice e.g. by using their ‘good’ hands or arms. The therapist often needs to intervene to prevent them from doing so. Children resist this; this resistance often slows down therapy, reduces its effectiveness and is detrimental to the motivation.
- Lack of cognitive challenge: Many training tasks are repetitive and do not help children to appreciate the reason for carrying them out. Especially when they can do the tasks in an easier way than the therapist requests they resist redoing them,

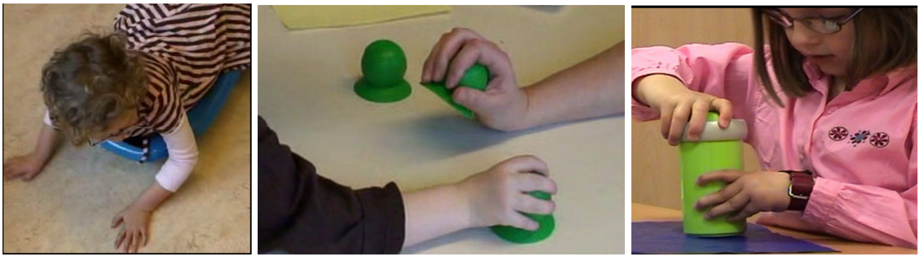


Fig. 2. Images from the video record of a therapy session featuring exercises currently given by occupational therapists to exercise elbow extension (left), wrist extension (middle) and supination (right)

losing interest and concentration. However, when these physical training tasks were embedded in puzzles or block building activities children showed more interest.

- Motivation and potential regression. After years of training many children, e.g., above 8 years old, lose motivation, and regard the sessions as work, not play. Children at that age often leave therapy centers to join mainstream education thus running the risk of regression. Therapists estimate that 20% of these children return to the therapy center for training after one or two years; this time round they are motivated again because they wish to be as independent as other children.
- Lack of reinforcement away from the therapy center. Therapists cannot force and have little means to stimulate children to use the affected hands and arms at home, so the total time spent exercising is very limited.
- As training is very personalized, children do not train in groups, so they miss chances for social interaction and the motivation and reinforcement associated with social interaction can not be utilized. A nice example of a therapy centre trying to tackle this is the Pirate Group at the St. Maartens clinic in Nijmegen, where a pirate theme structures role play and motivates the use of physical props, for which children have to reach, grasp, release, etc.

4 Design of a Tangible Training Game

The game design proceeded in an iterative fashion. The main aim of the design was to create a fun game for children that would motivate them to practice specific skills. First three different game concepts were designed, to support practicing supination, wrist extension and elbow extension in various combinations.

Given the focus on table-top interactive applications and the use of ESP described earlier, all design concepts involved, in some way or other, manipulating tangible interactive objects, while getting audio feedback and observing feedback from the computer on an horizontal array of led lights, (see figure 3).

The design concepts were visualized using video prototypes to show the physical interaction involved and the movements children were expected to carry out. These prototypes were reviewed by therapists; their feedback was generally positive regarding the playful activities anticipated for the children. They thought that audio and visual feedback would be enjoyed by children, thus motivating them for training, and that the system could, in principle, offer feedback as to the correct execution of

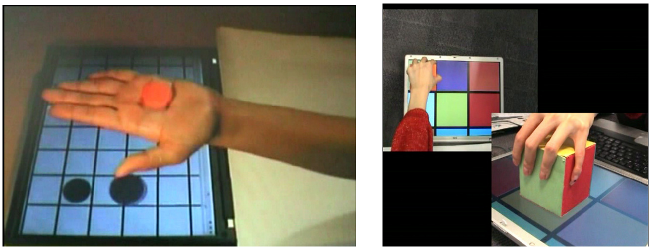


Fig. 3. Shots from the initial design concepts presented to therapists as video prototypes

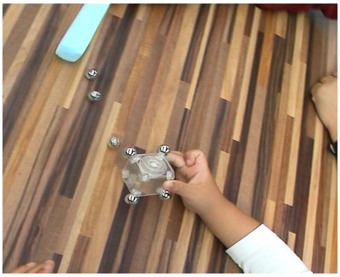
the exercises. Furthermore, they appreciated the possibility of modifying exercises throughout the game. Therapists offered several corrections regarding the movements designed for the children. It is clear that it is almost impossible for interaction designers to plan the right movements without specialized knowledge: motions foreseen by the design were too difficult. If children could carry out the exercises they would not need training any more; also the designer could not foresee the ways in which children would compensate for the skills they were supposed to train.

A brainstorm session was held in which a therapist took part. The original game concepts were changed or refined correcting the flaws found. Therapists thought that the games as they evolved were likely to improve training for the children, but the most pressing question at that point was whether children would enjoy playing the games and whether they would be motivated to exercise with them as intended. At this stage, most of the game was visualized in the form of video prototypes.

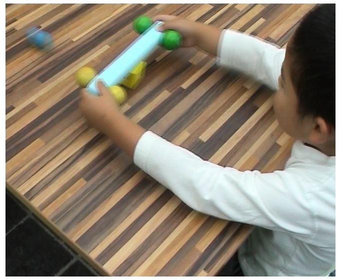
An evaluation session was held. Four children of different ages with Cerebral Palsy took part along with five non affected children. It was anticipated that the comparison would expose how affected children compensate for their problem and to compare their performance on the game. Five test tasks were given. None of them involved the ESP technology as the final game would, but each task involved some of the arm-hand functions that needed to be trained.

Example test tasks were as follows:

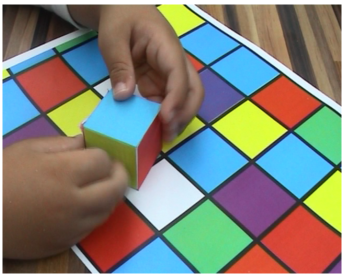
- Catching a moving ball. The facilitator uses a stick to roll a steel ball around on a table. Catching the moving ball is very challenging, involving wrist and elbow extension as well as supination (figure 4.a.)
- Hitting the ball back with a block. The child holds a wooden block with two hands and has to hit back an approaching rolling ball (a tangible version of the famous pong game, see figure 4.b).
- Children have to solve a color puzzle that requires them to roll a wooden block over a table surface in various directions. The correct sequence of moves is determined by the pattern of colours presented on the table surface (figure 4.c).
- Children manipulate a wooden block to roll over matching colours on a paper with coloured squares, along a trajectory specified by the therapist (such that wrist extension would be practiced) This test was done with a small sized cube but also with a larger one weighing 1kg, with an edge of 7cm (Figure 4.d).
- Children manipulate a colour hammer to match the colour of objects spread around the table by the therapist (Figures 4.e and 4.f).



(a) Catching the Ball



(b) Batting the Ball



(c) Trajectory Game with Small Cube

(d) Large Cube Manipulation

(e) Colour Hammer Game

(e) Colour Hammer Game

Fig. 4. Images from sesions with children and therapists for the appraisal of the low tech game

Children understood and enjoyed the games. Observation of children taking part in these play sessions with the designer showed that the ball picking and catching tasks were too difficult for affected children. The puzzles involving colors were hard for both groups to understand; the therapists commented that this difficulty was caused by the lack of feedback in this non-technological simulation of the game. Affected children were indeed seen practicing the required movements but they also compensated very often; this was a serious concern for the therapists who indicated the need to further refine the physical interaction. Note that the concern regarding compensation is only partly warranted. If during the game the desired movement is made often enough, it matters less that compensation also takes place often.

Final game concept and prototype

The final game was implemented using the ESP platform. The playing surface that resembles an electronic chess board was chosen to implement the games. The squares on the board can be lit in different colors using LED lights. The final prototype combines aspects of the game concepts discussed into three sub-games: the colored hammer, the colored block and the rotating colored block. These are described briefly below.

Colored hammer game

As shown in Figure 5(a), the hammer has an octagon-shaped head; the square faces of the hammer head are colored. Tiles on the checkerboard light up during the game in different colors. The player has to hit the colored squares with the face of the hammer with the matching color before it extinguishes. This requires players to perform supination, and elbow extension.

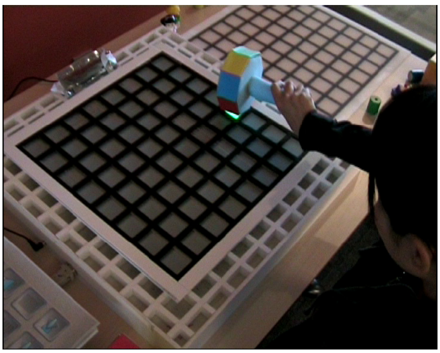
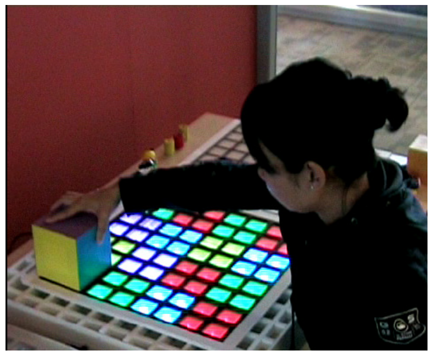



Fig. 5. (a) The colored hammer game. (b) Solid colored block game.

Colored Block Game

Children manipulate a colored cube with a side of 10 cm, which is twice as much as the side of the squares on the checkerboard; see figure 5(b). The squares on the

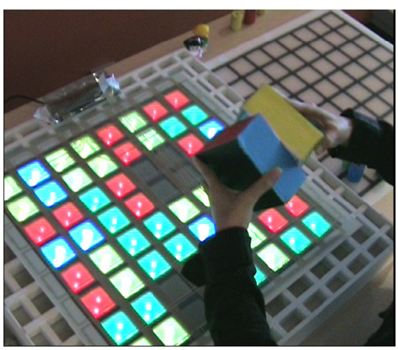


Fig. 6. Rotating colored block game

checkerboard light up in different colors (groups of 4 adjacent squares have matching colors). Children must place the cube on the face with the color matching the color of the tiles on the board to extinguish or 'delete' the group of squares. The games ends when all groups are deleted.

Rotating Colored Block

This game is an extension of the solid colored block game. In this case the color pattern shown on the board is more complicated (only pairs of adjacent tiles have the same color) and children have to rotate the parts of the block to match colors on the face of the cube to a 2 by 2 group of adjacent tiles on the checkerboard (see figure 6).

5 Evaluation of the Game

On site testing and observation was adopted as the main method to evaluate the game. After each test, interviews were conducted with the therapists with questions focusing on the training qualities of the game and the motivation and fun of children compared to current training methods.

Participants

Child	Gender & age	Type of CP	Severity	Affected part of body
1	M, 6 years old	Quadriplegia	very severe	4 limbs
2	M, 4 years old	Quadriplegia	relatively severe	4 limbs
3	M, 7 years old	Hemiplegia	mild to light	Left hand
4	M, 11 years old	Hemiplegia	mild to severe	Right hand
5	M, 11 years old	Quadriplegia	relatively severe	4 limbs
6	F, 6 years old	Hemiplegia	very light	Right hand
7	M, 9 years old	Hemiplegia	Mild	Left hand

5.1 Experimental Setting and Procedure

Play testing was carried out at the same two therapy centers, where also the observations had taken place at an earlier stage in the project. The evaluation was set up as part of individual therapy session. Participants took part individually under the supervision of a therapist.

A height-adjustable table was used for supporting the gameboard. This was useful not only because of the different sizes of the children but also to allow wheelchairs to fit under the table surface. This enabled the children’s arms to be in full contact with the board.

Each test session lasted about 20 minutes. The three sub-games were tested in the sequence: color hammer, color solid block and color rotating block (from lower to higher complexity).

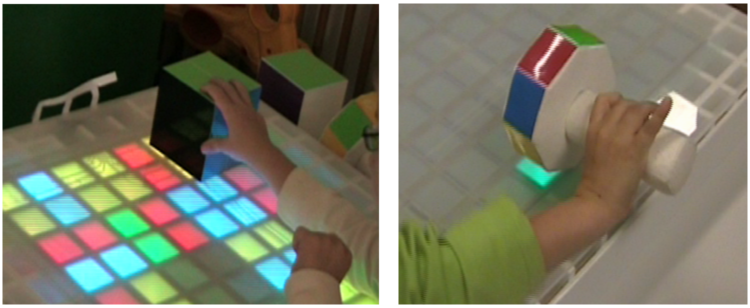


Fig. 7. Spontaneous extensions of the elbow of the affected arm motivated by the game

Therapists explained and demonstrated how to play the game. Then children played independently without instruction or help during the game. The observation of the children's performance, focused on accuracy, errors, desired movements and compensation. The therapy session was recorded on video for later analysis.

5.2 Results

All participants said they enjoyed playing the game, though their preferences regarding the three sub-games varied with age. The youngest children (4 to 6) enjoyed the hammer game most. Older children found it too easy and in general preferred the rotating block game most because of the cognitive challenge it provides.

Therapists were happy to observe children engage in the desired movements spontaneously, something that they said was not common in their standard therapy sessions. For example, one child performed a spontaneously extreme extension of the elbow, something this child does only when requested by the therapist (Figure 7). Other desired movements like extension of fingers, finger abduction were also seen quite often when playing the games (Figure 8).

There is also room for improvement. Other important movements, like extension of wrist and supination were observed only rarely during the evaluation. Also, several desirable movements were often observed in tandem with unwanted movements, e.g., a combination of supination (wanted) and wrist flexion (unwanted movement) was seen quite a lot (see figure 9).

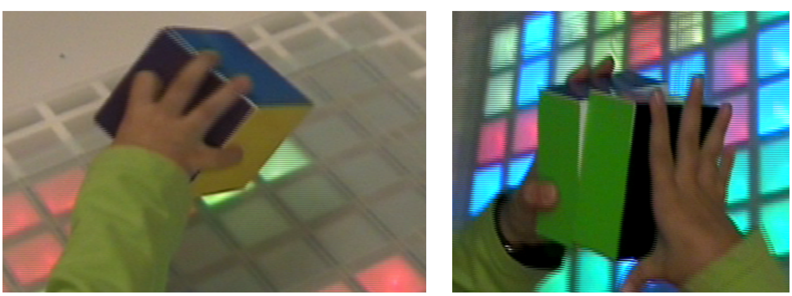


Fig. 8. Finger extension and thumb abduction seen during testing

Fig. 9. The combination of supination ans wrist flexion

The therapists found the games promising as a therapy aid since children did perform desired movements and they enjoyed it. However, to reach a conclusion with confidence regarding the effectiveness of the designed games and whether they are still fun for children after a few therapy sessions, a long term evaluation is needed involving a larger population.

All children extended their fingers in an extreme way to manipulate the block since it is relatively big compared to their hand sizes. Especially when playing the rotating block, the finger extension was better supported since they needed to rotate one part while holding it.

In general the evaluation showed that:

- *The game play is very energy consuming for the children with Cerebral Palsy. The* physical signs collected from observation, such as heavy breathing, taking clothes off, showed that children put a lot of physical effort into playing the game. The therapists also noticed this and remarked that this shows that the game is fulfilling its training purpose.
- *The game does encourage the children with Cerebral Palsy to make desired movements.* This was encountered in various forms, e.g., one child who has strong resistance in using the affected hand, started to use it spontaneously while rotating the block after sever failures in doing that by compensation.
- *Depth perception could influence the way children play the game.* During the test, we found that during the block game, most children first try to delete one color in different locations and then manipulate the block to see which side they will use for the next step. However, one child who has problems with depth perception played differently. He manipulated the block more and deleted the colors in no particular order. Therapists attributed this to him having difficulty to obtain an overview of the color pattern shown on the board.
- *All children used their affected hands to play the games.* The therapists did not specify that the children had to use their affected hand, but they have all been receiving therapy for a long time and they know they have to use the affected hand to play in the therapy room. Especially children with Hemiplegia, who have good hands as well, started to play the game with affected hand quite spontaneously.

Smaller interface usability issues were identified as well, e.g., ensuring that the colors on the board and the hammer match better.

6 Conclusion

This paper describes a design study that explored how tabletop games using tangible interaction can support therapy of children with Cerebral Palsy. Starting from contextual interviews and observations, opportunities for design intervention were identified, namely to provide motivating feedback to children following therapy and for designing the required physical interaction so that movements specified by therapists are practiced as part of a game.

A tangible interactive table-top game was developed iteratively with the participation of therapists, whose input was crucial in avoiding pitfalls and in designing the appropriate physical interaction. Indeed one of the requirements they expressed during the participatory design sessions was the ability to specify or adapt movements that would be used as elements of the game.

The game was evaluated, as a part of their therapy, with children suffering from Cerebral Palsy. All in all, the evaluation revealed both positive and negative aspects of the designed game; the game was experienced as fun and motivating which resulted in an increased duration and stimulation of hands and arms training. The game supports exercise for children with Cerebral Palsy, and was successful in evoking and training some of the most important movements that children with Cerebral Palsy need to train, e.g., elbow and finger extension, and thumb abduction were quite well supported. The extension of wrist and supination, were stimulated as well but less frequently.

The current designs do not completely address the problem of compensation movements, with children avoiding the movements trained by using other hands or skills that are not or are less impaired.

The generally positive evaluation of this game demonstrates the potential of tangible interactive technology for supporting therapy. The experience of designing this game is an example of how participatory design including children and therapists can help design the physical aspects of interaction in areas extending beyond the traditional domain of interaction design. Supporting therapists to specify the movements needed to play the game should be an interesting way to capitalize on the possibilities offered by tangible interactive technology.

Given the highly individual nature of the limitations of the children the treatment is inevitably highly personalized. It is therefore seen as very valuable by the therapists that can define individual exercises on the platform themselves using the high level programming interface of ESP.

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