Interactive Tangible Game for Collaborative Play Between Children with Cerebral Palsy

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Abstract. Cerebral refers to the brain, specifically the outer layer while palsy refers to the loss or impairment of motor function. Interactive tangible systems have been widely designed with aims of rehabilitation for users with cerebral palsy. However, there is still a lack of tangible systems that can support collaborative play between children with cerebral palsy. This paper describes the process of research, design, and development as well as evaluation of an interactive tangible game system with the purpose of supporting collaborative play as well as rehabilitation. Based on results of a pilot study, a new prototype iteration of tangible system incorporates multiplayer games with an accessible tangible interface. Two user experiments were conducted virtually with 8 participants from the Spastic Children's Association of Selangor and Federal Territory (SCAS&FT) who provided positive feedback and to gain a general population's point of view on system's usability, with results of 75 on the System Usability Score (SUS) showing that the system's functionalities were deemed effective and easy to use. Main findings of this paper are that children with cerebral palsy prefer playing with friends rather than alone and the system provides motivation for rehabilitation as well as social collaboration during use due to its multiplayer function. We further discuss future work that can improve the development of interactive tangible game for collaborative play between children with cerebral palsy.

Keywords: Interactive tangible system · Collaborative play · Game · Rehabilitation · Cerebral palsy

1 Introduction

Cerebral palsy (CP) is the most common motor disability in childhood and affects approximately 17 million people worldwide. In every 2000 babies born, 1–2 of them are diagnosed with cerebral palsy. Caused by damage to or abnormalities inside the developing brain during pregnancy of birth or within the first 2 to 3 years of a child's life, this permanently affects a person's ability to move and maintain balance [1]. There are three types of CP namely spastic CP (stiff muscles), dyskinetic CP (uncontrollable movements) and ataxic CP (poor balance and coordination) [2]. The severity of these disabilities' ranges from mild to severe in correlation with the degree of injury to the brain. Some children are diagnosed with a level of intellectual disability and impaired sensations as well as

H. Badioze Zaman et al. (Eds.): IVIC 2021, LNCS 13051, pp. 65–76, 2021.
https://doi.org/10.1007/978-3-030-90235-3_6

other medical disorders. This impairs the quality of life, independence, and all aspects of health ranging from physical to emotional.

Children with cerebral palsy may experience mobility limitations due to problems in fine motor control, strength, and range of motion [3]. This reduces their ability to participate in community and leisure activities such as sports and games which leads to disassociation from the community and the feeling of exclusion. Differences in their functional abilities can be seen in their daily activities such as sitting, walking and mobility. Children with cerebral palsy may also have impacted speech especially if the muscles of the tongue, mouth and throat are affected. This makes it difficult for a child to verbally express themselves with confidence. Hence, they are unable to make friends easily in comparison to healthy peers and this affects their ability to develop a concept of self and find meaning in life [4], causing them to develop a shy and reserved personality due to lack of social interaction.

Besides, collaboration is an important aspect in a child's growth and is a skill they must hone. The ability for a child to collaborate when they grow up is increasingly important in an era where work is done in teams of people rather than in isolation. Collaboration can be in the form of social interaction, engagement, and cooperative activities. Developing collaboration as a skill allows children to engage with each other It enables them to discover each other's strengths, weaknesses, interests, and capabilities [5]. In this environment of positivity, self-confidence and self-esteem may be boosted, allowing them to communicate comfortably. Clear and effective communication is a vital skill to have to convey ideas and messages [6]. There have been attempts to develop tangible interfaces for children with CP, however they do not place an emphasis on collaborative play, rather on single player games. There is research ongoing for designing tangible interfaces for collaborative play, however they have less focus on children with limited physical movement [7].

Therefore, this project aims to design an interactive tangible game system that allows collaborative play for children with CP between the ages of 12 to 17. The project incorporated games and an accessible interface inclusive to wheelchair bounded users. The system consists of multiplayer games to encourage socialization and collaboration when children play together. Having multiple games to choose from that are both fun and engaging increases the replay value of the system. The games included different level of difficulties to cater for children with varying severities. The project investigated ways that an interactive tangible game system could support both physical rehabilitation as well as social interaction between children with CP.

This paper begins with reviewing related work to give an overview of necessary background and describe the methods used for design to include initial ethnography and pilot study and user evaluation. Next, design guidelines and implications are discussed before final discussions and conclusions are made.

2 Related Work

Tangible interactive systems are perceptible by touch and require significant amounts of interaction between users and the system. It can provide feedback in the form of visual or auditory in response to an interaction with the user. Through extensive research, we have come across several tangible interactive systems designed for cerebral palsy users.

2.1 Interactive Rehabilitative Game Systems for Children with Cerebral Palsy

Previous work on interactive rehabilitative systems shows positive effects in training the upper limbs of children with CP. They include hand therapy exercises that include wrist and thumb extension and flexion, wrist stretch, wrist side movement, finger curl, finger flexion and extension as well as finger spread [8]. There is evidence that passive stretching increases the overall agility of children [9]. For example, Kinect2Scratch is a motion game that focuses on improving the upper extremities of children with CP with training on shoulder holding, hand-eye coordination and reaction time [10]. Results of the study show that although the system allows them to enjoy training, it was highlighted in the paper that a lack of multiplayer game mode eventually cause the children to lose interest gradually. Another similar project uses a multi-touch Microsoft Surface display combined with tangible inputs – wands with custom grips, foam balls and wearable kinematic sensor for monitoring [11]. It focuses on improving the fine motor skills of the upper limbs in children with CP by combining an immersive play environment and rehabilitative exercises.

Other studies further explored the use of tangible user interface with gamification in the rehabilitation of children with CP. For example, ShaRki is a tangible system that incorporates gamification to encourage enhanced hand movement for children with unilateral cerebral palsy [12]. Users will have to grasp a cylindrical tangible controller, equipped with sensors to measure arm movements, to play a game of feeding the crocodile. Grasping and releasing the tangible closes and opens the crocodile's mouth and rotating the wrists turns the crocodile's head. There are different levels and game modes designed for each motoric level. The system shows some success in using a tangible user interface to meet the therapeutic needs of targeted users. However, it does not support multiplayer and social engagement. There still exists a gap in understanding how to design tangible systems that can provide sustained interest and motivation in children's physical rehabilitative exercises.

2.2 Interactive Tangible Game System for Collaborative Play

There are several projects that aim to support collaborative play among children with special needs. However, current research on the development of collaborative technology for children with cerebral palsy is still lacking as most have focused on designing for children with Autism Spectrum Disorder (ASD) [7]. For example, Mazi is a tangible user interface which encourages play between 6 and 9-year-olds diagnosed with ASD [13]. However, this system is not suitable for children with a more severe case of cerebral palsy since it requires full body movement to fully engage with the system. In another example, POMA uses pretend play toys equipped with conductive foam to create unique touch-point patterns to use with an iPad in a gameplay [14]. However, collaborative gameplay only begins at level 6 which most children are unable to reach due to an eventual lack of interest to its repetitiveness.

There are only a few interactive tangible game systems that have been designed for children with CP to support collaborative play. For example, in PhysiTable, a programmable board game uses an accelerometer to detect the smoothness of the hand movement of children with CP [15]. It is a multiplayer game, where two children compete to see who can move the object to the destination first. However, the result of the study shows that children with severe CP tend to dislike the game as it is difficult for them to maintain smooth movements. The game mainly functions as an assessment tool hence there is little replay value as the game could easily become repetitive. Another study explores the use of interactive toy modules with sensors, light, and audio feedback, which can be combined with basic blocks from LEGO for specific hand and arm functional exercises [16]. It proposes collecting user performance data and tracking the systems' long-term effect in rehabilitation training and more tangible systems to support competitive and cooperative gameplay for both physical exercises and social development to help children with CP communicate with peers properly.

3 Context and Design Requirements

This project is carried out as part of research collaboration with Spastic Children's Association of Selangor & Federal territory (SCAS&FT). The SCAS&FT runs a spastic children's centre that provides services, facilities and activities that are used to care and treat these special children. Initial ethnographic study and interview sessions were conducted at the centre involving teachers and parents over a 2-month period which results showed that encouraging actions that rely on hands and/or fingers and stretching are extremely important to increase their motor movements and intellectual development by giving meaning to their movement. Furthermore, any features of the systems developed should aim to build confidence, be enjoyable as this will lead to prolonged attention and concentration spans and promote creative expression. We further identified the following 4 rehabilitation requirements that an interactive tangible system for children with CP should support: 1) Movement of the shoulder, 2) Pronation or flexion of the wrist, 3) Extension of the fingers, and 4) Smiling or laughing while interacting. A pilot study was carried out at the centre showcasing our early idea of a tangible musical soundscape developed using a Bare Conductive Touch Board. The system was designed to support physical rehabilitation and recreation for children with CP in the form of music playing and making. Suggestions from the study given by the teacher and parents was to introduce game elements to motivate users to interact with the system. Participants also expressed wishes to play together.

4 System Iteration

4.1 System Design

Based on results of the pilot study, our new prototype iteration became focused on supporting collaborative play as well as rehabilitation. Figure 1 shows the system architecture of the improved interactive tangible game system consisting of two sets of tangible input controllers to support collaborative play involving two players. To set up the system, users will have to plug in the Arduino USB cable into their computers to power up the controller. The controller consists of an Arduino and touch sensors. The touch sensors used to design the controllers are Trill Sensors in the shape of a Bar, Square, Ring, and TTP223 Capacitive Touch Sensor Modules. Users can then play and control the games using the touch sensor equipped controller. The sensors can read the touch inputs, made by children with CP when they extend their fingers to tap on the sensors and translating them to in-game actions.

Fig. 1. General layout of the interactive tangible system (left), P2 and P1 controller (right)

4.2 Hardware

Arduino and Unity. The games can be played by two players, thus requiring the use of two Arduino controllers. Player 1's Arduino Uno controller has the Trill Bar, Trill Ring, and 4 capacitive touch sensors attached. Player 2 has the Trill Square and 4 capacitive touch sensors attached. The Arduino controllers were programmed to read the values from sensors continuously. It will then send the data information through the COM3 port, signaling that the third capacitive touch sensor has been pressed. Port COM4 was used for player 2. In Unity, a library called Ardity was used to receive data from the serial ports. Ardity allows Unity to read and process serial data. The data is stored in a queue and can be processed by a message listener. The message listener oversees the interpreting of data, translating them into in-game actions.

Tangible Input Controller. A cardboard box was used to develop the tangible input controller (Fig. 1). The 4 capacitive sensors were placed on top of a foam sheet to absorb pressure since users will have to press on them and the pins on this sensor are at the bottom. The foam was then covered with color paper to improve the aesthetics and allowed easy understanding of the Rhythm game.

4.3 Game Design

The games in the system were designed based on guidelines for making video games accessible to users with CP [17]. Motivation both in the form of extrinsic (external incentive) and intrinsic (personal satisfaction) are key to designing a fun game. Besides, progressiveness also allows users to enter a state of flow when playing the game. To establish a flow, there is a structure of levels so that users will feel accomplished when they overcome a level. The following game features were integrated into the system:

- Dual player gameplay in either cooperative or competitive mode.
- Various game difficulty to cater for children with different abilities.
- High score system which logs user's performance and can record any improvements throughout usage. This also acts as a motivational factor.
- Children can play freely with minimal supervision.
- Incremental difficulty to enhance motivation.
- Trial and error where mistakes should be forgiving so users can learn from errors.
- Immediate feedback allowing cause-effect learning when immediate feedback is given upon every action.
- Social component to encourage collaboration and social interaction between players.

4.4 Software Development

The programming platform used in developing the interactive game system is Unity which uses C# for game creation. The sensors were set up correctly on the Arduino controllers before connecting to Unity. This is essential to allow the sensors to sense touch input and send the data to Unity for in-game actions. Two new games were developed to support collaborative as well as competitive play modes respectively:

Asteroids. The Asteroids game detects touch input from Trill Bar sensor for Player One and Trill Square sensor for Player Two. The sensor input will be translated to position a player's spaceship. The Trill Ring sensor input is used to adjust the volume. The game interface consists of the Main Menu, Difficulty setting and Game Play. The game play is cooperative where both players share 5 lives and work together to increase player scores by destroying asteroids and aliens. There are two spaceships and each player control their respective sprites by dragging along the sensors. The spaceships automatically shoot bullets, so no additional controls are required (see Fig. 2).

The difficulty of the game gradually increases as the number of asteroids increases with each level progression. An alien will spawn targets and attack a player. So, players will have to work together to destroy it. Each level ends when the alien and asteroids are cleared. Lastly, there is a scoreboard which acts as a motivational factor for players to improve and beat their previous best score.

Rhythm. The Rhythm game processes touch input from a total of 8 capacitive touch sensors, each player uses 4 capacitive touch sensors respectively. The Trill Ring sensor is used to adjust the volume. The sensor input will be translated into a note hit if players tap on the sensor when a falling arrow enters a colored tile. The game interface consists of the Main Menu, Difficulty setting, Song Selection and Game Play. There are three song choices that may be selected by players, each ranging between 30 to 45 seconds, in a length not to be too tiresome for users. The Game Play corresponds to a chosen difficulty. There are a few differences between each level besides the speed of arrows falling down. In the easy and medium modes, two fingers are required to tap on the sensors whereas in hard mode four fingers are required illustratied in Fig. 2. Users can use either their dominant or non-dominant arm. The speed increases with difficulty but it is set at a managable speed for CP users. The square tiles decrease in size for harder difficulties.

During game play, player scores and visual feedbacks will be displayed depending on how precise the players tap on the sensor once an arrow enters a tile. Higher scores will be awarded if the accuracy in players' response improve. A scoreboard will be shown at the end of game play.

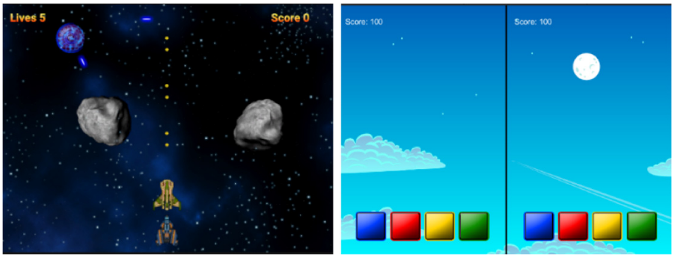

Fig. 2. Game play of asteroids (left) and rhythm (right)

5 Results

5.1 Results of Remote Usability Evaluation

An initial user evaluation was conducted to involve a general population sample. Due to the pandemic and Movement Control Order (MCO) imposed in Malaysia, the user evaluation was carried out remotely and limited to virtual demonstrations in order for participants to have an in-depth understanding of the system and also learn how users can interact with the system using the tangible input controller. The evaluation involved 52 participants in total. 28 of the participants were male, while 24 were female. 90.4% of the participants were in the age range of 18–25 years old, while others in the age range of 26 and above. The standard System Usability Scale (SUS) was used to investigate the usability of the interactive tangible game system. The SUS consists of ten questions, implemented on a 5-point Likert scale which 1 represented 'Strongly Disagree' and 5 represented 'Strongly Agree'. Additional closed and open-ended questions were included in the questionnaire to gain feedback on the perceived ease of use and effectiveness of the system to support collaborative play, in addition to recommendations on possible ways to improve the system. Table 1 shows the results of the SUS test. Overall, the SUS score is 75 which lies on the 3rd quartile, within the rating of 'Good'. Results indicated the system's functionalities were perceived as usable and acceptable, and participants were clear with the objective of the app. This would allow the system to be tested and used by children with CP in future.

In response to the questions to gain feedback on the effectiveness of collaborative play: a) to motivate users to use the system more often, and b) to increase social interaction during use, results showed that most participants agreed, where the average score to both questions was 4 (Agree) (see Fig. 3). Hence, most participants believed that using the interactive tangible game system in multiplayer mode may encourage users to use the system as they get to play along with a peer and engage in social interactions. Results also suggest that majority of participants consider the controller as straightforward and easy to use with an average score of 2.

Table 1. Results of system usability scale test

No	System usability scale questions	Average score
1	I think that I would like to use this system frequently	3
2	I found the system unnecessarily complex	2
3	I thought the system was easy to use	4
4	I think that I would need the support of a technical person to be able to use this system	2
5	I found the various functions in this system were well integrated	4
6	I thought there was too much inconsistency in this system	2
7	I would imagine that most people would learn to use this system very quickly	4
8	I found the system very cumbersome to use	2
9	I feel very confident using the system	4
10	I needed to learn a lot of things before I could get going with this system	2

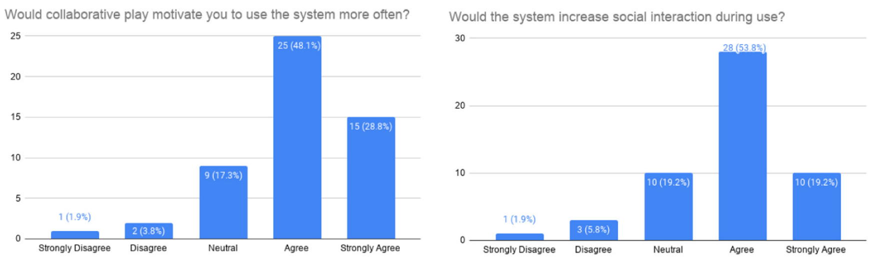

Fig. 3. Users' feedback on effect of collaborative play – (a) motivation (left) and (b) social interaction (right)

The questionnaire also included 2 open-ended questions where participants were asked to suggest genres of games that they would like to see added into the tangible interactive game system. 20% of participants suggested including retro or classic games such as Tetris. 18% of participants proposed including adventure games with an interactive story, while 16% of participants suggested fighting or first-person shooting games. Another 16% of participants suggested educational games such as puzzles. 11% of participants suggested racing games. 4% of participants suggested games of other genres such as horror. Virtual instruments and more music-based games were suggested by 7% of participants. Lastly, 4% of participants hoped to see sports related games.

Finally, participants were asked to suggest improvements to be made to the system. A total of 23% of participants commented on the design of the controller with suggestions to make it more compact, aesthetic, with a robust casing. 17% of the participants gave some suggestions to improve the games. For instance, rewards or powerups in the game to encourage players. Furthermore, 6% of participants suggested improvements to the portability of the system by using wireless controller and providing compatibility of the game with mobile phones. 8% of participants suggested improvements to the game user interface. For instance, they suggested to place instructions at the start of the game rather than using a separate instruction button and to combine all games into a single application. The rest of the participants commented that the system was great and hoped to see more games on the system.

5.2 Results of User Evaluation Involving Participants from SCAS&FT

Due to the pandemic, we were unable to conduct a physical user evaluation with targeted users involving children with CP at SCAS&FT. A virtual evaluation was conducted via Zoom to involve a live demonstration of the developed prototype system, followed by an interview session. The evaluation objectives were to evaluate the usability and effectiveness of the interactive tangible game system in motivating children to carry out physical rehabilitative exercises and encouraging social interaction through collaborative play. The participants involved were eight in total to include 3 children with CP, 1 female (F1) aged 14 years old, and 2 males (M1 and M2) aged 15 and 13 years old respectively. The three children have only mild CP with high functioning mobility and can move their fingers well. Other participants included 3 teachers and 2 parents. The interview questions aimed to gain feedback on various evaluation aspects such as usability, feasibility, ease of adaptation and accessibility.

Results of the interview showed that the system would be easy to use by all 3 children (F1, M1 and M2) where the children feedback that they would be able to play the games themselves without any assistance. One of the teachers affirmed this by saying, "It is easy for M3 to play as he can move his fingers very well. M2 also enjoys playing video games. He can type on his iPad, but it takes some time." The children confirmed that they would be able to reach out to touch the sensors easily and the arrangement of the sensors were comfortable. When participants were asked if they agree that the system would increase social interaction among children with CP, all of them agreed. Additional feedback revealed that the user interaction with the system was similar to physical occupational therapy that the children carry out in the center. As highlighted by a teacher, the system supports "typing" movements with fingers that the children carry out. She further suggested that extending the system to support the stretching of the shoulders and arms would increase the rehabilitative benefits to children with CP. All participants agreed that the incorporation of games would increase children's motivation to carry out physical therapy. The children were particularly interested in the multiplayer feature of the system.

Lastly, a suggestion was made by one of the teachers to allow the Rhythm game to be played with only one hand in the medium mode as it would be hard for children with CP to interact with 3 sensors. So, changes were made to the arrangement of sensors to allow the board to be placed horizontally such that upper arm movement is encouraged.

6 Discussion

Play is vital for a child's development in areas ranging from motor, cognitive, emotional, and social. Most participants believed that collaborative play is a preferred game mode for children, and has the potential of enhancing their social skills. This result built on existing evidence that children with cerebral palsy prefer multiplayer conditions [18]. Positive effects that collaborative play bring included motivation for rehabilitation as well as social collaboration. However, this requires more concrete confirmation and to study the systems' long-term effect on rehabilitation training and social collaboration. Despite the benefits that collaborative play brings, it should also be used with caution as users may be too involved in gaming, resulting in them using their dominant arm more instead of the affected arm that requires rehabilitation [18].

Results of our evaluation suggested good perceived ease of use and effectiveness of the system to support collaborative play. Future work would involve adding a game tutorial at the start of the game to demonstrate use of the sensors. Additionally, the system could be improved to allow users to fully use the system without the need of a mouse and keyboard interaction. Currently, typing players' names in the scoreboard and pausing the game required keyboard pressing. Hence interface improvements could be made to include additional touch sensors for pausing the game and a virtual keyboard for in-game input. Some participants also suggested that more arcade style games could be included in the interactive tangible game system to give players more choices to play with to prevent children with CP from getting bored with the system easily.

Based on participant feedback, further improvements could be made to the tangible input controller to improve its physical design to become more ergonomic and to achieve rehabilitation goals such as stretch outing or lifting arms to interact with the system. We propose using projection mapping, a technique to turn a wall or board into a display surface for digital projection. These digital projections of visual game interface onto a display surface embedded with touch sensors will allow for direct manipulation and seamless interaction with the interactive board or wall. Creating a sensor-based tangible board or wall with projection mapping that is physically larger in size would mean that bigger movements will be required to interact with the system and may be suitable to support multi-player group experience to facilitate healthy emotional development. To improve the accessibility of a tangible system, it could be designed in a modular way allowing it to be adjusted according to each child's height or reach.

From this research, the use of touch interfaces appeared to fit the needs of children with CP [19]. The touch sensors used in the system were sensitive and easily accessible. The Trill sensors can sense multiple touch points so children with CP can carry out tapping motions instead of dragging their fingers along. More research will be needed to explore the design and use of touch interfaces to encourage various motor movements to achieve higher rehabilitation goals such as movement of the shoulder and pronation or flexion of the wrist. For example, there are many user modes and readings that may be taken from Trill sensors such as pressure of finger. It is also possible to tune the sensitivity of the touch sensors to adjust the difficulty of the games.

All in all, the proposed touch based tangible system showed potential as an easy-to-use controller for children with CP. Our future work will focus on understanding how to design better tangible input controller to achieve higher physical rehabilitation goals with inclusion of suitable multiplayer games.

7 Conclusion

In conclusion, this paper presents a new tangible interactive game system that can support collaborative play between children with cerebral palsy. Previous studies involving design of tangible systems for collaborative play have less focus on children with limited mobility, while tangible systems for children with CP tend to cater for single users. Results from usability testing suggested that the developed system achieved good perceived ease of use and effectiveness to engage players in collaborative play. Future game design iteration should allow players to select their game difficulty level to include assigning placement of touch sensors based on physical rehabilitation goals and their music of choice to be played. The potential benefit of the interactive tangible game system is two-fold – to motivate children with CP to engage in their physical therapy exercises while encouraging social interactions and communication. Future work will involve studying the system on-site with actual children with CP in SCAS&FT and studying the effect of collaborative play in comparison to single user play.

Acknowledgements. We would like to thank the teachers, parents, and children at SCAS&FT for participating in this project.

References

1. Cerebral Palsy: Hope through research. https://www.ninds.nih.gov/Disorders/Patient-Caregiver-Education/Hope-Through-Research/Cerebral-Palsy-Hope-Through-Research/. Last Accessed 24 June 2021
2. Cerebral Palsy. https://www.cerebralpalsyguidance.com/cerebral-palsy/. Last Accessed 24 June 2021
3. Lin, C., Chen, W., Lin, C.: The effects of interactive music and bubble feedback using Arduino on enhancing physical activities for children with cerebral palsy. In: Proceedings of the 2017 International Conference on Education and Multimedia Technology, pp. 1–7. ACM New York, USA (2017)
4. Kang, L., Palisano, R., Orlin, M., Chiarello, L., King, G., Polansky, M.: Determinants of social participation—with friends and others who are not family members—for youths with cerebral palsy. Phys. Therapy **90**(12), 1743–1757 (2010)
5. Why Kids Should Develop Collaboration as A Life Skill. https://funacademy.fi/collaboration-as-a-life-skill/#:~:text=Collaboration%20helps%20children%20to%20discover,a%20fun%20and%20efficient%20wa. Last Accessed 24 June 2021
6. Ananiadou, K., Claro, A.: 21st Century Skills and Competences for New Millennium Learners in OECD Countries. OECD Education Working Papers (41), pp. 6–34 (2009)
7. Baykal, G., Van Mechelen, M., Eriksson, E.: Collaborative technologies for children with special needs. In: Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems, pp. 1–13. ACM, New York, USA (2020)
8. Hand Therapy Exercises: 39 Ways to Restore Mobility. https://www.flintrehab.com/hand-therapy-exercises/#stretching. Last Accessed 24 June 2021

9. Stretching as an intervention for Cerebral Palsy. https://www.physio-pedia.com/index.php?title=Stretching_as_an_intervention_for_Cerebral_Palsy&oldid=204753. Last Accessed 24 June 2021
10. Hung, J.-W., Chang, Y.-J., Chou, C.-X., Wen-Chi, W., Howell, S., Wei-Peng, L.: Developing a suite of motion-controlled games for upper extremity training in children with cerebral palsy: a Proof-of-Concept Study. Games Health J. **7**(5), 327–334 (2018). https://doi.org/10.1089/g4h.2017.0141
11. Dunne, A., Do-Lenh, S., Laighin, G., Shen, C., Bonato, P.: Upper extremity rehabilitation of children with cerebral palsy using accelerometer feedback on a multitouch display. In: Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology, pp. 1741–1754. IEEE, Buenos Aires, Argentina (2010)
12. Mittag, C., Leiss, R., Lorenz, K., Siebold, D.: Designing a tangible solution to encourage playful hand usage for children with cerebral palsy. Curr. Dir. Biomed. Eng. **6**(2), 20202008 (2020). https://doi.org/10.1515/cdbme-2020-2008
13. Nonnis, A., Bryan-Kinns, N.: Mazi: tangible technologies as a channel for collaborative play. In: Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems, pp. 1–13. ACM, New York, USA (2019)
14. Mahmud, A., Soysa, A.I.: POMA: a tangible user interface to improve social and cognitive skills of Sri Lankan children with ASD. Int. J. Hum. Comput. Stud. **144**, 102486 (2020). https://doi.org/10.1016/j.ijhcs.2020.102486
15. Mandil, M., Jamil, N., Gupta, S., Ahirrao, S., Sorathia, K.: PhysiTable: tangible interactive system for physical rehabilitation of children with cerebral palsy. In: Proceedings of the 7th International Conference on HCI, pp. 149–153. ACM, New York, USA (2015)
16. Bian, Y., Wang, X., Han, D., Sun, J.: Designed interactive toys for children with cerebral palsy. In: Proceedings of the Fourteenth International Conference on Tangible, Embedded, and Embodied Interaction, pp. 473–478. ACM, New York, USA (2020)
17. Compañ-Rosique, P., Molina-Carmona, R., Gallego-Durán, F., Satorre-Cuerda, R., Villagrá-Arnedo, C., Llorens-Largo, F.: A guide for making video games accessible to users with cerebral palsy. Univ. Access Inf. Soc. **18**(3), 565–581 (2019). https://doi.org/10.1007/s10209-019-00679-6
18. Lopes, S., et al.: Games used with serious purposes: a systematic review of interventions in patients with cerebral palsy. Front. Psychol. **9**, 1712 (2018). https://doi.org/10.3389/fpsyg.2018.01712
19. Spiller, M.G., Audi, M., Braccialli, L.M.P.: Motor performance of children and adolescents with cerebral palsy during the execution of computer tasks with different peripherals. Rev. CEFAC **21**, 4 (2019). https://doi.org/10.1590/1982-0216/20192140319