PLAY
CHILDREN
HANDS
MOTIVATION
toys4therapy
Designing Playful Smart Toys to Support Home-Based Hand Therapy for Children with Cerebral Palsy
Tamara Pinos Cisneros
HOME
THERAPY

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DESIGNING PLAYFUL SMART TOYS TO SUPPORT HOME-BASED HAND THERAPY FOR CHILDREN WITH CEREBRAL PALSY

Tamara Verónica Pinos Cisneros

TOYS4THERAPY

DESIGNING PLAYFUL SMART TOYS TO SUPPORT HOME-BASED HAND THERAPY FOR CHILDREN WITH CEREBRAL PALSY

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Tamara Verónica Pinos Cisneros

born on the 25th of September, 1981

in Quito, Ecuador

This doctoral thesis has been approved by:

The promotors:
prof. dr. ir. G.D.S. Ludden
em. prof. dr. B.A.M. Schouten BFA

The co-promotor
em. prof. dr. ir. B.J.A. Kröse

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MANUSCRIPT COMMITTEE:

Chair / secretary:	prof.dr.ir. H.F.J.M. Koopman
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To Tadeo and Adalie, my experts of play.

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Chapter 1

INTRODUCTION

1.1 CEREBRAL PALSY: A COMPLEX START TO LIFE

Sabrine is an 8-year-old girl who likes to colour unicorns, make bracelets, dance to the Kinderen voor Kinderen band and play with her older brother. Sabrine has spastic hemiplegic cerebral palsy. She was diagnosed shortly after her birth, the left side of her body is affected, and she has been doing therapy for as long as she can remember.

Cerebral Palsy (CP) is an umbrella term that describes a neuromotor impairment acquired at, before birth or during the first year of life, and often results in complex motor problems that can affect several body systems (CP Nederland, 2024). The prevalence of CP is 1.6 per 1000 live births in high-income countries, while the prevalence in low-income countries is around 3.6 per 1000 live births (McIntyre et al., 2022). Each child with CP is affected differently in terms of severity and the effects of the impairments present. However, four main types of CP have been identified based on which part of the brain has been affected: spastic, dyskinetic (athetoid), ataxic, and mixed (Cerebral Palsy Guide, 2025). A sub-classification is based on which parts of the body are affected: monoplegia (one arm or one leg), diplegia (either both legs or both arms), hemiplegia (one side of the body), triplegia (three limbs), quadriplegia (all four limbs), and double hemiplegia (four limbs but one side more affected than the other) (Cerebral Palsy Guidance, 2025). In this thesis, we will be focusing on spastic hemiplegia, a common presentation within spastic CP (spastic CP being the most prevalent CP type) (CP Nederland, 2024). Hemiplegia affects one side of the body, resulting in a spastic hand. Although spastic hemiplegia cannot be cured, timely therapy and assistive devices can

improve mobility and quality of life by building muscle strength, range of motion and coordination (NHS, 2023).

Cerebral palsy is managed through individualised, multidisciplinary care that prioritises function and participation. Core motor intervention includes occupational and physical therapy, surgery (in select cases), and the use of orthoses to enhance strength, range of motion, and bimanual skills. Evidence-based upper-limb programmes implemented in occupational and physical therapy, such as Constraint-Induced Movement Therapy (CIMT) and Bimanual Training (BiT), demonstrate improvement in manual performance in children with spastic hemiplegia (Chamudot et al., 2018). In CIMT, children have their preferred hand on a sling, forcing them to use their spastic hand. In BiT, children work with both hands in repetitive practice of bimanual activities. In some cases, orthopaedic surgery is used to improve muscle balance and joint positioning; however, fewer than 20% of children with CP qualify for surgery (van Munster et al., 2007). The use of orthoses aims to enhance body function and facilitate daily activities; yet, the benefits of using orthoses are diminished after the device is removed (Jackman et al., 2014). While CIMT and BiT interventions are effective when delivered and practised consistently, the dose of therapy at home often falls short because exercises are repetitive, challenging to fit into busy routines, and not always intrinsically motivating for children. This thesis explores a complementary route: smart toys that turn prescribed hand movements into play at home. In this work, a smart toy is a tangible play object that combines physical materials with sensors and actuators. In the context of therapy for children with CP, smart toys connect clinical goals with children's play at home**.** To accomplish this, I propose the addition of self-adaptive play complexity, which allows the smart toy to adjust its difficulty and content based on the child's performance, ensuring that practice remains "just right" and worth returning to. Therefore, the proposed design combines adaptive feedback and feedforward, as well as embodied interaction, to transform repetitive hand exercises into motivating play. In doing so, it addresses the persistent gap between clinic-designed exercises and the realities of at-home therapy.

Therefore, identifying the design features and requirements of smart toys for health is of key importance, as smart toys become more common as tools that can support children's health.

1.2 HOME THERAPY: WHERE CARE MEETS CONSTRAINT

Sabrine's parents looked for guidance early on and have been working with physical and occupational therapists for many years. They live in a small village an hour away from the therapy centre, and they take turns taking her to the therapy sessions there. Sabrine's therapist has advised her to continue exercising at home; if she does not continue to practice what she learns in therapy, she will lose movement in her hand. Sabrine does the exercises as instructed but she doesn't really enjoy them. She does them mostly because her parents insist she does.

In addition to the recommended physical and occupational therapy programs followed at clinics or rehabilitation centres, home-based therapy is necessary to maintain continuity of care and autonomy for children with CP. The goal of home-based therapy is to extend the skills acquired at the rehabilitation centre and integrate them into the daily routine of the family and the child. Resource constraints, waiting lists and limited access to therapy services for some families have meant that an alternative to in situ therapy is needed, which can be fulfilled by home-based therapy. Furthermore, continuing therapy exercises at home means increased frequency and integration into routines, empowerment of families and children and reduced travel and clinical burden. Home-based therapy is particularly relevant in low-resource settings, scarcity of health providers or during disruptions such as the COVID-19 pandemic.

Despite the benefits of home-based therapy, maintaining adherence comes with its challenges. A frequently mentioned barrier is low motivation in children, often linked to the repetitive and monotonous nature of traditional therapeutic exercises (Mohd Iqbal et al., 2025; Taylor et al., 2004) and lack of agency. Young (2024) has compiled in their dissertation (*Children and Young People's Experiences of Growing Up with Cerebral Palsy in Rehabilitation*) several testimonies of people with CP, where they expressed that they did not like exercising at home, and that "their position as children limited their agency not to participate in it". Participants mostly received therapy at home because their parents required them to do so, either by instruction or physical participation.

Moreover, children were expected to exercise at home regularly, which demonstrates a lack of autonomy and the pressure to exercise exerted by their parents affected the relationship with the children. Research has shown that when therapy routines feel tedious, children are less likely to engage consistently, and families may struggle to sustain participation over time (Mohd Iqbal et al., 2025). Another barrier in home-based therapy is the lack of structured guidance and adaptable tools. When a therapist is working with the child directly (in clinic), they can identify the skill level of the child and adapt an exercise to the child's needs. On the other hand, over-reliance on clinical sessions can prevent optimal integration with home life.

While adherence is often used as a marker of success in home-based therapy, adherence alone does not necessarily reflect meaningful engagement. Children may complete exercises due to parental insistence, yet experience therapy as an externally imposed obligation rather than a self-endorsed activity. In long-term conditions such as cerebral palsy, where therapy extends over years, this distinction becomes critical, as externally driven participation may be difficult to sustain over time without continuous supervision.

Parents have an important role in children's therapy (at home and in the clinic!). Niyonsenga et al. (2024) have identified the factors that affect parents' adherence to therapy: education level, depression, anxiety, stress, emotional exhaustion, high self-efficacy, high knowledge and ability, low perception of the barriers, and social support. Wingrat et al. (2024) add to that list: lack of time and lack of confidence. Therefore, implementing a successful home-based therapy program requires an understanding not only of the child but also of their family environment, avoiding caregiver burden and forced participation.

It is essential to highlight that the home-based program supports the clinic-based therapy, rather than replacing the therapist's role; hence, good communication with the therapist is also necessary. Inconsistent support or feedback from the therapist can prevent the child and caregivers from committing to completing the exercises (Niyonsenga et al., 2024).

To address these challenges, we need to reconsider how therapy is designed and delivered at home, not only through clinical goals, but through experiences that motivate, engage, and empower children. Research into game-based rehabilitation reinforces this point, demonstrating that introducing playful, interactive elements can transform therapy from a task into a motivating activity

(Pandey et al., 2024). From the child's perspective, the absence of playful engagement or intrinsic motivation can make therapy feel repetitive or boring, especially when exercises lack variety or are not tailored to the child's abilities (Meyns et al., 2018; Mohd Iqbal et al., 2025; Taylor et al., 2004; Weightman et al., 2010). These barriers highlight the need for supportive, motivating, and context-sensitive tools that reduce the burden on caregivers while helping children perceive therapy as something meaningful and enjoyable. If home therapy is integrated into moments of play, children may be more intrinsically motivated to engage with therapeutic activities, shifting therapy from an externally imposed task to an experience that aligns with their own interests and enjoyment.

In summary, the constraints to home-based therapy are complex, as it has several facets. These include children lacking motivation due to repetitive exercises and limited agency, parents facing stress, time constraints, and insufficient support, and a lack of adaptable, context-sensitive tools. These challenges cannot be solved by moving the clinical exercises into the home. Instead, a design approach that recognises home therapy as different from clinic-based care is needed. An approach that is embedded in family life, responsive to individual needs, and centred on intrinsic motivation. The design of therapeutic interventions must therefore go beyond clinical goals to consider the realities of families, making therapy not only accessible but also engaging, adaptable, and seamlessly integrated into the home environment and daily practices.

1.3 PLAY IN HEALTH: THE SERIOUS SIDE OF FUN

Now that she is 8, Sabrine will join the therapy program Handig2Handig. When she was younger, she used to join the Pirate Group. There she met Maaike and quickly became good friends, and now they will continue to see each other in the Handig2Handig program. This one-week program only happens a couple of times per year, therefore, Sabrine is very excited to see and play with Maaike again.

The Pirate Group and the Handig2Handig group are well-established therapy programs in the Netherlands (Aarts et al., 2012; van der Burg et al., 2013). The first one is aimed at children aged 2.5 to 8 years old, and the latter is for children aged 6 to 12 years old. What makes these programs special is the world that has been created for the children. The Pirate and the Handig2Handig groups use playful elements to encourage children to participate in the therapy. In the Pirate Group, children dress up as pirates and wear a sling to restrain their fully functional hands, forcing them to use the spastic hand that requires therapy. In this role-playing game, children participate in various activities that promote the movement of their spastic hands. The little pirates must clean up the ship, paint flags, make lunch for their fellow buccaneers, find treasures, and do all sorts of pirate activities. While they are inside this world of pirates, they are also learning how to use their spastic hands to perform different movements; these learnings will later be transferred to their daily activities. In the Handig2Handig Group, the children engage in activities they enjoy, such as mosaic, carpentry, cooking, board games, swimming, first with the non-affected hand in a sling (CIMT) and later with both hands (BiT) (Gordon et al., 2011). Some rehabilitation centres add a theme to the week, such as "Ik hou van Holland" [I Love Holland], based on a television quiz show (van der Burg et al., 2013). Although these therapy programs are based on two traditional therapy approaches, CIMT and BIT, the added playfulness facilitates learning and increases engagement in a fun and empowering way.

During one of the last days of the Handig2Handing program, Leony, Sabrine's therapist noticed that Sabrine could easily take the 2 cm diameter ball with her fingers so to make the exercise more challenging, she switched them to the 1cm diameter balls. Sabrine was very proud of herself and kept going!

While the value of physical and occupational therapy is undisputed, exercises can feel tedious or even painful when they are not presented in an engaging, playful way. Programmes such as the Pirate and Handig2Handig groups show how play can sustain motivation; without such support, completing routines is difficult. During the focused week of therapy, children play with peers, follow the advice of therapists who provide them with different toys, and quickly notice any

evolution in the movements they can do and can immediately adapt the exercise to the skills of the child.

Summer is over, and Sabrine gets back to her daily routine: school, an after-school program, swimming lessons, horse riding classes, and therapy every two weeks. The therapist instructed her to continue doing the exercises at home; she had made significant progress over the summer and didn't want to lose it. But once she is home, all she wants to do is play. She learned how to cut a cucumber using her spastic hand during the Handig2Handig week, so maybe she will help Dad with dinner. But she is not looking forward to doing some hand exercises. She does not enjoy them; she got a paper from her therapist that indicates how many times she must rotate her wrist, left and right, up and down, tap her fingers and open and close her hand. That does not sound fun...

Therapists and researchers continually seek ways to enhance their patients' motivation and help them adhere to their therapy programs, thereby ensuring the success of the therapy. To make therapy more attractive, practitioners are incorporating play into their therapeutic programs. There are different ways to involve people in activities, some of which make use of extrinsic motivators, such as the possibility of winning a prize or the promise of learning a new skill. Others are intrinsic motivators, where the willingness to participate in the activity stems from the participant's own interests, as it is an activity that they inherently enjoy or are interested in (Ryan & Deci, 2000). Behavioural theories distinguish between these forms of motivation in terms of sustainability. While extrinsic motivators can be effective in initiating behaviour, they are often less effective for maintaining long-term engagement once rewards or supervision are reduced. Self-Determination Theory further suggests that activities supporting autonomy, competence, and relatedness are more likely to be internalised and sustained over time. Play can be an activity that we are intrinsically motivated to take part in. Therefore, the inclusion of play in therapy can have a positive impact on patients and their motivation to adhere to the therapy if it is designed effectively. In this thesis, intrinsic motivation is therefore treated not as the only possible driver of engagement, but as a design goal that aligns with the constraints of home-based therapy, where sustained, self-initiated participation is required.

Therapists recognise the potential to use the engaging elements of play to motivate their patients because play can be active, sociable, meaningful, and enjoyable. It promotes social interaction, communication, and involvement, while providing relaxation and focus. Play, particularly in therapy, is rarely a solitary activity. The social aspect of play invites other participants, such as parents, siblings, or friends, to join the activity, forming play communities that contribute different but complementary roles (Salen Tekinbas & Zimmerman, 2003). Children are not passive recipients of therapy but active agents whose motivation, preferences and agency determine whether therapeutic activities feel like play or obligatory exercise (Young 2024). Parents function as co-therapists in home settings, facilitating exercises, providing encouragement, and interpreting therapeutic goals (King et al., 2004). Therapists provide clinical expertise, individualised exercises, support families and monitor progress (Camden et al., 2020). Therefore, designing technologies for home therapy must address the needs of this entire community by engaging children, supporting parents without increasing burden, and enabling therapists to maintain oversight and provide feedback.

Play theory helps explain this phenomenon. The “magic circle” is a term often used in games and play. Salen Tekinbas & Zimmerman (2003) define the magic circle as “shorthand for the idea of a special place in time and space created by a game”, where the player is immersed in a world with rules that differ from ordinary life. For home-based care, this matters: therapeutic toys and playful sessions can carry the goals of therapy into everyday routines, bridging the boundary between the magic circle of play and the child’s real-world environment. Unlike other types of games where the player remains within the magic circle, playing with therapeutic toys or participating in a playful therapeutic session has the effect of extending the therapy's benefits into the player's real-world environment.

What happens within the play experience, whether in a distinct magic circle or woven into everyday life, is equally important: A key mechanism for focus, optimal performance and well-being is engagement through “flow”. When we observe a child playing, we can see that they can easily immerse themselves in the activity and reach a state of flow (Csikszentmihalyi, 1990). This means that the activity entirely absorbs the child, and time and space seem to blur. When we integrate play into therapy, we can increase adherence by intrinsically motivating the participants with an environment of enjoyment and engagement. By

maintaining the patient/player's interest and an adequate level of challenge, adherence to treatment will increase, positively impacting the health and well-being of participants.

Play experiences are often mediated through tools and objects that shape how children engage and how other stakeholders can participate. While play has traditionally involved physical tools and toys, digital technologies now offer new possibilities for supporting the entire therapeutic play community by engaging children through interactive experiences while providing relevant data and feedback to parents and therapists. Reflecting this potential, technology-mediated play has entered rehabilitation: for example, the use of game consoles such as Nintendo Wii Sports (Chiu et al., 2014), sensor-based games like the NEOFECT Smart Kids (Choi et al., 2021), or controllers like the Leap Motion have targeted hand coordination (Tarakci et al., 2019), and video games such as Minecraft are being used for social and communication skills (Cadieux & Keenan, 2020).

Figure 1.1 Examples of technology used in therapy, from top to bottom: Nintendo Wii, Leap Motion, NEOFECT Smart Kids and Minecraft.

These examples (Figure 1.1) may differ in the tools used (e.g., game consoles, sensors), goals (e.g., improving motor skills, communication), and health

conditions (e.g., cerebral palsy, autism), but what these examples have in common is that they appeal to children's natural interest in playing. If we can apply similar principles in health, the boredom of therapy could decrease. These technologies create distinct experiential spaces that feel different from ordinary therapeutic exercise.

In this way, play can make therapy feel meaningful and self-motivating. Toys are the natural carriers of play into daily routines, serving as essential mediators of play experiences. Next to the previously mentioned technology that facilitates play, the emergence of smart toys opens new possibilities for designing play experiences that respond dynamically to children's actions and needs, offering tangible entry points for imagination, physical activity, and social interaction. After all, smart toys maintain the core of what a toy is: "objects designed for the act of play" (Zagalo & Branco, 2015).

1.4 SMART TOYS: DEFINITION, USES, AND IMPLICATIONS

Leony, her therapist, asks Sabrine if she practised the movements. Sabrine complains that she didn't really like the exercises. Leony brings out a box; inside, there is a peculiarly looking, blinking toy. It invites a squeeze, a twist, a tiny quest. Sabrine takes it home; she can't wait to show it to her brother. Laughing, she repeats the movements she avoided before, watching the lights change. Practice becomes play; home turns into therapy for Sabrine.

In this thesis, a smart toy is defined as a toy equipped with software, sensors, and data functionalities that enrich the interaction between the child and the toy (Komis et al., 2021). They have a mixture of physical and digital components (Tyni et al., 2016) and they may or may not connect to the internet or other devices (Mascheroni & Holloway, 2017). Related terms used in the literature are hybrid toys, connected toys, internet of toys and augmented toys. Smart toys provide embodied, real-world manipulation with immediate feedback (lights, sound, haptics). While current smart toys typically provide sensing and responsive feedback, few implement AI-driven self-adaptation for home therapy; this thesis investigates that gap. We also contribute the Smart Toy - CTT Framework (Context–Therapy–Technology) to guide

designers and therapists in aligning home routines, clinical goals, and toy interaction while keeping playfulness central.

With the advancement of technology, including AI models, smaller and more affordable sensors, actuators, and microcontrollers that support smart toys, more healthcare applications are being explored. For example, smart toys have been tested to support children with emotion regulation and coping strategies at home and school (Slovak et al., 2021; Theofanopoulou et al., 2019), such as Purrble (*Purrble*, 2025; Slovak et al., 2021), an interactive plush toy that uses haptic feedback to help people feel calm in moments of stress. Robotic toys are being used to promote social play among autistic children (Laurie et al., 2022). SAM (Crovari et al., 2019) is a dolphin-shaped smart toy designed to help people with neurodevelopmental disorders engage in different activities. And Mironcika et al. (2018) present *Get that cheese*, a board game with sensors for computerised fine motor skills assessment. For paediatric physical therapy, smart toys provide a combination of physical action and responsive feedback that allows targeted movement practice to be observable and self-adaptive, while preserving the play qualities that sustain motivation over time.

We define "self-adaptive play complexity" as incremental challenges and responsive feedback driven by sensed skill. In the case of children with CP, a smart toy with self-adaptive play complexity must adjust the difficulty of exercises to the child's skill level, providing a personalised play experience.

As with any other technology, we must be aware of the risks of smart toys. Smart toys that listen, sense, or connect bring privacy and safety considerations, even more so in the home environment, where data is captured in intimate spaces. Interviews with families using connected toys such as Hello Barbie (Moini, 2017) and CogniToys (McReynolds et al., 2017) show concerns about data retention, consent, and control. These concerns emphasise the need for transparent, responsible, privacy-preserving design.

Knowing the value of play in therapy and the potential to use smart toys in health, this thesis answers the following research questions:

RQ1: "*How can smart toys be designed to support motivation and adherence in home-based hand rehabilitation for children with cerebral palsy?*".

RQ2: *"How can self-adaptation support motivation and adherence in smart toys for rehabilitation?"*

1.5 RESEARCHER POSITIONALITY

The seed of this thesis was planted on the other side of the world, in Ecuador. I witnessed there the difficulties that families from low-income backgrounds have in accessing therapy programs for their children with CP. Although there are many differences between the Netherlands and Ecuador, the need to have alternatives to therapy in clinics and the struggle for children to adhere to home-based therapies are similar. I approach this work as a designer-researcher with a background in computer and systems engineering, collaborating with therapists and families in the Netherlands, with formative experiences in Ecuador. Also, as a mother of two (4 and 8-year-old) very active and curious children. This background shapes my emphasis on participatory methods, interdisciplinary collaboration, playful design, innovative technologies, and sensitivity to home-context constraints.

1.6 CONNECTING DIFFERENT WORLDS

This thesis is rooted in the belief that no single discipline can address the complexity of designing practical therapy tools for children. Participatory methods involving diverse stakeholders, as demonstrated by Hodson et al. (2023) offer paths to more inclusive design. Because the goal of this thesis requires the insights of therapists, the creativity of designers, the knowledge of engineers, and the imagination of children themselves, only with such a collaboration in place can we start to build bridges between the different relevant fields: health, design, and technology (human-computer interaction/child–computer interaction/digital health). However, connecting these worlds does not come without challenges. As highlighted in Groeneveld et al. (2018), designers and design researchers working in a healthcare context face several challenges regarding conducting fieldwork, involving end-users, dealing with sensitive situations, managing relations, building understanding between collaborators and end users, communicating the value of design, time and financial restrictions and establishing rapport. The introduction of smart technologies into home-based therapy for children significantly amplifies these challenges. Privacy and ethics concerns are raised by smart toys that perceive, adapt, and store data. Establishing rapport requires addressing not only interpersonal trust between researchers, therapists, and families, but also trust in the technology itself and the developers behind the technology. Particularly,

regarding the type of data that is collected, how it is secured, where it is stored, and whether it might be misused. The shift from the therapy centre to the home environment further complicates these dynamics, as families must welcome potentially observing technology into intimate home spaces.

The making of this research faced all these challenges, and this thesis addresses how we navigated the conflicts that arose when working in such a complex field.

1.7 APPROACH

This thesis adopts a Research through Design (RtD) approach (Zimmerman et al., 2007) to address a complex, situated problem: supporting home-based hand therapy for children with cerebral palsy. RtD enables us to generate knowledge by designing, deploying, and reflecting on artefacts in context. We treat the smart toy as an artefact that aligns clinical goals with children's play in domestic settings. Through iterative cycles of sketching, prototyping and in-situ feedback, we converged on a concept and refined it into a high-fidelity prototype - the Magic Monster - while articulating design knowledge (principles and the Smart-toy CTT framework) to guide future work in health and as practical insights for clinicians implementing home-based therapy programs.

Koskinen et al. (2011) describe three venues for RtD: lab, field, and showroom. This project primarily engaged the lab and the field. In the lab, we validated the Magic Monster's sensing and AI model and conducted early usability work with adults and with children with and without CP, allowing rapid and safe iteration before home trials. In the field, we deployed the Magic Monster in children's homes to capture authentic routines and examine adherence, the behaviour of interest, under real-world constraints. Using these complementary venues lets us balance control and external validity and progressively improve the design for everyday use.

The population of interest in this thesis are patients with cerebral palsy with spasticity in one of their hands. The patients selected for our studies have taken part in the therapy programs of the Roessingh Centre for Rehabilitation in Enschede or the Sint Maartenskliniek rehabilitation centre in Nijmegen. The inclusion criteria included:

- Aged between 7 to 12 years old
- Manual Ability Classification System (MACS)(Eliasson et al., 2007) levels I-II
- Having a goal relating to improving hand/wrist function
- Dominantly spastic presentation
- Normal or corrected-to-normal vision and hearing
- Able to co-operate, understand, and follow simple instructions for gameplay

1.8 THESIS STRUCTURE

This thesis includes six paper-based chapters and ends with a conclusion and discussion chapter. For readability, slight modifications were made to the original papers. The chapters follow a RtD approach, progressing from understanding the problem space to conceptualising, developing, and evaluating design solutions (artefacts), and finally synthesising this knowledge into a transferable framework. A visual overview of the thesis outline can be seen in Figure 1.2.

Chapter 2 presents a scoping review that identifies the innovative technologies being used in playful hand therapies and the playful elements employed in these therapies. This chapter establishes the current state of the art and identifies gaps in existing approaches.

Building on this foundation, **Chapter 3** describes a co-creation session with children to identify the needs they have in their hybrid (smart) play experience, in terms of interactions, topics, types of play, and their relationship with technology. This user-centred research complements the literature review by capturing the perspectives and needs of children.

To understand the transition from clinical to home settings, **Chapter 4** identifies the elements of therapies at rehabilitation centres that can be taken into the home environment to motivate children to exercise. This chapter bridges understanding user (children and therapists) needs with designing for the home context.

Integrating insights from the previous chapters, **Chapter 5** presents the design process of the Magic Monster, a case study used to put into practice what

we have learned about how to design smart toys that increase motivation and adherence to physical therapy at home for children with spastic CP. We evaluate this prototype via a longitudinal study to determine the effects of self-adaptive play complexity on engagement, motivation, and adherence.

Chapter 6 focuses on the AI functionality of the Magic Monster by evaluating how a mobile application developed to facilitate hand therapy can be extended to become adaptive by classifying hand and wrist dorsiflexion movements of its users in real-time. This chapter provides the technical foundation for implementing the adaptive functionality evaluated in Chapter 5.

Chapter 7 presents a process Framework for Developing Smart Toys for Home Therapy which provides a structured approach to designing smart toys for therapy. This chapter synthesises insights from all previous chapters into transferable design knowledge.

Finally, **Chapter 8** concludes this thesis with reflections on the research journey, the importance of embedding playfulness into the therapeutic process, and the complexity and usefulness of carrying out interdisciplinary design.

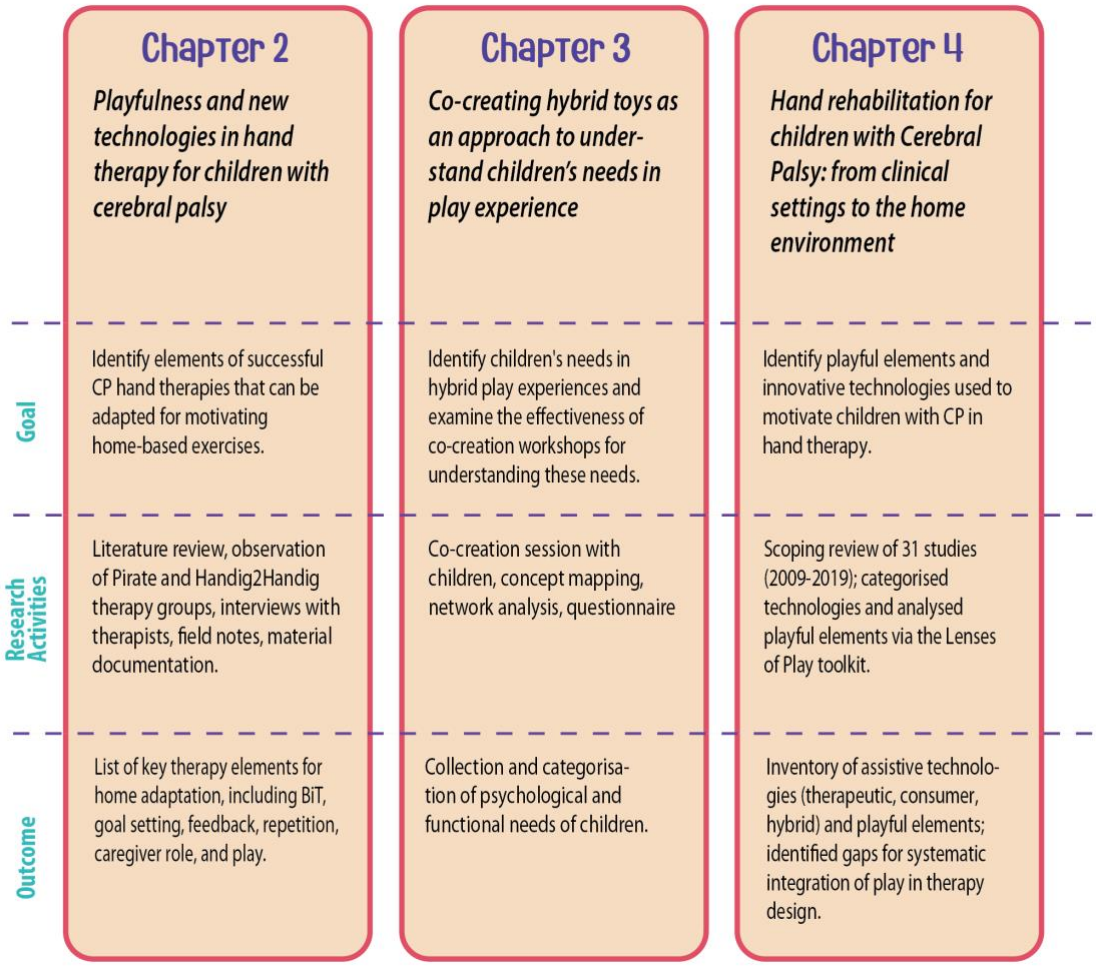

Figure 1.2 : Overview of thesis outline

Chapter 5	Chapter 6	Chapter 7
Design and evaluation of a smart toy for home therapy for children with cerebral palsy	*Wrist movement classification for adaptive mobile phone based rehabilitation of children with motor skill impairments*	*Smart Toy - CTT: Designing for children's wellbeing in home-based therapeutic play*
Design and evaluate a self-adaptive smart toy (Magic Monster) to improve motivation and adherence in home-based CP hand therapy.	Develop a mobile application that classifies wrist movements for adaptive rehabilitation exercises.	Provide a structured framework for designing therapeutic smart toys integrating context, theory, and technology.
Iterative design involving stakeholders and multiple design methods, multiple-baseline single-case study with 5 children over 3 weeks.	Developed movement recognition using phone sensors, tested classifiers on healthy subjects and 8 children with CP, integrated adaptive difficulty into an exergame.	Research through Design approach based on Toys4Therapy project; analysed existing frameworks, synthesised insights into 3-layer model (context, theory, technology).
Smart toy with self-adaptive play complexity improved motivation and engagement; highlighted potential for accessible, affordable home therapy tools.	Accurate classification of dorsiflexion movements; adaptive system improved interaction; demonstrated potential for personalised mobile-based therapy.	Smart toy - CTT framework offers guidelines to enhance engagement and therapeutic relevance in smart toy design.

1.9 PROJECT BACKGROUND

The work presented in this thesis is the result of the doctoral research project Toys4Therapy, made in collaboration with Twente University and the Amsterdam University of Applied Sciences (AUAS), the University of Amsterdam (UvA) and Eindhoven University of Technology (TU/e). The making of this project was an enriching activity shared with a team of different professionals. We designed the Magic Monster, our prototype described in Chapter 5, as part of the Smart Technologies Empowering Citizens (STEC) project, with IJsfontein and Philips as partners. Working with them helped us have a (very) high-fidelity prototype ready to be tested with our target group. Later, researchers from Utrecht University joined the team to investigate the possibilities for the movement recognition model (Chapter 6) and assist in its development with funding from the HUMAN-AI research program. Medical professionals of the Roessingh Centre for Rehabilitation in Enschede and the Sint Maartenskliniek rehabilitation centre in Nijmegen were also closely involved in this research. A team of students from Eindhoven University joined to develop the Squid Monster. Although not explicitly documented in this book, I also collaborated with groups of students from the AUAS (Digital Society School, Communication and Multimedia Design and Master Digital Design), which helped me gain insights into this topic and inform the direction of our prototypes. The involvement of students throughout a research project enriches both research and education.

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Chapter 2

PLAYFULNESS AND NEW TECHNOLOGIES IN HAND THERAPY FOR CHILDREN WITH CEREBRAL PALSY: A SCOPING REVIEW

This chapter was previously published as:

Pinos Cisneros, T. V., Brons, A., Kröse, B., Schouten, B., & Ludden, G. (2023). Playfulness and New Technologies in Hand Therapy for Children With Cerebral Palsy: Scoping Review. *JMIR Serious Games*, *11*(1), e44904.

Abstract

Innovative technologies such as game consoles and smart toys used with games or playful approaches have proven to be successful and attractive in providing effective and motivating hand therapy for children with Cerebral Palsy (CP). Thus, there is an increased interest in designing and implementing interventions that can improve the well-being of these children. However, to understand how and why these interventions are motivating children, we need a better understanding of the playful elements of technology-supported hand therapy. This scoping review aims to identify the playful elements and the innovative technologies currently used in hand therapy for children with CP. We included studies that design or evaluate interventions for children with CP that use innovative technologies with game or play strategies. Data were extracted and analysed on the type of technology, description of the system and playful elements according to the Lenses of Play, a play design toolkit. Thirty-one studies were included in the analysis. Fifty four papers were included in the analysis. The results show high use of consumer technologies in hand therapy for children with CP. While several studies used a combination of consumer technologies with therapeutic-specific technologies, only a few studies focused on the exclusive use of therapeutic-specific technologies. To analyse the playfulness of these interventions that make use of innovative technologies, we focused our review on three Lenses of Play: Open-ended Play, where it was found that the characteristics of Ludus, such as a structured form of play and defined goals and rules, were the most common ones, while strategies that relate to Paidia were less common. The most used Forms of Play were physical or active form and games with rules. Finally, the most popular Playful experiences were control, challenge, and competition. The

inventory and analysis of innovative technology and playful elements we provide here can be a starting point for new developments of fun and engaging tools to assist hand therapy for children with CP.

2.1 INTRODUCTION

2.1.1 Background

Children with hand motor skills deficiencies face challenges daily. They may have difficulties with daily activities like eating, getting dressed, or socialising with friends and families. Physical and occupational therapies can ameliorate the motor skills of these children (Novak et al., 2013). One group with hand motor skills deficiencies is children with Cerebral Palsy (CP). Despite therapists' efforts, the interventions available for this group are repetitive and thus perceived as demotivating (Velasco et al., 2017). Providing therapy via a motivating activity positively impacts improving motor skills as patients are more willing to take part and adhere to the treatment. Therefore, rehabilitation researchers and therapists constantly look for ways to innovate and improve existing therapies.

Challenges of current therapy at home include lacking the means for personalization, monitoring of progress of the exercises and high cost of devices. Children with CP present a diverse degree of motor function, no two children will be affected in the same way. Therapists therefore adjust the exercises according to each child; however, this type of personalisation is challenging if the therapy is to be done at home. Also, therapists need to provide tailored and timely feedback for the child to sustain motivation and increase adherence when doing therapy at home. Trying to provide this help at home can become a heavy workload and pressure on the therapists and caregivers.

New technologies, such as the E-link, the Hand Tutor, or the Surface Electromyography, present advantages in hand rehabilitation like data analysis, customization, feedback, and adaptability to the home environment (Levanon, 2013) however, their high cost means that families cannot make use of them easily. Two known approaches to increase motivation are the use of new technologies and play. Next to this, the benefits of play in the development of children have been widely studied, showing that the motivational nature of play encourages children to participate and learn. Thus, one of the approaches that therapists have successfully used in rehabilitation centres is to perform exercises through play (Rodger & Ziviani, 1999). One successful example of play-based therapy is the Pirate Therapy (Aarts et al., 2012), which highlights the importance of motivating children to work towards a goal via playful activities. Researchers have also

studied the use of new technologies, such as Virtual Reality (VR), Augmented Reality (AR), game consoles, and robots, that are familiar and appealing to children because they provide opportunities for play via interactive games while enriching the therapeutical experience (Levanon, 2013).

Furthermore, these new technologies provide monitoring and automatic feedback on performance, the opportunity for repetition to improve motor skills, and sharing experiences between children and others. These are also financially accessible technologies that require low technical support, making them appropriate to use at home. Some examples of successful studies on hand therapy for children with CP and other motor disabilities are the studies conducted by Reid (Reid, 2004) and analysed in the review by Pereira et al. (Pereira et al., 2020). They concluded that VR is suitable for supporting hand therapy. Koutsiana et al. (Koutsiana et al., 2020) concluded in their review that serious games are an alternative to provide motivation in therapy. Moreover, Winkels et al. (Winkels et al., 2013) showed positive results in participants' usability, user satisfaction, and enjoyment in gaming with the Wii sports games, boxing, and tennis. Ayed et al. (Ayed et al., 2019) highlight in their review that the interest on the field of virtual reality systems for rehabilitation is increasing. However, neither of these studies provides an overview of the extent and range of the research on playful technological interventions. There does not seem to be a systematic approach to how and when we use technology and play in therapy for children. Many studies experiment with available technologies that can be adjusted for therapy without paying much attention to the play elements that can be applied. Therefore, there is a need to have an overview of what the field has been doing for the last decade and to deepen our understanding of the use of play in therapy.

2.1.2 Objectives

The range of playful technological interventions can be studied along multiple dimensions. First, the type of technology (motion sensing, game consoles, etc.) can be used to categorise the research. Second, the type of playful elements (competition, rules, fantasy, etc.) can help structure the analysis. Therefore, in this scoping review, we aim to identify which innovative technologies are part of playful hand therapies and what are the playful elements used in these interventions. This information will provide researchers, designers, and practitioners with an overview of current therapies for children with CP that make use of innovative technologies

and play. Furthermore, we aim to provide starting points to design new therapies that are supported by innovative technology and play (which makes them suitable for other environments than just the rehabilitation centre) and that engage and motivate children.

2.1.3 Designing playful interactions

To analyse and determine if and which playful elements have been applied in technology-supported hand therapies for children with CP, we used The Lenses of Play (Bekker et al., 2014). The Lenses of Play is a design toolkit used to create playful interactions. For example, Almahmoud (Almahmoud & Arbor, n.d.) used the Lenses of Play to design a toy for autistic children. We have chosen to use it as our framework because it provides a multidimensional examination of play beyond traditional therapist-centred approaches, making a distinction between games and free play (Salah et al., 2014) and providing a diverse set of playful elements like control, and competition among others. Other frameworks or models used in therapy, such as Theraplay(Booth & Winstead, 201), or SCOPE-IT (Schott et al., 2013), refer more to the behaviour of children in connection with their caregivers and occupational performance. And although play is an essential element, these frameworks lack the focus on what makes an activity or object playful for the children. The Lenses of Play focus on the object, game, and user interaction. This framework will help us to understand better how playfulness is used and identify the necessary ingredients to design new playful experiences for therapy. In the future design of playful therapies, this can lead to a common and more specific language to be used by the different stakeholders involved in innovative, technology-supported therapies: clinicians, children, and their parents, as well as technology developers.

We will first briefly describe the technologies found through our review. Subsequently, identifying the playful elements used within therapies that use new technology will support more systematic reflection and understanding of the potential benefits of using these technologies.

2.2 METHODS

A scoping review aims to compile relevant literature and map critical concepts of a specific topic. For this scoping review, we used the five-stage framework proposed by Arksey and O'Malley (Arksey & O'Malley, 2005): 1) identifying the research questions, 2) identifying relevant studies, 3) study selection, 4) charting the data, and 5) collating, summarizing and reporting the results.

2.2.1 Identifying the research questions

In line with the main objectives of this scoping review, we want to answer the following research questions: Q1. Which innovative assistive technologies are used in hand therapies for children with CP? Q2. Which playful elements are embedded in the technology-supported therapy to motivate children with CP?

2.2.2 Identifying relevant studies

To identify relevant studies, we did comprehensive searches in the Scopus, Web of Science and CINAHL databases for medical and human-computer interaction studies published in English between January 2009 and December 2022. The last search was done on the 17th of January 2023. The keywords used were cerebral palsy OR cerebral paresis OR cerebral palsies; AND play* OR game OR gamification OR toy; AND child OR children; AND therapy OR rehabilitation OR treatment; AND hand OR upper limbs. The queries that were run on all the databases can be found in Appendix A.2.

2.2.3 Study selection

After removing duplicates, the titles and abstracts were analysed according to the inclusion and exclusion criteria set by two reviewers (AB and TVPC). The criteria of inclusion for the analysed articles were: (i) study subjects were children (0 to 18 years) with spastic CP; (ii) the therapy described was focused on hands or upper limbs motor skills; (iii) the therapy used innovative technology (i.e., electronic tools, systems, and devices); (iv) the therapy used playful elements such as (video) games

or toys; and (v) the publications consisted of peer-reviewed academic articles or conference proceedings that were published between 2009 and 2022. The criteria for exclusion included (i) insufficient information about the game or play activity or referred to traditional therapies without the support of technologies (e.g., bimanual, constrained-induced movement, pirate therapy) (ii) Lack of focus on the treatment used (iii) Written in a different language than English, (iv) unavailability to access the full text at the time of analysis (v) incomplete inclusion criteria. Disagreements between reviewers about exclusion criteria were resolved through discussion.

2.2.4 Charting the data

The data extracted from the selected studies included authors, date of publication, research question(s) or aim, sample size, frequency, time and duration of therapy, hand movement, intended environment (home/rehabilitation centre), the technology used, description of the system and playful elements according to the Lenses of Play.

2.2.5 Collating, summarizing, and reporting the results

The PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analysis extension for Scoping Reviews) guidelines (Tricco et al., 2018) were followed for reporting the results, the PRISMA-ScR checklist is included in the Appendix A.1 A. The protocol was registered with the Open Science Framework. The authors (TVPC, BK, BS, GL) met to determine categories of technologies, evaluate the playful elements of the Lenses of Play, and analyse the extracted data. To determine categories of technologies, we investigated their functionality and determined commonalities; for example, Kinect and Leap Motion are used to detect movement hence we created a Motion sensor category. To identify the playful elements used in the interventions, we analysed the information provided for each intervention through each of the lenses of play. To do so, we looked at the design principles, play mechanisms, and goals that were included in the interventions and described in the paper. In the case of commercially available games and technologies, we also investigated the information provided on the developers' websites (*LibertyTM*, n.d.)(*Mindwave - Brainwave Sensing Headset*, n.d.)(*5DT Data*

Glove Ultra, n.d.)(*Novint Falcon*, n.d.)(*Geomatic Touch*, n.d.)(*NEOFECT Smart Kids Home Version*, n.d.). For example, when analysing a study with the lens of play "Playful experiences", if the intervention described a game where the player had to grab a specific number of virtual butterflies and place them in a jar, the game will be categorised under the *completion* of a playful experience because the player must complete a task. The same was done with the other lenses by following the definitions of each element of the Lenses of Play.

2.3 RESULTS

The total number of studies found on Scopus was 166, while 126 were found on Web of Science (including Medline) and 58 on CINAHL, giving 350 studies, including duplicates. The first author (TP) removed duplicated studies, giving 239 studies. The first two authors (TP and AB) conducted the analysis of titles and abstracts based on the inclusion and exclusion criteria. It yielded a total of 66 studies that were full-text reviewed for data extraction by one of the authors (TP). Figure 2.2 depicts the number of studies identified at each process stage following the PRISMA flow diagram. Finally, the total amount of studies included was 54 (Table 2.1).

In recent years, there has been an increase in interest in developing and researching hand therapies that use innovative assistive technology and playful elements. Figure 2.1 shows the distribution of the selected papers in the period from 1999 to 2022.

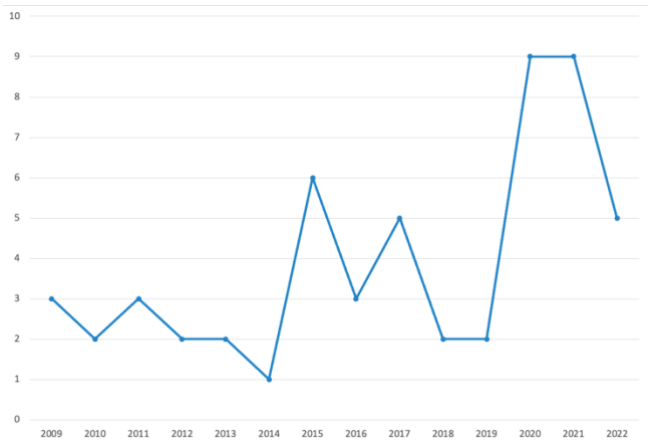

Figure 2.1: Publications per year

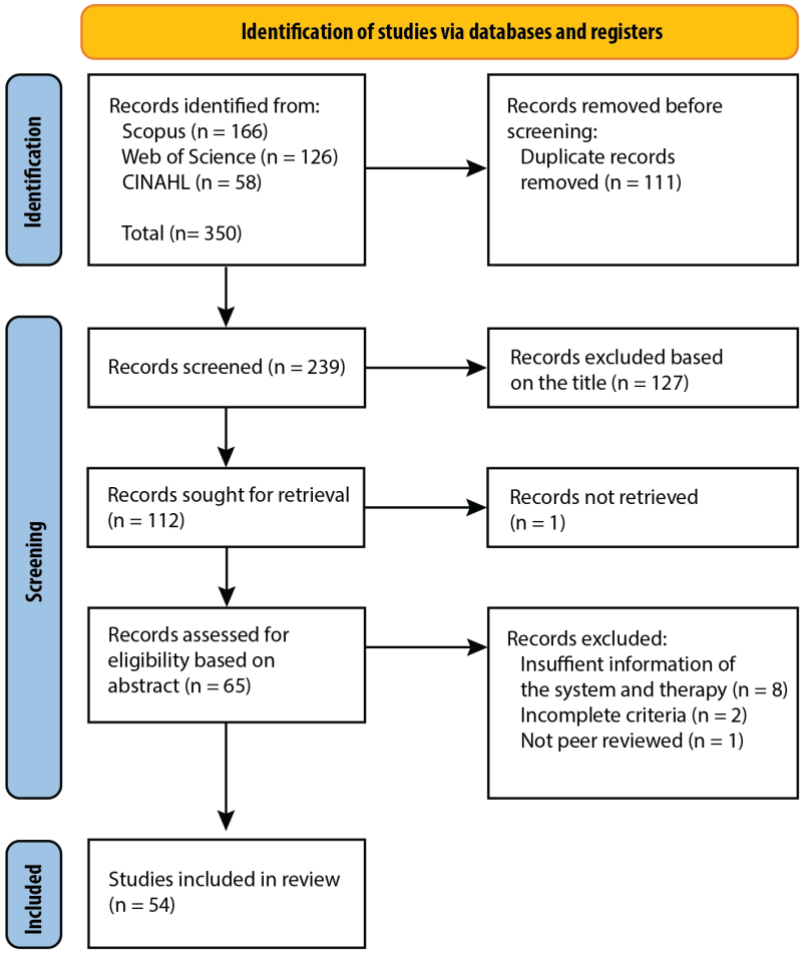

Figure 2.2 PRISMA flow diagram of search process

Table 2.1 Summary of analysed studies and assistive technology (Original purpose of the technology and Type of hardware)

Authors:	**Study:**		**Technology:**
	Goal	**Participants**	**Category, System**
Category 1: Therapeutic-specific technology			
(Bian et al., 2020)	To develop toy modules in combination with LEGO blocks to support hand and arm training.	5 children, aged 5-10, 1 with amentia, 4 with hemiplegia	*Category:* Smart Tangibles (Smart blocks) *System:* Path building with the smart blocks and LEGOs

Authors:	Study:		Technology:
	Goal	**Participants**	**Category, System**
(Guberek et al., 2009)	To evaluate the level of cooperation and satisfaction of children when practicing arm and hand movements during play-like activities in a physical environment.	Children aged 5-12.	*Category:* Motion Sensing (IREX) *System:* IREX system with the game Zebra Crossing, child attempts to touch as many stars as possible while advancing the crosswalk.
(Mandil et al., 2015)	To use tangible user interface in designing tabletop activities to help motivate children with motor disabilities to increase the number of exercises and improve the motor proficiency and quality of life.	4 children with CP, aged 6-14. 3 physiotherapists.	*Category:* Smart Tangibles (PhysiTable) *System:* PhysiTable with 3 different paths defined with leds. Music and color used for feedback. The player uses a cube to trace the path.
(van Delden et al., 2012)	To study the use of tangible interactive games for the repetitive training of upper limbs in the therapy of children with CP.	4 therapists; 16 children with CP, aged 2.5-8; 14 non-CP children aged 8-9	*Category:* Smart Tangibles (Smart Toys and TagTiles) *System:* The smart toys are used to manipulate the TagTiles.
(Wu et al., 2022)	To develop an Interactive Story Box to facilitate rehabilitation of speech, cognition, and motion.	4 children with CP, aged 4-8	*Category:* Smart Tangibles (Interactive Story Box) *System:* Raspberry PI, RFID readers, tangible objects to create an interactive box. Story maps are controlled with characters in shape of a puzzle.
Category 2: Consumer technology			
(Acar et al., 2016)	To investigate the efficiency of Nintendo® Wii games in addition to neurodevelopmental treatment in patients with CP.	30 Children with CP, 16 females, aged 6-15.	*Category:* Game consoles *System:* Nintendo Wii, with the virtual reality games (tennis, baseball, and boxing).

Authors:	Study:		Technology:
	Goal	Participants	Category, System
(Avcil et al., 2021)	To compare the effects of neurodevelopmental therapy and video game-based therapy for upper extremities.	30 children with CP, aged 6 to 15	*Category:* Game consoles (Nintendo Wii), Motion sensing (Leap Motion) *System:* Two video games to improve hand and grip functions. "CatchAPet" to touch rabbits with repetitive wrist flexion/extension movements and "Leapball" to grasp a virtual ball with all fingers and throw it by finger extension
(Chen et al., 2021)	To evaluate the feasibility of a Kinect-based constraint-induced therapy	10 children with CP in phase one and 8 children with CP in phase 2	*Category:* Motion Sensing (Kinect), Computers *System:* Video game where the child is a warrior defending their island. The Kinect detects the hand movements to throw cannonballs
(Chiu et al., 2014)	To investigate whether Wii Sports Resort™ training is effective and if any benefits are maintained.	62 hemiplegic children aged 6-13.	*Category:* Game consoles (Nintendo Wii) *System:* Nintendo Wii, with Wii Sports Resort games, from easiest to hardest: Bowling, Air Sports, Frisbee, and Basketball. 10 minutes per game.
(De Oliveira et al., 2016)	To develop a virtual reality game using Unity 3D to aid motor and cognitive rehabilitation in children with CP.	8 clinical experts.	*Category:* Computer (PC), Motion Sensing (Leap Motion), Wearables (Mind wave) *System:* 6 Phases of video game in a PC controlled by the Leap Motion. Mind wave used to keep track of player's attention.
(El-Shamy & El-Banna, 2020)	To investigate the effect of Wii training on hand function.	40 children with hemiplegic cerebral palsy, aged 8–12 years.	*Category:* Game consoles (Nintendo Wii) *System:* Playing 4 Wii games: tennis, boxing, bowling, and basketball
(Elsaeh et al., 2017)	To develop a high-level control in which the human brain is stimulated by the visual, audio, and tactile sensation to transmit instructions	2 children with hemiplegia aged 7 - females, 10 males.	*Category:* Computer (PC), Controller (Novint Falcon) *System:* 3 Video games on a PC using the Novint Falcon controller.

Authors:	Study:		Technology:
	Goal	Participants	Category, System
	to the affected upper limb's joints.		
(Garcia-Hernandez et al., 2021)	To examine how the subjective experience of seeing and controlling a half-body avatar, or an abstract hand representation in a virtual environment, for training upper limb movements may affect motor performance.	19 children aged 7-9.	*Category:* Computer, Motion Sensing (Kinect) *System:* A video game with body or hand representation where participants have to reach and grab a ball
(Gieser et al., 2015)	To recognise and classify static gestures from the Leap Motion by comparing classification techniques, decision trees, Support Vector Machines, and k-nearest neighbors. Create and evaluate a game to detect hand gestures.	Volunteers and experts.	*Category:* Computer (PC), Motion sensor (Leap Motion) *System:* Virtual game developed on Unity for PC and controlled via Leap Motion.
(Golomb et al., 2009)	To describe the learnings of providing home telerehabilitation to people with CP, and to suggest ways to address some of the barriers to home telerehabilitation in this population.	3 adolescents with CP.	*Category:* Console (Playstation 3), Controller (5DTD Ultra sensing glove. *System:* Custom games programmed in Java3D for PlayStation 3 and controlled with 5DT5 Ultra sensing glove.
(Golomb et al., 2010)	To investigate whether in-home remotely monitored virtual reality videogame-based telerehabilitation in adolescents with hemiplegic CP can	3 patients with severe right hemiplegic CP, aged 13-15.	*Category:* Console (Playstation 3), Controller (5DTD Ultra sensing glove. *System:* The 5DT5 Ultra sensing glove has 5 fiber optic sensors in each of the 5 fingers, it is connected to a PlayStation 3 with Linux and the games were

Authors:	Study:		Technology:
	Goal	Participants	Category, System
	improve hand function and forearm bone health and demonstrate alterations in motor circuitry activation.		programmed using open source Java3D API.
(Goyal et al., 2022)	To report the use of a VR gaming system and haptic feedback and its effectiveness.	1 child, aged 6	*Category:* Game consoles (Play Station) *System:* Driving simulation game with PlayStation 4.
(Gregory et al., 2012)	To enable play for children with CP that continuously entertains, which will allow extended play over long durations.		*Category:* Smart Tangibles (Pleo), Controller (Wii Nunchuk) *System:* A Wii Nunchuk is used to teach dance movements to Pleo.
(Hernández et al., 2018)	To test the usability of the gaming station with clinicians and children with CP and to establish the feasibility in a 12-week clinical trial.	6 therapists and 6 children with CP, aged 7- 16.	*Category:* Controller (Novint Falcon) *System:* Force feedback Novint Falcon game controller, custom grips, arm/wrist supports and software to be used with mainstream games.
(Hsieh et al., 2020)	To improve hand perfor- mance while playing with Chinese puppets modified with Lego robots.	42 children with CP	*Category:* Smart Tangibles (Lego Mindstorms NXT) *System:* Modified puppets with Lego, using servo motors, sensors and connecting cables
(Hung et al., 2018)	To study the feasibility and possible efficacy of a suite of motion-controlled games designed for upper extremity training in children with CP using Kinect2Scratch.	13 children with CP, mean age 6.9 years old.	*Category:* Computer (PC), Motion sensor (Kinect) *System:* 3 Video Games in a PC with screen with Kinect sensor. Scratch visual programming and Kinect2Scratch software.
(Kassee et al., 2017)	To compare a Nintendo Wii intervention to single-joint resistance training for the upper limb.	6 children with spastic hemiplegic cerebral palsy (CP) aged 7 to 12.	*Category:* Game Consoles (Nintendo Wii) *System:* Experimental group: Nintendo Wii controllers, and selected games. Control group: TheraBand, Elite band and

Authors:	Study:		Technology:
	Goal	Participants	Category, System
			squeeze ball with a list of exercises.
(Kottink et al., 2017)	To assess the feasibility, in terms of gaming experience, a mixed-reality system for rehabilitation of the arm and hand function.	5 children aged 7-12 with CP and 10 adults aged 30-70 with stroke or brain injury.	*Category:* Motion Sensing (Kinect), Computers (PC). *System:* HandsOn game: reaching, grasping, and releasing a physical object to control a PC video game using Kinect.
(Leal et al., 2020)	To verify if there was any performance improvement in a task performed in a virtual environment and if it is transferable to the real environment.	28 children with CP, aged 6-15	*Category:* Motion Sensing (Kinect), Computers, Smart Tangibles (Touchscreen) *System:* Check Limit Game, pop bubbles with the touchscreen or gestures.
(Li et al., 2009)	To assess if a low-cost, VR therapy home-based system can promote movements of the hemiplegic upper extremity that the child finds difficult.	5 children with CP aged 8.	*Category:* Motion Sensing (EyeToy), Game console (PlayStation2) *System:* Virtual reality therapy home-based system that consists of video games (Secret Agent, Mr. Chef) for PlayStation2 and controlled with EyeToy.
(MacIntosh et al., 2020)	To assess the feasibility of an intervention that combines a co-created gaming technology with biofeedback and coaching.	19 children, aged 8-18.	*Category;* Wearables (Myo Armband), Computers *System:* Dashy Square video game played with the use of electromyography and MYO armband.
(MacIntosh et al., 2022)	To describe the design and evaluation of a biofeedback virtual game.	9 children	*Category;* Wearables (Myo Armband), Computers *System:* Dashy Square video game played with the use of electromyography and MYO armband.
(Nai et al., 2019)	To analyse the use of Vive trackers to estimate forearm axial rotation for the purpose of supporting interaction with serious games.	8 healthy subjects aged 21 - 31.	*Category:* Motion Sensing (HTC Vive trackers), Computers (PC) *System:* HTC Vive trackers attached to a wrist bracer to control a serious game system on a PC. One tracker used around the palm and another around the centre of the forearm.

Authors:	Study:		Technology:
	Goal	Participants	Category, System
(Pruna et al., 2017)	Evaluate the use of a haptic device and VR games in upper limb rehabilitation in children.	5 children with mild spasticity, aged 7-12. 4 children with Down syndrome and difficulty of movement in upper limbs, aged 9-12.	*Category:* Controller (Geomagic Touch), VR headsets (Oculus Rift). *System:* Two interactive virtual environment games (watering plants and order objects). The haptic device (GeomagicTouch) acquires the movement generated by the user and an Oculus Rift provides immersion in the use of the system.
(Stansfield et al., 2015)	To further investigate whether improved measures of motor performance will be seen with the use of motion-based VR gameplay.	1 10-year-old boy.	*Category:* Computers (PC), Wearables (Polhemus Liberty). *System:* PC with the Polhemus Liberty tracking sensor, a screen and memory game played alone, in cooperation or competition.
(Tarakci et al., 2020)	To study the potential efficacy of an 8-week program with the Leap motion controller-based training as a therapeutic method for upper extremity rehabilitation in comparison with conventional rehabilitation programs in children with CP, Juvenile idiopathic arthritis (JIA) and brachial plexus birth injury (BPBI).	Group I (CP n=15, JIA n= 18, BPBI n=9). Group II (CP n=15, JIA n=25, BPBI n=10) Aged 5-17.	*Category:* Motion Sensing (Leap Motion), Computers (PC). *System:* 2 rehabilitative video games on PC using Leap Motion: Fizyosoft CatchAPet and Fizyosoft Leapball.
(Winkels et al., 2013)	To explore the effect of the Nintendo Wii training on upper extremity function in children with CP.	15 children with CP.	*Category:* Game consoles (Nintendo Wii). *System:* Children played the boxing and tennis games provided in the Nintendo Wii Sports video game console.
(Yildirim et al., 2021)	To investigate the effect of Leap Motion Based Exergame Therapy.	20 children with CP, aged 8-15.	*Category:* Motion Sensing (Leap Motion), Computers *System:* Two video games controlled with a Leap Motion.

Authors:	Study:		Technology:
	Goal	Participants	Category, System
			Leap Ball: grab a ball and throw it into a box of matching color. Catch a Pet: touch the moles in a certain order.
(Zoccolillo et al., 2015)	To investigate the effectiveness of video game therapy with respect to conventional therapy in improving upper limb motor outcomes.	22 children with CP, aged 4 -14 years. GMFC between I and IV.	*Category:* Game consoles (Xbox), Motion Sensing (Kinect). *System:* videogame of the console X-box using the Kinect device for motion capture. Six games available: "Space pops", "20.000 Leaks", "Rally Ball", Boxing, Volley, and bowling.
Category 3: Therapeutic and consumer technology			
(Amonkar et al., 2022)	To evaluate the feasibility of implementation, acceptance, and perceived efficacy of a joystick-operated ride-on-toy intervention to promote upper extremity function.	11 children with CP, aged 3-14, 11 caregivers and 6 clinicians.	*Category:* Joystick ride-on-toy *System:* Children rode the ride-on-toy (car) navigating with the spastic hand and performing task throught out the path (collecting objects, throwing balls, avoiding obstacles).
(Bortone et al., 2020)	To determine the efficacy of immersive Virtual Environments and wearable haptic devices.	8 children with CP or developmental dyspraxia.	*Category:* Wearable (Haptic device for the fingertip), VR headsets (Oculus Rift VK2) *System:* Collecting coins in a VR environment and placing them in a moving piggy bank. Slide a token out of a virtual labyrinth with the finger. Difficulty changes with time.
(Choi et al., 2021)	To investigate the efficacy of a virtual reality rehabilitation system of wearable multi-inertial sensors for upper limb.	80 children, aged 3-16 with brain injury including CP.	*Category:* Wearable (Neofect Smart Kids), Computers *System:* Games with activities of daily living promoting wrist and forearm articular movements using wearable inertial sensors.

Authors:	Study:		Technology:
	Goal	Participants	Category, System
(Cifuentes-Zapien et al., 2011)	To study if a video game can be used as an interface for a robot for the rehabilitation of the pronation and supination movements of children with CP.	One healthy 11-year-old right-handed child.	*Category:* Computers (PC), Robotics (Robotic Arm). *System:* A PC video game developed for an upper limb rehabilitation robot for children with CP. The video game simulates a formula one race car on a racetrack. The car's horizontal position is controlled by the pronation and supination motions.
(Crisco, Schwartz, Wilcox, Brideau, et al., 2015)	Evaluate play activity recorded by the controller for two toys and three computer games.	20 children aged 5-11.	*Category:* Controller (Arm and elbow remote), Smart Tangibles (smart toy: car and dog), Computers (PC).
			System: A specially designed arm and elbow remote controller was used to interface wirelessly with two smart toys.
			System: A specially designed arm and elbow remote controller was used to interface wirelessly with three video games.
(Crisco, Schwartz, Wilcox, Costa, et al., 2015)	To develop and evaluate the measurement accuracy of innovative, motion-specific play controllers that are engaging rehabilitative devices for enhancing therapy and promoting neural plasticity and functional recovery in children with CP.	6 typically developed children (3m,3f 5-11 years).	*Category:* Controller (Arm and elbow remote), Smart Tangibles (smart toy: car) *System:* The play Arm and elbow remote controller was designed with a conformable, ergonomic handle to accommodate varying levels of contractures among children with CP and control a car.
(Dunne et al., 2010)	To describe the hardware platform, present the design objectives derived from iterative design phases and meetings with clinical personnel, discuss the current game designs and	Expert clinicians on CP.	*Category:* Wearables (Accelerometer), Smart Tangibles (Multitouch display, Tangible objects). *System:* 3 games played (Find the bone, Spelling, Catch the butterflies) the tangible objects control the game in a multitouch display. An accelerometer

Authors:	Study:		Technology:
	Goal	Participants	Category, System
	identify areas of future work.		measures body changes and modifies the game e.g., butterflies fly off jar.
(Fu et al., 2020)	To determine if children could tolerate 9 lab treatment sessions and administer up to 7.5 hrs/wk of CCFES video game therapy at home	3 children aged 8-11 with hand hemiplegia.	*Category:* Computer, Wearables (Arm sensors, Electrical stimulation electrodes) *System:* 4 video games (Paddle Ball, Sound Tracker, Skee Ball and Marble Maze).
(Hernandez et al., 2021)	To explore the effectiveness of interactive computer play with haptic feedback.	13 children with CP, 7–16 years	*Category:* Controllers (Novint Falcon, Custom levers), Computers *System:* 4 commercial video games to train wrist movement: Crazy Rider, Swooop, Funky Karts, and Lil Mads and the Gold Skull. 5 video games to train elbow and shoulder movement: Looney Tunes Dash, Heroes of Loot, Bird Brawl, Pac-Man and Save the Day
(Minh et al., 2021)	To test a design of two interactive toys and an open game.	4 children with CP, aged 2-3.	*Category:* Computers, Smart Tangibles (Smart toys) *System:* A stuffed stick toy with a 6-DOF inertial measurement unit (IMU) and a force sensor-incorporated gloves to squeeze a ball used to play "Catch the worms in the garden"
(Mirich et al., 2021)	To assess the efficacy of VR rehabilitation.	1 child, aged 4	*Category:* Wearables (Neofect Smart Kids), Computers *System:* Functional activity game with different activities like turn pages, painting, wiping a table, playing ping pong selected based on the needs of the patient.
(Mittag et al., 2020)	To present the design and implementation of a tangible device for hand training.		*Category:* Wearables (Arm sensors), Computers *System:* A video game controlled by the sensors and interactions with the tangible controller.

Authors:	Study:		Technology:
	Goal	Participants	Category, System
(Parmar et al., 2021)	To improve rehabilitation programs for children and adults with neurodevelopmental disorders ia game-based telerehabilitation.	6 children with CP, 10 adults recovering from a stroke.	*Category:* Wearables (Motion therapy mouse), Computers *System:* The motion mouse is attached to different objects like a ball, to control movement in a commercial video game (Big Fish Game).
(Peper et al., 2013)	To examine the potential effects of the training on bimanual coordination and identify if the training had beneficial effects on the affected arm's performance.	6 children with CP aged 7-12	*Category:* Controller (Custom levers), Computers (Laptop) *System:* Two horizontal levers, a laptop computer, and an additional monitor. Left-hand movements produce vertical displacements, and right-hand movements horizontal displacements.
(Preston et al., 2016)	To study the feasibility of using computer-assisted arm rehabilitation computer games in schools, their preference for single player or dual player mode, and changes in arm activity and kinematics.	9 boys and 2 girls with CP aged 6–12, mean 9 years	*Category:* Robotics (Robotic Arm), Computers (PC) *System:* An assistive robotic arm, connected to a computer with co-operative and competitive games.
(Psychouli et al., 2017)	To propose a system that can enhance children's motivation during the implementation of a CIMT session and that could explore differences in compliance rates, motivation levels and intervention feasibility.	Non-CP children, and 3 groups of CP children (CIMT, RT, CIMT+RT), aged 5-11.	*Category:* Wearables (Arm Sensors), Smart Tangibles (Smart Toys). *System:* Arm and hand with sensors (accelerometer, magnetometer, gyroscope for upper and lower arm, flexsensors on the wrist and fingers) that control the 4-wheeled robotic vehicle (DFRobot Cherokee).
(Sabry et al., 2020)	To develop a low-cost virtual reality rehabilitation system with a data glove and virtual games.	8 children with CP, aged 5 to 12.	*Category:* Wearables (Data glove), Computers *System:* Data glove is used to play video games: "Grasp the ball".

Authors:	Study:		Technology:
	Goal	Participants	Category, System
(Stroppini et al., 2022)	To determine the feasibility and efficacy of the MusicGlove to motivate hand function.	3 children with hemiparetic CP, aged 6-17	*Category:* Wearables (MusicGlove), Computers *System:* A video game is controlled with the glove. The patients tap their fingers to make musical notes according to the notes that show up on the screen.
(Van Loon et al., 2011)	To test a set of video games, developed to loosen the coupling between the hands of children with CP.	7 children with spastic unilateral CP aged 7-12	*Category:* Controller (Custom levers), Computer (PC) *System:* Three computer games that challenged the participants to move their hands according to six different bimanual coordination patterns executed with custom levers.
(Weightman et al., 2011)	To compare upper limb kinematics of children with CP using a passive rehabilitation joystick with adults and able-bodied children to better understand the design requirements of computer-based rehabilitation devices.	9 adults (aged 23–30), 9 children (aged 7–9) and 7 children with CP (aged 5.5–7)	*Category:* Controller (Joystick), Computers (PC) *System:* A computer game in which the child controlled a ‘‘spaceship’’ collecting ‘‘satellites’ with the use of a joystick.

2.3.1 Innovative Assistive Technology

The authors identified two ways to classify the innovative assistive technologies used in the analysed studies: Original purpose of the technology and type of hardware.

Original purpose of the technology

This first type of classification refers to therapeutic-specific technology, consumer technology, and the combination of therapeutic and consumer technology, Table 2.1 shows the details of the studies per category. Therapeutic-specific technology has been developed for the sole purpose of being used in hand therapy and it was used in 5 studies. An example of this type of technology is the IREX, which is a video gesture control technology that allows patients to be immersed in a video game

where users can exercise by interacting with the elements of the game (Guberek et al., 2009). Consumer technology is commercially available technology used in entertainment or other fields, but that has been modified to be used in hand therapy, consumer technology was used in 29 studies. The authors of the included studies identified this type of technology as potentially beneficial and motivating due to their existing functionalities, interactions, familiarity, and lower costs (Tarakci et al., 2020). For example, Acar et al., (Acar et al., 2016) investigated the efficiency of Nintendo Wii games together with neurodevelopmental treatment in patients with CP. They analysed 'out of the box' games like tennis, baseball, and boxing, focusing on the upper extremities. Besides the observed improvements in speed and functional independence, children perceived the use of the Nintendo Wii as a reward. The rest of the studies (20 in total) made use of a combination of Therapeutic-specific technology and Consumer technology; an example is presented in the studies by Golomb et al., (Golomb et al., 2009, 2010), where custom games were developed to be used with the PlayStation 3 console (Consumer technology) in combination with the 5DT Ultra sensing glove (Therapeutic specific technology). The games encouraged hand movements such as opening and closing or thumb extension; speed was also trained by challenging the player to chase a butterfly by flexing or extending the fingers rapidly.

Types of hardware

This second type of classification refers to a more general category of hardware or technologies, such as VR headsets, game consoles, wearables, motion-sensing, controllers, smart tangibles, and robotics (Table 2.2). When analysing the types of hardware, it was found that the most common technologies used were computers (n=32), as they were often used to deploy a video game and to connect with other types of technology. Wearables were one of the most used technologies (n=19), wearables are continuously in close contact with the body to capture the movement of the hand or arm while they can provide direct haptic feedback. Some of these technologies include gloves like the 5DT Ultra sensing gloves, the Neofect Smart Kids, the Data glove, and the Music glove. Smart tangibles were used in 15 of the studies, they include smart toys such as the TagTile, a device similar to an electronic board game (van Delden et al., 2012), and the dancing dinosaur Pleo!Dance! (Gregory et al., 2012). Motion-sensing technology were also frequently used (n=14); a device that belongs to this category is the Kinect, which was used in the studies by Hung et al., (2018), Kottink et al., (2017) and Zoccolillo et al., (2015) because of its capabilities to capture the upper extremities and movements of the

users from a distance. Another widely used type of hardware was controllers (n=11), for example, the Novint Falcon, a haptic device that acts as a controller like a computer mouse but with a shape that allows for higher degrees of freedom. This device, which allows for resistive force feedback on the spastic hand, was used by Elsaeh et al., (Elsaeh et al., 2017) and Hernández et al., (Hernandez et al., 2021; Hernández et al., 2018), where limitations of movements and direction are adapted to the interactions needed in the virtual games used and the possibilities of the spastic hand. Some studies focused on using one type of innovative assistive technology. In contrast, most studies (n=43) used a combination of one or more types, such as PCs with robotic arms (Cifuentes-Zapien et al., 2011), smart toys with an arm and elbow remote controller and a PC (Crisco, Schwartz, Wilcox, Brideau, et al., 2015), wearables and smart tangibles (Dunne et al., 2010) and, custom levers with a PC (Van Loon et al., 2011) to name a few. The complete list of studies that use a combination of different types of hardware is included in Appendix A.4.

Table 2.2 Technology classification based on Type of hardware – the complete list of papers is available in Appendix A.3

Type of hardware	***Name***	***Amount***
Computers	PC	n=26
n=32	Laptop	n=4
	Tablet	n=2
Controllers	Custom levers	n=3
n=11	Geomagic Touch	n=1
	Joystick	n=2
	Motion Therapy mouse	n=1
	Novint Falcon	n=3
	Wii Nunchuk	n=1
Game consoles	Nintendo Wii	n=6
n=11	Play Station	n=4
	XBox	n=1
Motion Sensing	EyeToy	n=1
n=14	HTC Vive trackers	n=1
	IREX	n=1
	Kinect	n=6
	Leap Motion	n=5
Robotics	Robotic Arm	n=2
n=2		
Smart Tangibles	Interactive Story box	n=1
n=15	Lego Mindstorms NXT	n=1
	Multitouch display	n=2
	Pleo!	n=1

	PhysiTable	n=1
	Ride-on-toy	n=1
	Smart blocks	n=1
	Smart toys	n=5
	TagTiles	n=1
	Tangible objects	n=1
VR headsets n=2	Oculus Rift	n=2
Wearables n=19	5DT sensing gloves	n=2
	Accelerometer	n=1
	Arm and elbow remote	n=2
	Arm sensors	n=4
	Electrical stimulation electrodes	n=1
	Data glove	n=1
	Mindwave	n=1
	Music glove	n=1
	Myo armband	n=2
	Neofect Smart Kids	n=2
	Polhemus Liberty	n=1

2.3.2 Lenses of Play

Bekker et al., (Bekker et al., 2014) defined the Lenses of Play as a toolkit that includes different perspectives on play that can inform design decisions throughout the design process. Initially, four lenses were defined: Open-ended play, Forms of Play, Stages of playful interactions, and Playful experiences. In a later publication, [77] (Bekker et al., 2015) introduced a fifth lens: Emergence, which relates to the system's perspective and how it can provide meaningful interactions. This analysis focuses on the lenses: Open-ended play, Forms of Play, and Playful experiences (Figure 2.3), the lenses Stages of playful interactions and Emergence have been omitted because little information was provided about these aspects of play in the studies included in this review. It was possible to identify the playful elements used in the proposed interventions for the other lenses (Table 2.3).

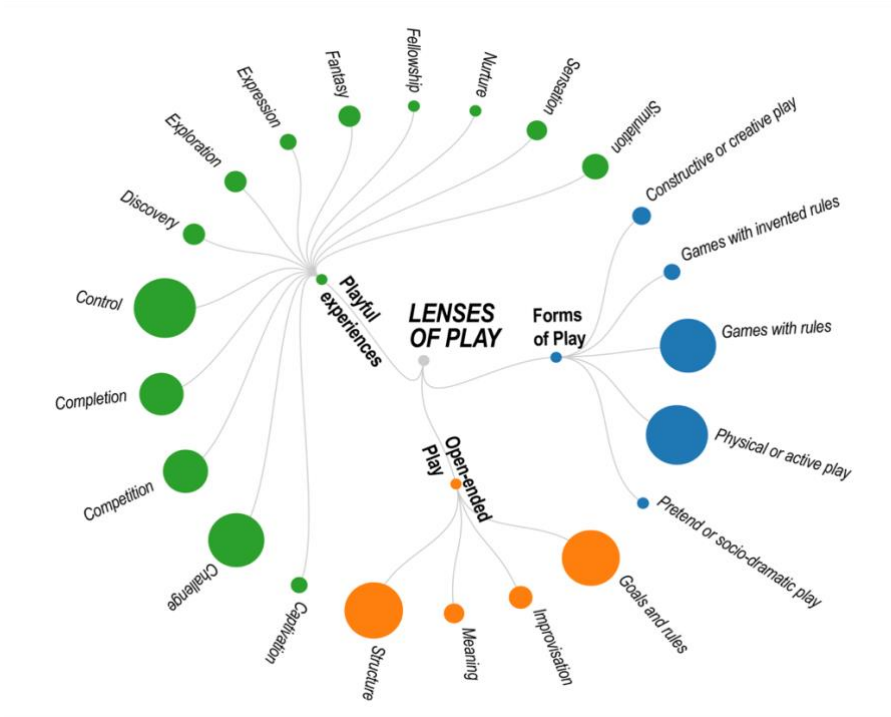

Figure 2.3 Lenses of Play, the size of the circles, represents the frequency of use of the play element in the publications.

Table 2.3 Summary of analysed studies by lenses of play

		Categories		
Lens	**Play element**	**Therapeutic specific technology**	**Consumer Technology**	**Therapeutic and consumer technology**
Open-ended Play	**Improvisation**	(Bian et al., 2020)	(Gregory et al., 2012; Hsieh et al., 2020)	(Amonkar et al., 2022; Crisco, Schwartz, Wilcox, Brideau, et al., 2015; Crisco, Schwartz, Wilcox, Costa, et al., 2015; Mirich et al., 2021; Psychouli et al., 2017)
	Structure	(Guberek et al., 2009; Mandil et al., 2015; van Delden et al., 2012; Wu et al., 2022)	(Acar et al., 2016; Avcil et al., 2021; Chen et al., 2021; Chiu et al., 2014; De Oliveira et al., 2016; Elsaeh et al., 2017; El-	(Amonkar et al., 2022; Bortone et al., 2020; Choi et al., 2021; Cifuentes-Zapien et al., 2011; Crisco, Schwartz,

		Categories		
Lens	**Play element**	**Therapeutic specific technology**	**Consumer Technology**	**Therapeutic and consumer technology**
			Shamy & El-Banna, 2020; Garcia-Hernandez et al., 2021; Gieser et al., 2015; Golomb et al., 2009, 2010; Goyal et al., 2022; Hernández et al., 2018; Hung et al., 2018; Kassee et al., 2017; Kottink et al., 2017; Leal et al., 2020; Li et al., 2009; MacIntosh et al., 2020, 2022; Nai et al., 2019; Pruna et al., 2017; Stansfield et al., 2015; Tarakci et al., 2020; Winkels et al., 2013; Yildirim et al., 2021; Zoccolillo et al., 2015)	Wilcox, Brideau, et al., 2015; Dunne et al., 2010; Fu et al., 2020; Hernandez et al., 2021; Minh et al., 2021; Mirich et al., 2021; Mittag et al., 2020; Parmar et al., 2021; Peper et al., 2013; Preston et al., 2016; Sabry et al., 2020; Stroppini et al., 2022; Van Loon et al., 2011; Weightman et al., 2011)
	Goals and rules	(Guberek et al., 2009; Mandil et al., 2015; van Delden et al., 2012) (Wu et al., 2022)	(Acar et al., 2016; Avcil et al., 2021; Chen et al., 2021; Chiu et al., 2014; De Oliveira et al., 2016; Elsaeh et al., 2017; El-Shamy & El-Banna, 2020; Garcia-Hernandez et al., 2021; Gieser et al., 2015; Golomb et al., 2009, 2010; Goyal et al., 2022; Hernández et al., 2018; Hung et al., 2018; Kassee et al., 2017; Kottink et al., 2017; Leal et al., 2020; Li et al., 2009; MacIntosh et al., 2020, 2022; Nai et al., 2019; Pruna et al., 2017; Stansfield et al., 2015; Tarakci et al., 2020; Winkels et al., 2013; Yildirim et al., 2021; Zoccolillo et al., 2015)	(Amonkar et al., 2022; Bortone et al., 2020; Cifuentes-Zapien et al., 2011; Crisco, Schwartz, Wilcox, Brideau, et al., 2015; Crisco, Schwartz, Wilcox, Costa, et al., 2015; Dunne et al., 2010; Fu et al., 2020; Hernandez et al., 2021; Mirich et al., 2021; Mittag et al., 2020; Parmar et al., 2021; Peper et al., 2013; Preston et al., 2016; Sabry et al., 2020; Stroppini et al., 2022; Van Loon et al., 2011; Weightman et al., 2011)

		Categories		
Lens	**Play element**	**Therapeutic specific technology**	**Consumer Technology**	**Therapeutic and consumer technology**
	Meaning	(Bian et al., 2020)	(Gregory et al., 2012; Hsieh et al., 2020; Pruna et al., 2017)	(Crisco, Schwartz, Wilcox, Brideau, et al., 2015; Psychouli et al., 2017)
Forms of Play	**Constructive or creative play**	(Bian et al., 2020; Wu et al., 2022)	(Gregory et al., 2012; Hsieh et al., 2020)	(Stroppini et al., 2022)
	Pretend or socio-dramatic play		(Gregory et al., 2012; Hsieh et al., 2020)	
	Physical or active play	(Bian et al., 2020; Guberek et al., 2009; Mandil et al., 2015; van Delden et al., 2012; Wu et al., 2022)	(Acar et al., 2016; Avcil et al., 2021; Chen et al., 2021; Chiu et al., 2014; De Oliveira et al., 2016; Elsaeh et al., 2017; El-Shamy & El-Banna, 2020; Garcia-Hernandez et al., 2021; Gieser et al., 2015; Golomb et al., 2009, 2010; Goyal et al., 2022; Gregory et al., 2012; Hernández et al., 2018; Hsieh et al., 2020; Hung et al., 2018; Kassee et al., 2017; Kottink et al., 2017; Leal et al., 2020; Li et al., 2009; MacIntosh et al., 2020, 2022; Nai et al., 2019; Pruna et al., 2017; Stansfield et al., 2015; Tarakci et al., 2020; Winkels et al., 2013; Yildirim et al., 2021; Zoccolillo et al., 2015)	(Amonkar et al., 2022; Bortone et al., 2020; Choi et al., 2021; Cifuentes-Zapien et al., 2011; Crisco, Schwartz, Wilcox, Brideau, et al., 2015; Crisco, Schwartz, Wilcox, Costa, et al., 2015; Dunne et al., 2010; Fu et al., 2020; Hernandez et al., 2021; Minh et al., 2021; Mirich et al., 2021; Mittag et al., 2020; Parmar et al., 2021; Peper et al., 2013; Preston et al., 2016; Psychouli et al., 2017; Sabry et al., 2020; Stroppini et al., 2022; Van Loon et al., 2011; Weightman et al., 2011)
	Games with rules	(Guberek et al., 2009; Mandil et al., 2015; van Delden et al., 2012)	(Acar et al., 2016; Avcil et al., 2021; Chen et al., 2021; Chiu et al., 2014; De Oliveira et al., 2016; Elsaeh et al., 2017; El-	(Amonkar et al., 2022; Bortone et al., 2020; Choi et al., 2021; Cifuentes-Zapien et al., 2011; Crisco, Schwartz,

		Categories		
Lens	**Play element**	**Therapeutic specific technology**	**Consumer Technology**	**Therapeutic and consumer technology**
			Shamy & El-Banna, 2020; Garcia-Hernandez et al., 2021; Gieser et al., 2015; Golomb et al., 2009, 2010; Goyal et al., 2022; Hernández et al., 2018; Hung et al., 2018; Kassee et al., 2017; Kottink et al., 2017; Leal et al., 2020; Li et al., 2009; MacIntosh et al., 2020, 2022; Nai et al., 2019; Pruna et al., 2017; Tarakci et al., 2020; Winkels et al., 2013; Yildirim et al., 2021; Zoccolillo et al., 2015)	Wilcox, Brideau, et al., 2015; Dunne et al., 2010; Fu et al., 2020; Hernandez et al., 2021; Mittag et al., 2020; Parmar et al., 2021; Peper et al., 2013; Preston et al., 2016; Sabry et al., 2020; Stroppini et al., 2022; Van Loon et al., 2011; Weightman et al., 2011)
	Games with invented rules		[28]	(Crisco, Schwartz, Wilcox, Brideau, et al., 2015; Crisco, Schwartz, Wilcox, Costa, et al., 2015; Psychouli et al., 2017)
Playful experiences	**Captivation**	(Wu et al., 2022)	(Gregory et al., 2012; Hsieh et al., 2020)(Pruna et al., 2017)	
	Challenge	(Guberek et al., 2009; Mandil et al., 2015; van Delden et al., 2012)	(Acar et al., 2016; Avcil et al., 2021; Chen et al., 2021; Chiu et al., 2014; De Oliveira et al., 2016; Elsaeh et al., 2017; El-Shamy & El-Banna, 2020; Garcia-Hernandez et al., 2021; Gieser et al., 2015; Golomb et al., 2009, 2010; Hernández et al., 2018; Hung et al., 2018; Kassee et al., 2017; Kottink et al., 2017; Leal et al., 2020; Li et al., 2009; MacIntosh et al., 2020, 2022; Nai et al.,	(Amonkar et al., 2022; Bortone et al., 2020; Choi et al., 2021; Cifuentes-Zapien et al., 2011; Crisco, Schwartz, Wilcox, Brideau, et al., 2015; Dunne et al., 2010; Fu et al., 2020; Mirich et al., 2021; Mittag et al., 2020; Parmar et al., 2021; Peper et al., 2013; Preston et al., 2016; Psychouli et al., 2017; Sabry et al., 2020; Stroppini et al., 2022;

		Categories		
Lens	**Play element**	**Therapeutic specific technology**	**Consumer Technology**	**Therapeutic and consumer technology**
			2019; Pruna et al., 2017; Stansfield et al., 2015; Tarakci et al., 2020; Winkels et al., 2013; Yildirim et al., 2021; Zoccolillo et al., 2015)	Van Loon et al., 2011; Weightman et al., 2011)
	Competition	(Bian et al., 2020; Guberek et al., 2009; Mandil et al., 2015; van Delden et al., 2012)	(Acar et al., 2016; Avcil et al., 2021; Chen et al., 2021; Chiu et al., 2014; De Oliveira et al., 2016; El-Shamy & El-Banna, 2020; Goyal et al., 2022; Hernández et al., 2018; Hung et al., 2018; Kassee et al., 2017; Leal et al., 2020; Li et al., 2009; Nai et al., 2019; Stansfield et al., 2015; Winkels et al., 2013; Yildirim et al., 2021; Zoccolillo et al., 2015)	(Bortone et al., 2020; Crisco, Schwartz, Wilcox, Brideau, et al., 2015; Dunne et al., 2010; Fu et al., 2020; Hernandez et al., 2021; Mirich et al., 2021; Mittag et al., 2020; Parmar et al., 2021; Peper et al., 2013; Preston et al., 2016; Stroppini et al., 2022)
	Completion	(Mandil et al., 2015; van Delden et al., 2012; Wu et al., 2022)	(Avcil et al., 2021; Chen et al., 2021; Elsaeh et al., 2017; Garcia-Hernandez et al., 2021; Gieser et al., 2015; Goyal et al., 2022; Leal et al., 2020; MacIntosh et al., 2020, 2022; Nai et al., 2019; Pruna et al., 2017; Stansfield et al., 2015; Yildirim et al., 2021)	(Amonkar et al., 2022; Bortone et al., 2020; Choi et al., 2021; Fu et al., 2020; Hernandez et al., 2021; Minh et al., 2021; Mirich et al., 2021; Parmar et al., 2021; Preston et al., 2016; Stroppini et al., 2022; Van Loon et al., 2011; Weightman et al., 2011)
	Control	(Bian et al., 2020; Guberek et al., 2009; Mandil et al., 2015; van Delden et al., 2012; Wu et al., 2022)	(Acar et al., 2016; Avcil et al., 2021; Chen et al., 2021; Chiu et al., 2014; De Oliveira et al., 2016; Elsaeh et al., 2017; El-Shamy & El-Banna, 2020; Garcia-Hernandez et al., 2021; Gieser et al., 2015; Golomb et al., 2009, 2010; Goyal et al., 2022;	(Amonkar et al., 2022; Bortone et al., 2020; Choi et al., 2021; Cifuentes-Zapien et al., 2011; Crisco, Schwartz, Wilcox, Brideau, et al., 2015; Crisco, Schwartz, Wilcox, Costa, et al., 2015; Dunne et al., 2010; Fu et al., 2020;

		Categories		
Lens	**Play element**	**Therapeutic specific technology**	**Consumer Technology**	**Therapeutic and consumer technology**
			Gregory et al., 2012; Hernández et al., 2018; Hsieh et al., 2020; Hung et al., 2018; Kassee et al., 2017; Kottink et al., 2017; Leal et al., 2020; Li et al., 2009; MacIntosh et al., 2020, 2022; Nai et al., 2019; Pruna et al., 2017; Stansfield et al., 2015; Tarakci et al., 2020; Winkels et al., 2013; Yildirim et al., 2021; Zoccolillo et al., 2015)	Hernandez et al., 2021; Minh et al., 2021; Mirich et al., 2021; Mittag et al., 2020; Parmar et al., 2021; Peper et al., 2013; Preston et al., 2016; Psychouli et al., 2017; Sabry et al., 2020; Stroppini et al., 2022; Van Loon et al., 2011; Weightman et al., 2011)
	Discovery	(Bian et al., 2020; Wu et al., 2022)	(De Oliveira et al., 2016; Hsieh et al., 2020)	(Crisco, Schwartz, Wilcox, Brideau, et al., 2015; Crisco, Schwartz, Wilcox, Costa, et al., 2015; Psychouli et al., 2017)
	Exploration	(Bian et al., 2020; Mandil et al., 2015)	(De Oliveira et al., 2016; Gregory et al., 2012; Hsieh et al., 2020; Kottink et al., 2017)	(Crisco, Schwartz, Wilcox, Brideau, et al., 2015)
	Expression	(Bian et al., 2020)	(Gregory et al., 2012; Hsieh et al., 2020)	(Psychouli et al., 2017)
	Fantasy	(Wu et al., 2022)	(Gregory et al., 2012; Hernández et al., 2018; Hsieh et al., 2020; Hung et al., 2018)	(Peper et al., 2013; Weightman et al., 2011)
	Fellowship		(Stansfield et al., 2015)	(Preston et al., 2016)
	Nurture		(Gregory et al., 2012)	(Peper et al., 2013)
	Sensation		(Elsaeh et al., 2017; Hernández et al., 2018)	(Bortone et al., 2020; Choi et al., 2021; Psychouli et al., 2017; Stroppini et al., 2022)
	Simulation		(Elsaeh et al., 2017; Goyal et al., 2022; Hernández et al., 2018; Hung et al., 2018;	(Cifuentes-Zapien et al., 2011; Dunne et al., 2010; Stroppini et al., 2022)

		Categories		
Lens	**Play element**	**Therapeutic specific technology**	**Consumer Technology**	**Therapeutic and consumer technology**
			Kassee et al., 2017; Li et al., 2009; Zoccolillo et al., 2015)	

Lens 1: Open-ended play

According to Bekker et al., (Bekker et al., 2014), "Open-ended play can be positioned somewhere between paidia and ludus". In paidia or free play, there is no end goal; it's chaotic, there is space for improvisation and spontaneity, allowing for expression, meaning, and playing for its sensation. At the same time, ludus refers to games with fixed rules, structure, end goals, and challenge or competition. The open-ended play lens refers to the four properties that characterize paidia and ludus: improvisation, structure, goals and rules, and meaning, as defined by de Valk et al., (de Valk et al., 2013). Players can create their own game during *improvisation* without preparation, while *structure* leaves little room for chaos or spontaneity in a game. If *goals and rules* have been defined, the game will have a finite status with a fixed process. Finally, players can add *meaning* to the interaction possibilities that the designers have established.

As shown in Table 2.3, most interventions presented in the articles have characteristics that refer to ludus, a structured form of play (n=49) with defined goals and rules (n=48). In contrast, elements that refer to paidia, such as improvisation (n=8) and meaning (n=6), were found in fewer studies. For example, Dunne et al. (Dunne et al., 2010) used three video games, Find the bone, Spelling, and Catch the butterflies, on a multitouch screen where tangible objects are used to play the games. An accelerometer measures body changes that indicate changes in inclination and use of compensatory movements. Changes in body posture modify the game, e.g., butterflies fly off the jar. The three games have a clear structure and set of rules (ludus) that the player must comply with to reach a goal, like catching all the butterflies inside a jar.

On the other hand, Crisco et al., (Crisco, Schwartz, Wilcox, Brideau, et al., 2015) propose a system where a robotic car and a robotic dog are controlled with a play controller. Children can play with the toys by performing different wrist motions in this system. There is no set of rules (paidia) besides the type of movements the

controller allows. The interaction with the toys is not fixed and can rapidly change according to the children's interests (improvisation and meaning).

Lens 2: Forms of Play

This lens refers to children's development of skills via different forms of play. There are four primary forms of play according to (Bekker et al., 2014); a description can be found in Table 2.4. All the analysed papers refer to an intervention with a physical or active form of play, as they all aim to provide physical therapy for the players. Most interventions also presented games with rules (n=45); the only interventions that did not have games with rules were those that had more of an open-play approach assisted with a toy for example (Bian et al., 2020; Crisco, Schwartz, Wilcox, Brideau, et al., 2015; Crisco, Schwartz, Wilcox, Costa, et al., 2015; Gregory et al., 2012; Wu et al., 2022). The intervention proposed by Gregory et al., (Gregory et al., 2012) contains three forms of play, constructive or creative play, pretend or socio-dramatic play, and physical active play, where the player interacts with Pleo!Dance! the dinosaur and teaches it to dance by using a remote control.

Table 2.4 Properties of Play Lens 2: Forms of Play

Forms of play	Description (Bekker et al., 2014)
Constructive or creative play	Creating and constructing something from objects.
Pretend or socio-dramatic play	Acting out roles, often using toys and props.
Physical or active play	Sensory-motor play with objects. In pre-school years this may involve rough-and-tumble play. Older children engage in play with a more vigorous component to test strengths and skills.
Games with rules	Playing games in social groups with fixed predetermined rules
Games with invented rules	Playing games with modified or rule sets invented

Lens 4: Playful experiences

According to the Play Lens 4: Playful experiences, there are 20 different types of playful experiences: captivation, challenge, competition, completion, control, discovery, eroticism, exploration, expression, fantasy, fellowship, nurture, relaxation, sadism, sensation, simulation, subversion, suffering, sympathy, and thrill. We identified 13 out of the 20 playful experiences in the included studies, these are described in Table 2.5. Control was the most used playful experience (the

complete summary can be seen in Table 2.3). Control could be found in interventions that relied on structure and rules and in those with a more open play form. For example, (Gregory et al., 2012) consisted of playing and teaching a dinosaur to dance, where playful experiences of captivation, control, exploration, expression, fantasy, and nurture could be found. At the same time, other interventions relied on more competitive (n = 29) and challenging (n = 45) experiences against avatars in the system, another player, or oneself, like in Wii Sports (Acar et al., 2016; Avcil et al., 2021; Chiu et al., 2014; El-Shamy & El-Banna, 2020; Kassee et al., 2017; Winkels et al., 2013).

Table 2.5 Properties of Play Lens 4: Playful experiences

Type of Playful experiences	Description
Captivation	Experience of forgetting one's surroundings.
Challenge	Experience of having to develop and exercise skills in a challenging situation.
Competition	Experience of victory-oriented competition against oneself, opponent, or system.
Completion	Experience of completion, finishing and closure, in relation to an earlier task or tension.
Control	Experience power, mastery, control, or virtuosity.
Discovery	Experience of discovering a new solution, place, or property.
Exploration	Experience of exploring or investigating a world, affordance, puzzle, or situation.
Expression	Experience of creating something or expressing oneself in a creative fashion.
Fantasy	Experience of make-believe involving fantastical narratives, worlds, or characters.
Fellowship	Experience of friendship, fellowship, communality, or intimacy.
Nurture	Experience of nurturing, grooming or caretaking.
Sensation	Meaningful sensory experience.
Simulation	Experience of perceiving a representation of everyday life.

2.4 DISCUSSION

This scoping review aimed to provide an overview of the innovative technologies used in hand therapies for children with CP and identify the playful elements used in such interventions. The 54 analysed studies showed that therapists and researchers are investigating a broad diversity of technology combined with play to

make therapy more pleasant, engaging, and effective for children. And to overcome some of the challenges and needs encountered in hand therapy such as the lack of personalization, monitoring of progress, high cost of devices, and the need for tailored feedback, increased adherence, and motivation.

The results of this study show high use of consumer technologies such as the Nintendo Wii, PlayStation, Leap Motion, and several smart toys, to name a few, as a response to the need for financially accessible technology for therapy. This can help lower the therapy costs while allowing to practice in different contexts, for instance, at home or school. Also, considering the familiarity and interest children already have with these types of technology, they could more easily be accepted and adopted. Another important finding was the variety of technologies used; we identified at least 41 different devices. These devices come with a diversity of characteristics such as motion tracking (Kinect, Leap Motion, IREX, etc.), haptic feedback (Smart tangibles, TagTiles, Geomagic Touch, controllers, etc.), or can be more general support systems (PC, Laptop, game consoles) that can easily be used to deploy a video game. Interestingly, 43 out of the 54 studies used a combination of types of hardware; for example, de Oliveira et al., (De Oliveira et al., 2016) used the Leap Motion in combination with Mindwave and custom software developed for the explicit purpose of therapy. The combination of commercial and custom hardware brings together the strengths of a robust technology that require low technical support and that can be used at home without extensive financial burden, with the requirements that specific treatments can bring.

From our analysis of play elements, we see different approaches to how play has been implemented and the type of technology used to enhance motivation and adherence: via video games, where the participants had to execute an action with their hands to advance in the game, and via toys or other types of tangible devices which allowed for a more open form of interaction to engage the user while doing the exercises. The findings show that under Play Lens 1: Open play, “structure” and “games and rules” were most used in video games. The opposite can be observed in games with toy-like tangibles such as Pleo (Gregory et al., 2012), TagTiles (van Delden et al., 2012), Lego Mindstorm(Hsieh et al., 2020), and PhysiTable (Mandil et al., 2015), which allow for a more open play approach, where there is a structure of the game in terms of narrative. Still, there is plenty of space for the players to explore and create their own rules, adding space for improvisation and meaning. Although not all the studies reported on motivation and improvement of skills, those that did show that play has a vital role in motivating children to do

their therapy while helping them improve their motor skills. This further supports the idea that *play* is a valuable factor in therapy because it appeals to children. Once they are in a state of flow or immersion in the game, they can perform different hand movements with repetition without becoming burdensome. Moreover, they can share the experience and create bonds through play with other children and family members.

One anticipated finding was that all the studies fit into the Form of Play (Play Lens 2), "physical or active play", which refers to sensory-motor play with objects and test of strength and skills, which is paramount in physical therapy. Furthermore, there should be flexibility in this "physical or active play" to be personalised to the skill level of children with CP, and the use of technology can provide this personalisation with the use of sensors and intelligent systems. The other Form of Play that was identified the most was "games with rules", where participants often encounter a predefined goal and a clear set of rules that they had to comply with to play the game. Control (n=54) and Challenge (n=45) were the most used Playful experiences (Play Lens 4). They are often characteristics of video games and are also found in traditional therapy with toys guided by a therapist. The commonality of these approaches is that the participant had to accomplish a task by controlling an object in the virtual environment or a physical object. This control was strongly linked with the exercise that had to be performed with the spastic hand. In the case of therapy at home, it is challenging to achieve the guidance that therapists provide, but the use of technology can help solve this problem (Chen et al., 2021).

2.4.1 Design new therapies supported by innovative technology and play

From this analysis, we cannot draw strict conclusions regarding the impact of using one technology versus another. We are also left with questions on how best to use open play or games with goals (Play Lens 1) and how to choose a specific play experience (Play Lens 4). Nonetheless, the playful elements and technology inventory gathered here can be a starting point for designers, researchers, and clinicians who wish to develop new interventions for children with CP. Researchers and designers should first be aware of the consequences and affordances of using one specific technology and the type of play they want to provide with the intervention. The analysed interventions present toys and video games that offer different types of play and play experiences with their advantages and disadvantages. While commercially available video games can be easier to develop and access, they might not fit the child's specific level of disability.

In some cases, combining such technology with specialised software can provide better training. On the other hand, toys can provide haptic feedback, allow object manipulation with both hands, and more freedom in the type of play, giving room for creativity. When designing new interventions, it is essential to consider certain aspects such as type of play experience, level of challenge, competition, and physical activity. The kind of play experience could be games with rules or open play. The level of challenge should not frustrate the child but keep them motivated. With competition, we can give the possibility to compete against themselves or someone else.

Further research can include comparing the different play strategies' effectiveness (for motivation and improvement of motor skills) and designing new interventions that use smart toys or other physical and digital play tangibles to broaden the knowledge base. Another interesting area of focus would be to study in more depth how hand therapy for children with CP can benefit from using new technologies, including artificial intelligence. The possibilities of using artificial intelligence in this area are broad; we will mention four examples here: 1) the application of artificial intelligence for personalization (tailored to the skills of the user), 2) adaptive play complexity (changing complexity depending on the progress made in therapy or skills) 3) balanced play (the skills of different participants are levelled out) 4) the use of data to help the therapists and caregivers to provide adequate support to the patients or create competition within a community to develop a shared experience. Many opportunities can make the experience of hand therapy more entertaining for children, and the combination of technology and play is a direction that can help achieve that.

2.5 STRENGTHS AND LIMITATIONS

This chapter provides a comprehensive review of the current state of hand therapy for children with CP, with a focus on the use of innovative technologies and playful elements. With this review, we have synthesised a wide range of literature and identified key technologies and approaches in the field. We are also proposing a novel approach by including the Lenses of Play to analyse and understand the application of playful elements in technology-supported hand therapy. This framework provides a new perspective on play and offers a diverse set of elements that can inform the design of new therapies.

We acknowledge that this scoping review has limitations, first is the lack of details of the interventions. The Lenses of Play allowed us to examine the articles from different perspectives. However, because the main goal of the researched articles was to study the effectiveness of the interventions or propose new types of interventions, they did not contain a complete description of all the features of the games or toys, their design process, and the play experience. This could have added bias because we relied on the limited information provided in the studies and on the experience and knowledge of our team and the publicly available information of some of the technologies. Another limitation is the lack of scientific publications on other games, toys, and commercially available technology that therapists include in their program. A further limitation is that we only included studies written in English, excluding work published in other languages.

2.6 CONCLUSION

With this scoping review, we have found that the role of play in the interventions that use innovative technologies in hand therapy for children with CP is to create an enjoyable activity for children that can also help them improve their motor skills. We have provided an overview of how and which technologies are available, and which playful elements are part of the interventions. Currently, the field shows diverging strategies and a variety of playful experiences supported by technology. Whether via a video game or a toy, with rules and structure, or open play, repetition becomes fun and engaging. While playing, children enjoy the activity and forget that they are doing repetitive hand movements. Technology is an appealing medium to support play; it provides advantages like measuring hand and arm movement and integrating them in the interaction with the games. In addition, it has functionalities for personalisation according to the degree of spasticity of the child and their personal preferences. Technology can also give feedback to guide the therapy and the game and improve the play experience while collecting valuable data for the therapists, the caregivers, and the children. The implementation of personalised and adaptive therapies in the home or school environment can help relieve the workload on the caregivers and rehabilitation centres. Together with play, innovative assistive technologies provide an intrinsic incentive to exercise and continue with therapy.

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Chapter 3

CO-CREATING HYBRID TOYS AS AN APPROACH TO UNDERSTAND CHILDREN'S NEEDS IN PLAY EXPERIENCE

This chapter is largely based on:

> Pinos Cisneros, T., Escobar Vega, F., Kröse, B., Schouten, B., & Ludden, G. (2021). Co-creating hybrid toys as an approach to understand children's needs in play experience. In *Young Children's Rights in a Digital World: Play, Design and Practice* (pp. 219-236). Cham: Springer International Publishing.

Abstract

Using hybrid toys to deliver physical therapy is an innovative way to engage children in personalised healthcare. However, there is an urgency to understand children's needs in their digital-physical play experience, to effectively design these toys. The aims of this explorative study were to identify the needs of children in their play experience, and to examine co-creation workshops as a mean to do that. Ten children and thirteen observers participated. Participants were asked to reflect on what they like most about play, while building a hybrid toy and discussing the rationale behind their actions. The statements were written down by the observers and analysed via concept mapping and network analysis to categorise them. Finally, the children filled in a questionnaire after the session to assess the acceptance of the workshop. We have found that the identified needs can refer to different aspects from psychological to practical functionality, providing a wide panorama of requirements. The results of the questionnaire show that children enjoyed the topic, the use of technology and the process of co-creation. The combination of co-creation with concept mapping allows us to collect and categorise the identified needs to further develop future designs.

3.1 INTRODUCTION

Physical and occupational therapy can make important contributions to improving people's wellbeing, however despite efforts to make therapies engaging (Aarts et al., 2012), patients often find them challenging and uninviting due to their repetitiveness. The rise of emerging technologies, including hybrid toys, gives therapists the opportunity to explore other tools that can be used in assessments and intervention sessions. Eventually, the use of such tools could benefit patients because they could allow for more personalised therapies and improve patient engagement. Throughout this chapter, the terms 'hybrid toy' or 'hybrid play' will refer to the combination of physical and digital elements in toys or play experience. This combination provides new opportunities for play, by adding feedback, automatization or data collection. Extensive research has shown the importance of play in the development of children (Piaget, 1945; Vygotsky, 1967) and user-centred design's relevance in creating better products (Sanders & Stappers, 2008). Although co-creation, as an approach of user-centred design, has been widely studied, and hybrid toys have been studied to some extent (Tyni et al., 2016), few studies have investigated co-creation of hybrid toys as a way to understand the user's needs.

The study presented in this chapter analyses the impact of prototyping hybrid toys during a co-creation workshop, intended for children 7-12 years old. The research questions addressed are (1) which needs do children have in their hybrid play experience in terms of interactions, topics and type of play and (2) can we better understand those needs by co-creating hybrid toys with them. To answer our first question, data was gathered and analysed via concept mapping, a method that has previously been used to determine users' requirements (Ogden, Barr, & Greenfield, 2017). To gain deeper insight into the results of concept mapping we used network analysis. Furthermore, to answer the second research question we used a questionnaire, as it is standard in collecting participants' feedback (Alreck & Settle, 1994). Understanding children's needs in their hybrid play experience will help designers create new toys with applications in fields such as health, while empowering children in their use of technologies. In this study we have identified different aspects of children's play experience with hybrid toys such as: psychological needs, practical functionality, opinions and requirements.

3.2 HYBRID TOYS AND UNDERSTANDING THE USER

3.2.1 Play objects and technology

Play is a fundamental part of children's development as it helps them discover the world while developing skills, identity and self-esteem. Despite there being different definitions of play, for the remainder of this chapter, we will refer to 'play' as "the quality of mind during enjoyable, captivating, intrinsically motivated and process-focused activities" (Kudrowitz & Wallace, 2009). Current generations of children are growing up in a world where technology is ubiquitous. From mobile phones, smart televisions and robot vacuum cleaners to home assistants, children today are surrounded by a diversity of devices. It is only natural that their play experience is becoming more linked to these new technologies. Recently, the diversity and sophistication of toys that include electronics have increased, and we refer to them as hybrid toys. These are understood as play objects that have a mixture of physical and digital components (Tyni et al., 2016), using software, sensors, and actuators is common and they may or may not connect to the internet or other devices (Mascheroni & Holloway, 2017). Related terms are: smart-toys, connected toys, internet of toys and augmented toys. These toys have been gaining popularity as younger generations find the borders between the physical and digital less obvious, and their familiarity with technology is more natural. They can provide immediate and diverse feedback, data collection, interactivity and personalised behaviour. Examples of hybrid toys are: care toys such as Tamagotchi and Hatchimals, educational toys that help children learn to program like Doc Clementoni and GoTo drawing machine, and advanced action figures that expand the video game experience like Amiibo.

Besides being used for recreation, hybrid toys are starting to be used in education and health. In their review of "Smart Toy based learning" Cagiltay, Kara & Aydin (2014) present an analysis of hybrid toys in education. According to these authors, hybrid toys become cognitive tools by providing interactive learning experiences. They are used to teach mathematics, coding, languages, cultural values (Al-Khalifa et al., 2018), music (Luo et al, 2018), communication skills, creativity, and social interaction (Ihamäki & Heljakka, 2018), to name a few fields. In the health domain, adding sensors in toys, and the possibility to record and store data have likewise opened new opportunities. Smart toys could be (and to some extent already are) used for therapies, sports and assessment of cognitive and

motor skills. In this domain, researchers have for example developed toys that encourage social interaction for children with autism (Farr, Yuill, & Hinske, 2012), toys that detect delays in motor skill development (Mironcika et al., 2018; Sander et al., 2017) and toys and games that promote movement (Levac et al., 2010). Although potential uses of these toys have been described in the literature, there are limited studies that emphasise children's perception and preferences in hybrid toys and how technology is affecting their play experience.

3.2.2 Understanding the user

Co-creation is a design practice where the user is considered the expert and is asked to take an active participation in the design process (Sanders & Stappers, 2008). It is used by designers as a methodology to better understand users and their needs. The importance of involving users in earlier levels of this process relates to the needs of relevance, perspective and ownership (Plattner, Meinel, & Leifer, 2012) towards the object or system to be designed. Previous studies have used this approach to design character toys (Ihamäki & Heljakka, 2017) and learning environments (Kangas, 2010). Other examples are Game Jams, which are events that provide educational value for participants, while generating new knowledge by creating prototypes of games or video games in a short amount of time (Deen et al., 2014). With this in mind, we designed a co-creation session where children could build hybrid toys in a space open for experimentation and discussions.

3.3 METHODOLOGY

3.3.1 Co-creation

The co-creation workshop "Digital & Physical Play – Digital Camp" took place at the Amsterdam University of Applied Sciences and at the Public Library of Amsterdam, on the 16th and 17th of November 2018. Ten adults and nine children participated. We asked the participating children to reflect on what they like most about play, which themes, or topics they are interested in, what type of features they like in toys and how they would use technology. This was done by building a prototype and

discussing the rationale behind their actions following a design thinking process (Plattner et al., 2012). This process was structured in five main steps:

Empathise – Understand the design challenges. This involves empathising with the user, understanding the needs and the ecosystem around the activity. Participants were asked to create a Persona of their intended user as a way to understand and empathise with the target audience.

Define – Summarise requirements of the design, what does it need to have/do to be able to suit the user(s). Participants were asked to reflect on the needs and desires of their persona as a way to extract insights and design criteria.

Ideate – Use the defined criteria to come up with ideas and concepts that fit the users. Participants were asked to do brainstorming using lotus blossom (Vangundy, 2004), and pick the concept that best fit their design criteria.

Prototype – Build a prototype of the most promising design concept(s). Participants were asked to build high-fidelity prototypes of their concepts.

Test – Test the prototype with users. Participants tested their high-fidelity prototypes with their target audience.

Data was collected from the session and explored via concept mapping and network analysis. Finally, we used a questionnaire to analyse the acceptance of the co-creation process (Figure 3.1)

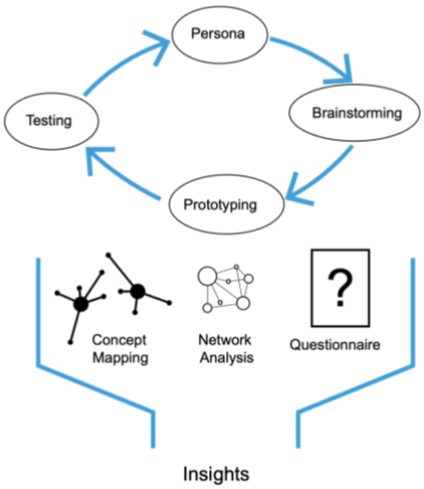

Figure 3.1 Co-creation cycle used in the workshop

3.3.2 Concept mapping

Concept mapping is a structured process that is focused on a topic or problem that needs to be solved (Figure 3.2). It involves input from several parties, which produces a graphical view (concept map) of their ideas and concepts. It allows participants to easily visualise how these ideas (statements) are interrelated and how they can be clustered (Trochim, 1989). There are six main steps that Trochim defines as part of this process:

1. Prepare the project by choosing a focus, recruiting participants, and scheduling the mapping.
2. Generate ideas, where participants will formulate statements that answer the seeding question.
3. Structure ideas, where the previously mentioned statements or ideas will be organised by the participants in clusters.
4. Compute maps, and statistical analysis is done on the clusters of ideas generated. For this study we used the open source tool R-CMap (Bar & Mentch, 2017) to aid us generate this analysis.
5. Interpret maps: where stakeholders and researchers analyse and interpret the maps.
6. Utilise maps: bring the results into practice, which in our case will be developing new hybrid toys.

We used concept mapping to get an overview of the main clusters that were identified within the statements. Additionally, we wanted to have an overview of the entire network and see how the different statements related to each other; for that we used network analysis.

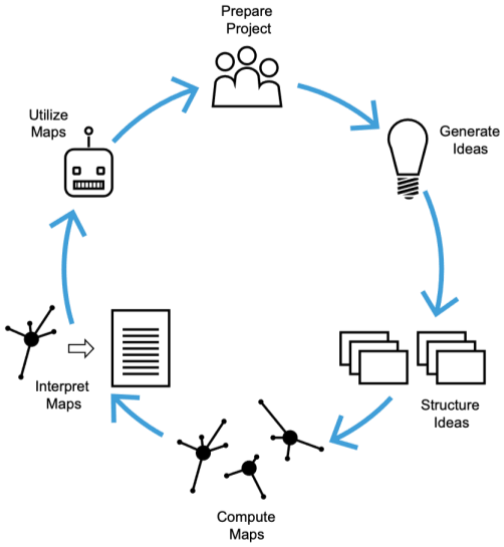

Figure 3.2 Concept mapping structure

3.3.3 Network analysis

Network analysis is a method that allows examining the relationships between nodes (statements) and edges (relationships that connect them). This uncovers the relationship, closeness and clusters of similarity that nodes have within networks (Borgatti, Mehra, Brass, & Labianca, 2019), and an overview of the connections between the different nodes. Network analysis was used to help identify the similarity and links between the network of statements made by the participants of the session.

3.3.4 Questionnaire

A questionnaire was filled in by nine of the ten children that participated once the co-creation session ended (one of the participants had to leave early). The questionnaire consisted of open questions and Likert scale questions asking about the children's perception of the co-creation session, their use of technologies, their creativity and further interest in the topic of the workshop.

3.3.5 Study

We designed and conducted an exploratory workshop of co-creating hybrid toys, where children worked together with adult participants in creating a prototype. In this section we will describe the materials, participants, and structure of the workshop.

Materials: Participants could use a variety of electronic tools: Nintendo Switch with their programmable interface provided by Nintendo Labo, LittleBits a collection of electronic building blocks, Makey Makey an interface that replaces the keyboard with the use of conductive material, and the Touch Board a microcontroller that can play sounds via the use of electrodes. Participants also had access to Legos, craft material and a laser cutter.

Day 1: Nine design students and design/game professionals (7 females, 2 males; age-range: 24-42y) participated in a workshop. After reviewing theory about the importance of play and different types and characteristics of hybrid toys (Tyni et al., 2016), participants worked in teams of three to create a prototype of a toy with physical and digital elements. They started by defining a persona, then participants used Lotus blossom for ideation, the result of this process was three different prototypes of hybrid toys. These hybrid toys were used in day two as thought-provoking tools.

Day 2: Ten children (7 boys, 3 girls; age-range 7-12y) were invited to participate as 'experts of play'. With consent from the children's parents, video and photographs were taken. The children first tested the prototypes created by the observers during the first day of the workshop in order to get them into a playful mood, get comfortable as a group and collect feedback from their play experience. They were divided into teams (one of four and two of three participants) supported by observers (adult participants and coaches) to create their own prototype of a hybrid toy. The role of the observers included taking note of behaviours and comments of the children. Coaches had experience with the tools provided and helped troubleshoot issues. A brainstorming session (3.3) helped children identify themes and objects that they found interesting and decide which play object they were going to build. During the prototyping session they experimented with the tools provided, thought about which type of actions they wanted their toys to perform, and made a sketch of what they wanted to build. As a result of this session, each team built a hybrid toy: 'Monster car', 'Horror House' and 'The roller coaster' (Figure 3.4). At the end, there was a round of testing and feedback. All of their remarks during this process were recorded by the observers as statements.

Figure 3.3 Some ideas from the brainstorming session

Figure 3.4 Prototypes day 2: Monster car, Horror house and Roller coaster

In Concept Mapping, ideas are generated based on a seeding question; for this research, the seeding question was: *"Which characteristics of hybrid toys and play experience motivate children to play?"*. During the workshop, observers wrote down statements that answered the question, and during a closing session, they

compiled a final list of statements based on what the children said. This list was later verified with video and audio recordings from the day. To generate a concept mapping analysis, observers clustered statements based on similarity. They rated their importance (based on children's behaviour and comments) on a Likert scale (1 to 5) by using a digital tool (Figure 3.5)(Brons, 2018).

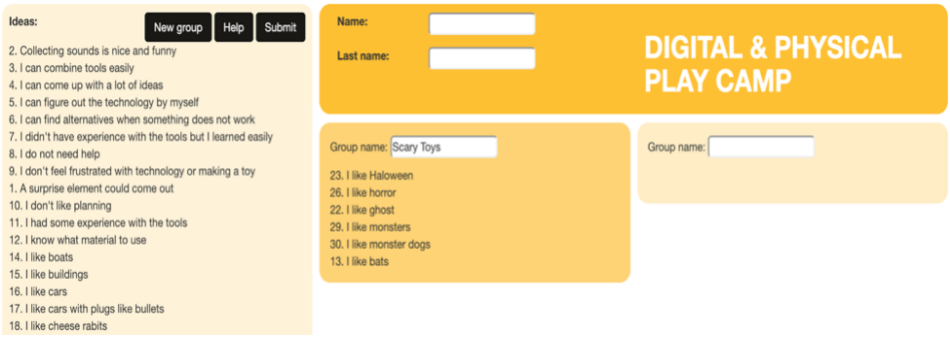

Figure 3.5 Clustering tool

3.3.6 Results

The observers (n=13; 8 students/design professionals and 5 coaches) identified 81 statements, six of which clustered the statements answering the seeding question. By using concept mapping, we clustered those 81 statements into 8 clusters (Table 3.1).

Table 3.1 Clustered statements

	Curiosity and freedom		DIY technology
3	I can combine tools easily	*25*	I like high technology vehicles
4	I can come up with a lot of ideas	*34*	I like robots
5	I can figure out the technology by myself	*35*	I like scary
6	I can find alternatives when something does not work	*43*	I like to do crafts
7	I didn't have experience with the tools but I learned easily		**Technology variety**
8	I do not need help	*32*	I like Nintendo Switch
9	I don't feel frustrated with technology or making a toy	*39*	I like technology
12	I know what material to use	*50*	I like to see a personalised message
21	I like free play	*51*	I like to use digital tools
41	I like to be part of participatory design	*55*	I like videogames
42	I like to be relaxed	*57*	I liked the birthday cake toy
44	I like to explore	*63*	I want electricity
45	I like to feel curious	*76*	LitteBits is just another block

46	I like to have instructions at the beginning but play freely after.	**Themes for toys**	
47	I like to make different combinations	*13*	I like bats
52	I like to use my imagination	*14*	I like boats
	Hybrid functionality	*15*	I like buildings
1	A surprise element could come out	*16*	I like cars
65	I want to combine the digital and physical worlds	*17*	I like cars with plugs like bullets
69	I want to know which musical instruments are used	*18*	I like cheese rabbits
74	It is not necessary to add digital	*20*	I like dogs
	How to play	*22*	I like ghost
10	I don't like planning	*23*	I like Halloween
19	I like destruction	*24*	I like helicopters
40	I like to be competitive	*26*	I like horror
48	I like to play with lego freely, without instructions.	*28*	I like light
56	I like when a game is exciting	*29*	I like monsters
73	It is nice to play together	*30*	I like monster dogs
77	Making a toy is playing	*31*	I like monster tanks
80	The game could have a specific environment	*33*	I like remote control cars
	Game structure	*36*	I like snakes
11	I had some experience with the tools	*37*	I like spiders
27	I like lego	*38*	I like tanks
49	I like to play outside	*53*	I like trucks
64	I want to build a tomato charger to a phone	*54*	I like vampires
68	I want to know which action triggers a sound	*59*	I want a house that walks
72	It is funny to be barefoot	*60*	I want a robot house
79	The game could be played in the dark	*61*	I want a roller coaster
	Feedback signal	*62*	I want animals
2	Collecting sounds is nice and funny		
58	I missed the use of sounds		
66	I want to have variety of sounds		
67	I want to hear other sounds		
70	I want to see more emojis		
71	It could use a secret language		
75	It is super cool to send and receive a signal		
78	More messages could be sent		
81	The use of remote control is fun		

The dendogram plot (Figure 3.6) and the ray cluster map (Figure 3.7) show the clustered statements. Table 3.1 shows that the cluster "Curiosity and freedom" scored highest on importance. This cluster shows that children enjoyed combining tools easily, exploring, feeling curious and having free play as a component of their play activity. This indicates the importance of open play as a format for toys. In the second-highest scoring cluster, "Hybrid functionality", the contradictory statements "I want to combine the digital and physical world" and "it is not necessary to add digital" indicate that the addition of digital elements must be meaningful. As Goldstein (2012, p. 29) has stated, "If a toy is no fun to play with, no amount of technology will increase its desirability as a play object". The "Feedback

signal" cluster highlights the importance of sound as a part of the toy. The "Technology variety" cluster shows the acceptance of the tools used in the workshop. In the "Themes for toys" cluster we see a list of topics that children enjoy in their play experience. The "How to play" and the "DIY technology" clusters provide diverse views of elements that can be part of the toys. Furthermore, what is noticed is that the statements identified relate to different needs: psychological needs, practical functionality, opinions and requirements, which encompass a wide range of users' needs.

Table 3.2 Summary of clusters

Cluster ID	N	Mean	SD
Curiosity and freedom	16	3.92	0.47
Hybrid functionality	4	3.75	0.29
How to play	8	3.35	0.59
Game structure	7	2.90	0.79
Feedback signal	9	2.87	0.69
DIY technology	4	2.67	0.76
Technology variety	8	2.46	0.82
Themes for toys	25	1.73	0.31

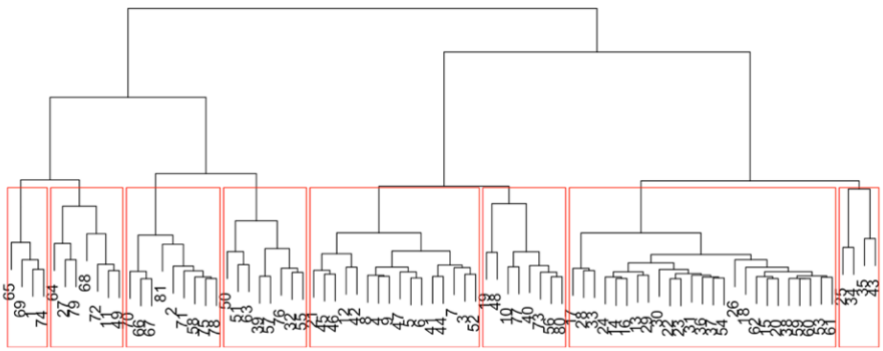

Figure 3.6 Dendogram plot

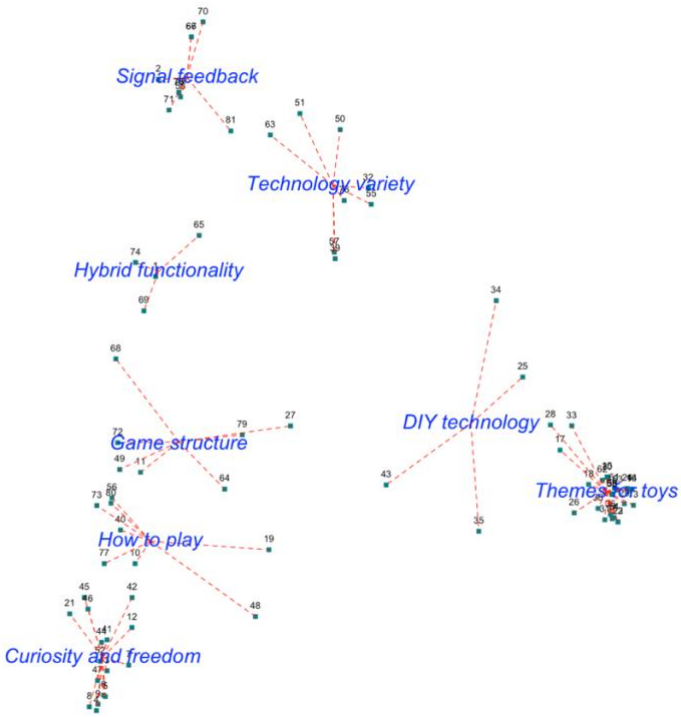

Figure 3.7 Ray cluster map

The network analysis of the statements (Figure 3.8) shows that there are two main clusters of information. The cluster on the right revolves around conceptual themes that the children would like their toys to have. The second cluster revolves around the activities that they find interesting/fun when playing. This second cluster is divided into two subclusters that centre around expectations and desires that the children have about the physical characteristics of toys and the interaction expectations and desires about play itself. In the middle of both clusters is a sub-cluster that revolves around what the children find important when making their own toys.

The cluster related to themes is tightly packed and the cluster around activities is spread out, therefore, we can identify themes that are around shared common interests. Moreover, there is a lot of diversity surrounding the concepts that deal

with these themes. The statements indicate that the children made no clear distinction between the characteristics of the play experience and the toy (or toy system).

The results of the questionnaire used to assess the children's acceptance of the workshop show their enjoyment (Figure 3.8) and what they learned (Table 3.3). They also expressed their interest in learning more about robots, programming, making toys and the technical tools used during the workshop. In a short amount of time (five hours), they were able to build the prototypes, learn about the technology and discuss what they would like to see in their hybrid toys. As one of the children mentioned, "[these tools] add some magic".

Table 3.3 Some statements of what children learned

I have learned…
How you can make robots
I have learned that everyone can figure things out
That we can use other things as a controller
How to make things with the switch
You can do more things if you know Little Bits

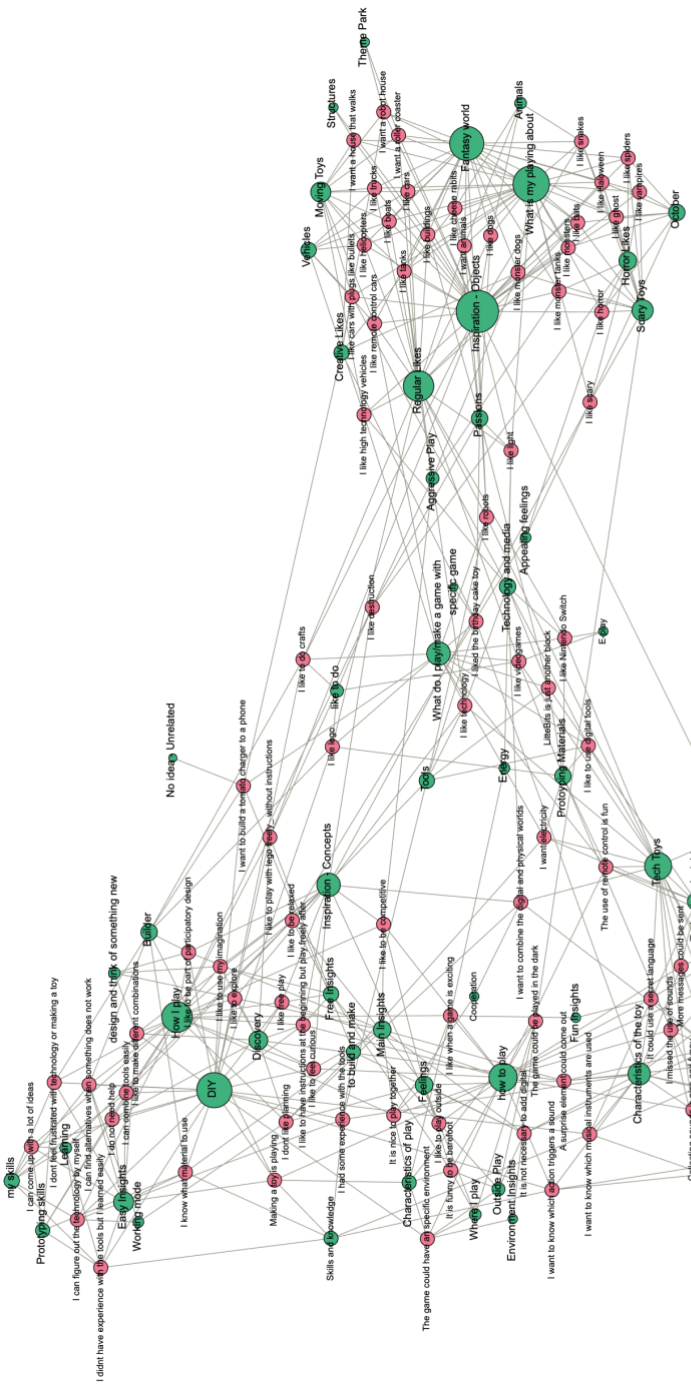

Figure 3.8 Network analysis of statements

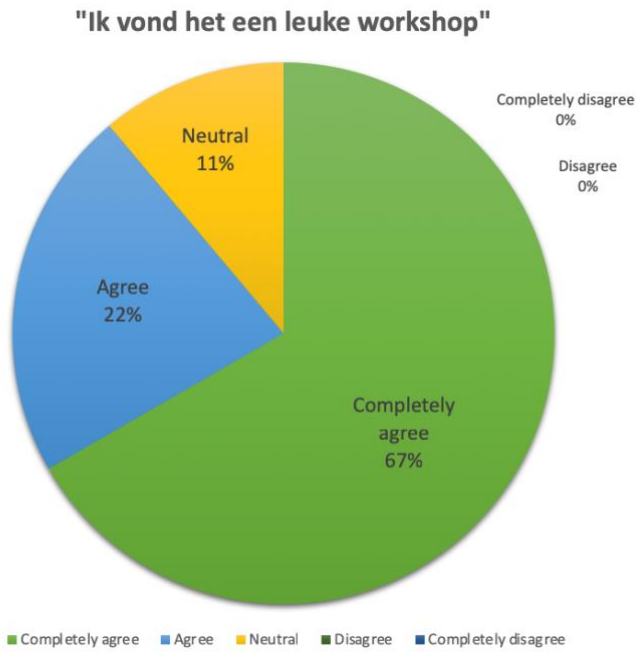

Figure 3.9 Question on acceptance: "I thought it was a nice workshop"

3.4 DISCUSSION

Prior studies have noted the value of co-creation in understanding users. The generated concept map further supports the idea of using the co-creation of hybrid toys as a playful and educational experience to understand users' needs better. However, our findings may be limited by the number of participants, the lack of diversity among participants and cases of miscommunication with the observers. Although we believe that co-creation workshops can lead to a better understanding of a target group, further research should develop workshops with more diverse groups of children. Moreover, this approach should also include therapists, children, and their families to identify the specific requirements of hybrid toys that can facilitate therapies.

Although some of the coaches acted as translators, one of the main issues encountered was the language barrier between observers and children. This study was conducted in The Netherlands where most of the participating children only spoke Dutch, while some of the observers did not speak Dutch. This will be taken into consideration for future studies.

Another limitation of the current study is that the importance rating was made by the observers, as an attempt to identify what they have learned from the users. It would be interesting to conduct a future study with bigger and more diverse groups of children and see how they would rate the statements themselves.

3.5 CONCLUSIONS

The present study aimed to understand the needs of children in their hybrid play experience and to examine co-creation workshops as a means to understand the user. This study has compiled a list of insights that can be a starting point for designing new prototypes of hybrid toys for use in health and other fields. These insights refer to different aspects: psychological needs, practical functionality, opinions, and requirements. They provide a rich overview of children's needs and thoughts about these types of toys. From a design perspective, these insights help designers make informed decisions. This study has also found that empowering children with technology makes ideas more tangible and allows for richer design criteria to develop hybrid toys. The innovative aspect of this workshop is that it was not just about co-creation, but also tinkering with technology. While ideation and concepting provide useful information, prototyping with technology can trigger conversations about the needs of the user in hybrid play experiences. In this setting, children have the opportunity to experiment with these tools, have a more active role in the design of their toys and think about their potential.

The combination of co-creation and concept mapping can lead to valuable results when designing solutions by triggering and documenting ideas. The children who participated in the workshop expressed their interest in learning more about robots, programming, making toys and the tools used (Little Bits, Makey Makey and Nintendo Switch). From this we can conclude that it was a pleasurable experience for the participants and that this format could continue to be used to understand better the needs of the user. Despite the exploratory nature of the study, the results presented show that we, as designers, can identify the users' needs from working and playing alongside with them. In future studies we will analyse which specific elements, like sound for example, can be used to improve physical and occupational therapies.

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Chapter 4

HAND REHABILITATION FOR CHILDREN WITH CEREBRAL PALSY: FROM CLINICAL SETTINGS TO HOME ENVIRONMENT

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For children with unilateral spasticity, therapy plays a crucial role in the improvement of their motor skills. Of particular interest are Constraint-Induced Movement Therapy and Bimanual Training for children between 4 and 18 years old. These therapies are intense programs that focus on training unimanual and bimanual skills. Moreover, these skills help children perform everyday activities that promote their sense of independence, such as preparing food or dressing themselves. However, after these short training sessions are finished, the lack of adherence to follow-up programs at home increases the risk of losing the skills gained. Technology-supported home-based therapies offer opportunities to provide personalised training that will maintain and improve the developed fine motor skills. A question is how to design these home-based therapies in a way that they are complementary to regular therapy and extend their benefits. In this study, we observed two successful and commonly used interventions for the treatment of children with Cerebral Palsy in the Netherlands: The Pirate and the Handig2Handig groups. We analysed current literature of these programs and observed assessment and therapy sessions, which provided further information about the process, the structure and the tools used. Then, we identified which elements characterise these therapies that could also be used at home, and what the challenges are for their implementation. Finally, this study resulted in a list of elements that can be implemented in the development of future home-therapies; the identified elements are: BiT, goal setting, feedback, opportunity of repetition, the role of the caregiver and the role of play. We discuss these findings while considering the opportunities that smart personalised technologies in the home environment bring to a future vision of technology-supported at-home therapy for this group.

4.1 INTRODUCTION

Cerebral Palsy (CP) is a disorder caused by damage in the brain with consequences for movement and posture impairments. According to CP Nederlands, the Dutch organization of people with CP, cerebral palsy is the most common cause of impairment in children and spasticity is its most common form. This creates obstacles in development, confidence and overall quality of life. Physical and occupational hand therapies intend to help children increase manual performance to overcome these obstacles. Constraint-Induced Movement Therapy (and its modified version) (CIMT) and Bimanual Training (BiT) are such therapies. They are commonly used to treat hand spasticity and have been successful (Chamudot et al. 2018). Specialised rehabilitation centres can successfully provide these therapies; however, specialists recommend additional daily home therapy to maintain the skills learned. In the case of children, there is a lack of continuity of progress in the home environment. Some of the reasons mentioned for this are low motivation in children to perform repetitive activities, tiredness after school activities and the disruption of the family routine. Then the question arises: what are the elements of the therapies at rehabilitation centres that could be taken into the home environment to motivate children to exercise? Therefore, we studied two groups based on CIMT and BiT that are widely used in the Netherlands (Pirate group and Handig2Handig group). A better understanding of these programs can lead to design tools for home therapies to improve the well-being of children with CP and their families.

4.1.1 Hand Therapy

Hand therapy for children with CP aims to increase the range of motion, coordination and strength of the affected upper extremity and thus gain autonomy. A lack of treatment can lead to fixed contractures of the muscles and joints, which in turn contribute to physical and emotional pain.

Constraint-Induced Movement Therapy (CIMT)

In CIMT the unaffected (non-spastic) hand is restrained with a sling or similar device that limits the movement of the arm. The core elements are repetitive practice and shaping used through activities selected to elicit movements in the joints with most deficit and with potential for improvement, and considering age and preferences of the children (Gordon, Charles, and Wolf 2005). In the modified version for children

(mCIMT) the therapy is done during 3 to 6 hours per day instead of 24 hours as in the original version for adults. Daily play activities are broken into repetitive tasks with increasing complexity. Feedback is given to explain the appropriate movement and to give encouragement. Two example activities are puzzles to elicit precision grasp, release accuracy and in-hand manipulation and board games to elicit supination, wrist extension and precision grasp. According to Novak et al. (2013) CIMT is effective in providing improvement of motor activities (speed and dexterity) while being aligned to the families' goals.

Bimanual Training (BiT)

BiT focuses on the use of both hands to provide functional independence during daily activities. According to Charles and Gordon (2006) bimanual interventions are needed to increase the coordination of both hands, something that children with CP struggle with. The objective of BiT is to learn to use the affected hand as an assisting hand in predefined goals (e.g.: dressing, eating, cutting with scissors). Children learn movements via bimanual activities in a child friendly setting. The activities involve repetitions of the movements that have deficit. This is accompanied by strategies to increase the difficulty of the task to match the increasing ability of the child and the desired goals. Activities include card games, video games and arts and crafts. Furthermore, BiT also has a family centred approach. Studies (Novak et al. 2013) have shown BiT to be effective in improving motor activities .

Pirate group and the Handig2Handig groups

The Pirate group is an intervention protocol designed for children with CP aged 3 – 8 (Aarts et al. 2012). It is based on four components: (1) combination of mCIMT with BiT, (2) motor learning theory and strategies, (3) play in a group therapy context and (4) involvement of parents in a homework programme. The Pirate group is an 8 weeks program where children attend the rehabilitation centre 3 times a week, 3 hours a day. During the first 6 weeks the focus is on mCIMT activities followed by 2 weeks of BiT aimed at extending play and self-care activities. The intervention has a "pirate" theme as a way to motivate the children to use only the affected hand.

Handig2Handig is an intervention based on the Pirate group but aimed at older children, 8-18 years old (van der Burg, Aarts, and Steenbergen 2013). It is an intense one-week program where mCIMT and BiT activities are practiced working towards predetermined goals. In Handig2Handig the exercises are also done via playful activities with opportunity of repetition. During the program children work on

mCIMT and on BiT activities in an equal amount of time. In the last two days of the intervention, extra attention is given to the initially set goals.

4.2 METHOD

Observations of the Pirate and Handig2Handig groups were conducted at Roessingh Rehabilitation centre in Enschede, The Netherlands. Due to the availability of the therapy programs the observations were divided into two stages. In the first stage, two assessment sessions of participants of the Pirate Group and one assessment session of a future participant of the Handig2Handig group were observed in June 2019. There were 3 female participants in this session (aged 4-17). The second stage was an observation of the Handig2Handig rehabilitation group in August 2019, with 6 participants (3 female, aged 9-17). Qualitative data were gathered via field notes, where the following themes were recorded: setting, exercises, material used, role of the therapists, and behaviour of the children. Interviews with the therapists were conducted to gain a deeper understanding of the process, limitations, and potential role of new technologies in the therapies. With the compiled information, we made a list of possible elements that characterise the therapies. This was later verified with the existing literature, and finally, an expert reviewed the items and provided feedback. Photos of the materials (toys, drawings, and equipment) were taken with the authorisation of the organisers of the sessions.

4.3 RESULTS

4.3.1 Pirate Group and Handig2Handig assessment session

The assessment sessions for both groups have a similar structure, and they mainly differ in the use of age-appropriate toys.

SETTING: Table 4.1 shows the description of the setting assessment session.

Table 4.1 Setting of the Assessment Sessions

Objective	**To establish comparable metrics at the beginning and at the end of the program to determine improvement.**
Participants	Child Occupational therapist Physiotherapist Parent (to accompany)
Structure	1 hour of bimanual exercises directed by an occupational therapist and 30 minutes of Unilateral exercises directed by a physiotherapist.
Protocols used	Assisting Hand Assessment (AHA) Melbourne Assessment Video Observation Aarts Aarts (VOAA)
Observed hand movements	Pinch, hold and release, grasp, reaching with elbow extension, supination and dorsiflexion.
Physical space	Room with a table, one chair for the child and one chair for the therapist. The parent is present in a place close to the child to give reinsurance but at a distance to not interfere. The session is video recorded. All the tools used are at a close proximity from the therapist.

Exercises and materials: The session consists of a series of exercises (Table 4.2) that allow the therapists to observe the child's quality of hand movements. The exercises are playfully done in repetitions within a set time frame. A variety of materials are used to maintain the motivation and as a reward (the child can later eat the cake and chocolate).

Table 4.2 Exercises and materials of the assessment session

Bimanual exercises: These activities help identify how the children do movements with both hands, and if/when there were compensatory movements.	
Activity	***Description***
A chocolate in a cake	Take a cake from an oven, make a whole in the cake and place a chocolate in it
Store the cookies	Pass a rope through a wooden ring and store them in a container
AHA	Handle different toys: music box, crown, marbles in a bottle, etc.
Cubes storing	Move cubes, from one side of a box to the other, first with the non-affected hand then with the affected hand
Unimanual exercises: Following the Melbourne Assessment, the child is asked to only use the "pirate" (affected) hand.	
Activity	***Observed movement***
Button	Reach forward
Crayons	Grasp and release

Chocolates	Pincer grasp and release
Block	Manipulation
Image	Pointing
Caress the head and neck and reach out and touch shoulder	Supination, pronation and reach

Role of therapists: The therapists provide instructions on the actions to be performed. Because the exercises are a sequence of steps, sometimes the children need reminders of the following step. Encouraging feedback was often heard like "Goed zo!" [Well done!].

Behaviour of the children: Most participants were willing to take part in the activities. However, frustration and embarrassment were observed in challenging activities, while defiance was noted in easy exercises.

4.3.2 Handig2Handig rehabilitation sessions

After an initial assessment, the children, together with their parents, define their goals (Figure 4.1), which are displayed in the common room as a reminder.

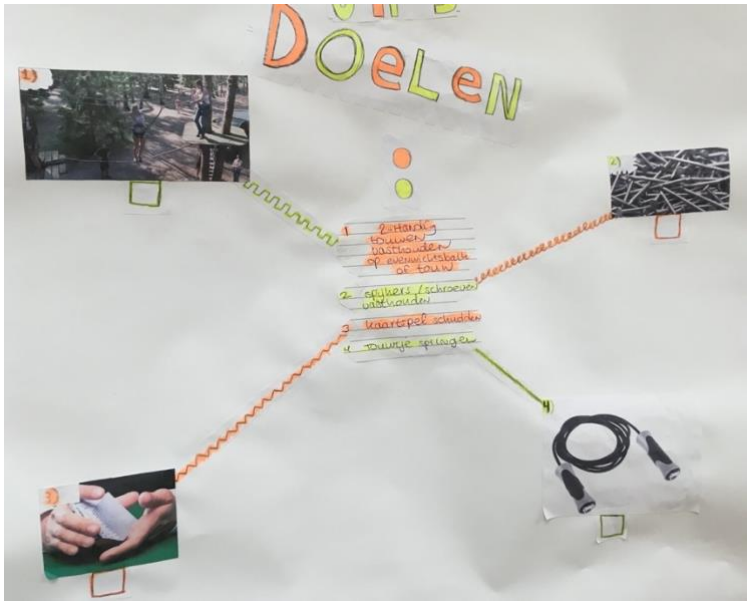

Figure 4.1 Goals of one of the participants [climbing, tightening screws, shuffling cards, jumping rope,]

Setting: Table 4.3 shows the description of the setting of the Handig2Handig session.

Table 4.3 Setting of the rehabilitation sessions

Objective	**Reach predefined motor goals by improving the fine motor skills of children.**
Participants	6 Children 6 Therapists
Structure	Group activity: a shared moment between all the children and therapists, parents are also present. 4 hours of mCIMT 4 hours of BiT
Observed hand movements	Pinch, hold and release, grasp, reaching with elbow extension, supination and dorsiflexion.
Physical space	Several rooms in the children's rehabilitation department, including the swimming pool, carpentry workshop and music classroom.

Exercises and materials: Exercises (

Table 4.4) were done with the aid of toys (Figure 4.2) to promote hand movement related to the goals. For example, to learn to zip a jacket, a pincer grasp is exercised by moving the pegs of the smart pegboard (Figure 4.2). These activities are designed and proposed by the therapists, but the children can also choose.

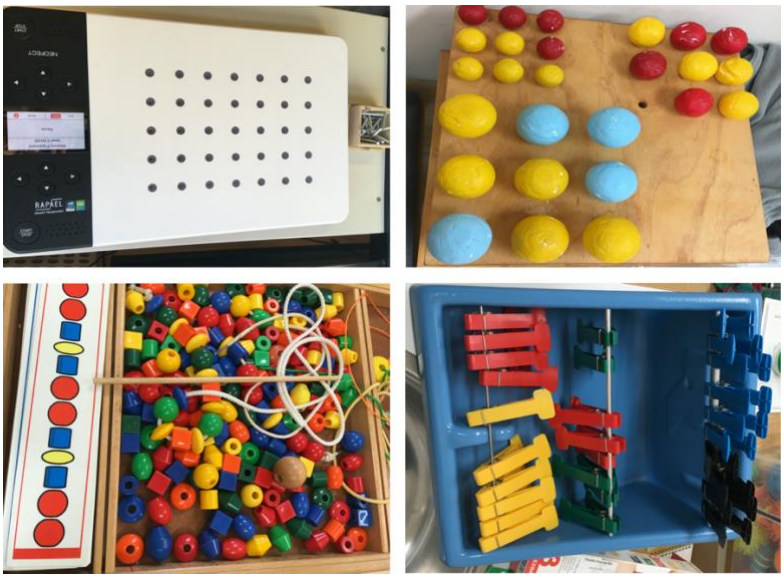

Figure 4.2 Example of toys used: Smart pegboard NEOFECT, beads and string, balls, clothespins.

Table 4.4 Exercises and materials of the rehabilitation session

Unimanual exercises: Wearing a sling to practice mCIMT activities	
Therapy putty	To exercise grasp and release
Wooden tic tac toe, clothespins and Smart pegboard NEOFECT	To exercise pincer grasp and rotation
Cosmo Training	To exercise upper limbs extension and to run
Bimanual exercises: Children do more practical daily activities without the sling.	
Lunch	Half of the children and therapists are in charge of preparing lunch
Carpentry workshop	The other half work on a wooden box, they exercise by assembling, nailing and painting the box
Music class	With a percussion class different rhythms and combinations are practiced
Swimming pool	Different team games like tossing the ball and racing
Goal training	Allocated time to specifically practice the selected goals

Role of therapists: During this process the therapists play close attention to the improvement of the children, provide feedback and adjust the complexity of the exercises accordingly.

Behaviour of the participants: All the participants were enthusiastic to participate, showing improvements and camaraderie through the activities. Furthermore, the trust in the therapist was notorious.

Interviews: At the end of both sessions, we asked the therapists a series of questions to clarify what was observed, the protocols used, the overall structure of the sessions and what they consider the motivating factors to participate: shown improvement, playfulness, fun, nice games, little presents like stickers, verbal encouragement and commitment of the family. In addition to the demotivating factors, some exercises are too complicated, there is a lack of variation in activities, and parents experience tiredness and pressure. We also interviewed Dr. Pauline Aarts, creator of the studied programs. We discussed the programs, the role of new technologies in home-therapies and reviewed the list of characteristic elements, which is outlined in Table 4.5.

Table 4.5 Characteristic elements of the therapies that can be used in home-therapy

Element	**Description**
BiT	The importance of using both hands in activities at home gives confidence and independence. Although mCIMT is highly effective in hand therapy, it is preferred to do it only at the rehabilitation centers

	where there is a constant attention of the therapists and falls or accidents can be prevented
Play	Children find playing an appealing activity and they are naturally drawn to engage in them, keeping them motivated
Role of the parents or caregivers	Similar to what the therapists do at the rehabilitation centre, parents could have a role of providing feedback, proposing variety of exercises and adjusting the complexity
Goal setting	Aligned with the practices of BiT and mCIMT, the setting of goals gives direction towards a certain achievement which will increase motivation
Implicit and explicit feedback	Provide instructions of the relevant tasks, how to perform it, number of repetitions, outcome and performance.
Opportunity of repetition	Motor learning strategy that allow children to achieve relatively permanent changes in motor skills.

4.4 DISCUSSION

This study set out with the aim of identifying the elements of successful hand therapies that could be applied in home-therapy. These findings may be somewhat limited by the number of sessions observed and the sole perspective of the therapists interviewed. Further research should be undertaken to investigate the perspective of the children and their parents and to obtain a deeper understanding of the home situation. Nonetheless, this first list of elements highlights opportunities in home therapy that new technologies can support. For example, smart personalised technologies provide customisation of exercises to match the movement disorder of the child and the established goals. They monitor the actions performed and their quality. They detect and adapt to fit improvements in hand motion, and they promote playfulness and feedback to maintain motivation. During the observations, a high interest from the children to use the 'smart' tools (Cosmo, Neofect, etc.) was noted, which is understandable as computer games and new technologies are popular among children. And because they can provide opportunities for repetition in a motivating way, other researchers are starting to use them. For example, at Saint Maartenskliniek (in Nijmegen, The Netherlands) there are already initiatives to use VR and Leap Motion. Next steps are to analyse existing home programs further and compare them with our list of elements, expand the scope of this research and involve more participants, because in times of social isolation (due to Covid-19 at the time of writing), the urgency of successful home-therapies is emphasised when access to rehabilitation centres is limited.

4.5 ACKNOWLEDGEMENTS

We thank the therapists at the Roessingh Rehabilitation Centre and Dr. Pauline Aarts from the Sint Maartenskliniek for sharing their knowledge, experience, and feedback.

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Chapter 5

DESIGN AND EVALUATION OF A SMART TOY FOR HOME THERAPY FOR CHILDREN WITH CEREBRAL PALSY

This chapter has been submitted to the Interacting with Computer Journal:

Pinos Cisneros, T., Kröse, B., Schouten, B., Nederhand, M., Ali Salah, A. Schoorl, K. Hepping, A.M. & Ludden, G. (2025). Design and evaluation of a smart toy for home therapy for children with cerebral palsy.

Continuous hand therapy is necessary for children with spastic cerebral palsy to maintain motor function, but repetitive exercises can be demotivating, particularly during home therapy, where the absence of a therapist limits feedback and personalisation. Technology-based therapies for hand rehabilitation are emerging as promising solutions, but the potential of smart toys with self-adaptive play complexity and machine learning is yet to be explored. This research presents the Magic Monster, a smart toy designed to motivate children to perform hand therapy at home. The toy combines playful interactions with AI for calibration and self-adapting play complexity to personalise therapy. The Magic Monster was designed following an iterative design approach and evaluated through a non-blind, randomised, multiple-baseline, AB single-case study that followed the SCRIBE guidelines. Five children with cerebral palsy (7–12 years) participated in a three-week home-based intervention. The findings show that smart toys have the potential to enhance motivation and engagement, highlighting its interactive, accessible, and cost-effective characteristics as a therapeutic tool. These results suggest that smart toys like the Magic Monster can play an important role as at-home rehabilitation for children with cerebral palsy, offering a customized and enjoyable alternative to traditional therapy methods.

5.1 INTRODUCTION

Cerebral palsy (CP) “is the most common cause of (motor) disabilities in children in the Netherlands,” (CP Nederland, 2024) and worldwide, its prevalence is approximately 2 out of 1000 births (Oskoui et al., 2013). CP is an umbrella term that, amongst others, includes hemiplegia, which affects one side of the body. In the case of spastic hemiplegia, the predominant impairment in hand motor function is caused by spastic and paretic muscles of the affected side. The impaired muscle function generates limitations in activities that prevent children with spastic CP from being independent and adds extra pressure on their caregivers (Raina et al., 2005). Physical and occupational therapy benefits the well-being of children with CP by teaching them mechanisms to obtain independence and self-sufficiency in daily activities and by training the affected muscles not to lose functionality (Klevberg et al., 2017). Because the severity of spasticity varies per child, the approach is carefully selected based on the goal of the treatment (Patel et al., 2020). However, these therapies are often perceived as repetitive, demotivating, and challenging to fit into the daily routine of the children and their families. At the same time, in a rehabilitation centre, the close accompaniment of therapists helps maintain motivation. Therefore, achieving the much-needed adherence to the therapy at home is challenging. Maintaining and continuing recurrent training of the muscles at home is also an issue due to the heavy load on the caregivers and the lack of adequate and affordable equipment. This chapter presents the design process and evaluation of a playful alternative using smart toys to support therapy in the home environment.

The use of ‘play’ as a motivator for children with disabilities to adhere to their therapy programs has been studied in different settings because play is intrinsically motivating (Rodger and Ziviani, 1999). Ryan and Deci (2000) define intrinsic motivation as doing an inherently interesting or enjoyable activity. Play is a natural activity for children; it is how they learn about the world, socialise with others, and develop skills. Children’s innate curiosity and imagination fuel play (Piaget, 2013). Play aligns with the needs of the children to engage in an activity that suits their interests, providing a sense of autonomy that empowers them (Vygotsky, 1967). Brown and Vaughan (2009) emphasised that play provides meaningful and shared activities that foster social connections and collaboration, allow children to acquire new skills by testing their boundaries, and are essential for cognitive, emotional, and physical development, making them a critical component in

therapeutic settings. It is also considered of utmost importance for learning 21st-century skills, such as problem-solving, collaboration, and creativity (Yogman et al., 2018). In the field of occupational therapy, play has been identified to have two main roles, as pointed out by Lynch et al. (2018): Play as a means to an end (achieve a motor, sensory or cognitive goal) and play as an occupation, which highlights the importance of play for children.

For children with CP, therapy is crucial to maintain function and perform daily activities, like playing, eating, dressing, and writing (Cerebral Palsy Guide, 2024). Being able to perform these activities independently promotes a sense of accomplishment and helps increase self-esteem. Adequate hand function can also enhance a child's interaction with family members and peers, allowing them to develop social skills. Furthermore, hand therapy aids the development of fine motor skills that allow children to manipulate and grasp objects and engage in play activities that are vital for their development. A lack of proper hand therapy contributes to the deterioration of muscle movement and other muscle complications such as contractures (i.e. permanent tightening of muscles) or joint deformities. Periodic hand therapy prevents the worsening of these issues. This underscores the necessity for regular therapy sessions. Unfortunately, many children with CP do not have access to therapy sessions due to distance, cost, lack of time of parents and other limitations. A home-based therapy alternative can provide the opportunity to make therapy more accessible. Although this often means an extra load for caregivers, it is necessary to design tools that empower families by helping them actively participate in the therapy without experiencing this as burdensome and complicated and that can adapt to the specific needs of the children. Smart toys can help fill that gap; we can define smart toys as toys with software and sensors that can be part of a wireless network, with data capabilities that enrich the interaction between the child and the toy (Komis et al., 2021). Smart toys combine interactive and engaging interactions with the power of data-driven insights that can be valuable for therapists while improving the therapeutic and playful experience.

Considering the child's context and individual skills in the therapeutic setting is also essential, and self-adaptive technologies can provide the necessary personalisation. Vaughan et al. (2016) highlight in their overview of self-adaptive technologies within virtual reality training the importance of self-adapting systems for rehabilitation. Self-adaptivity can provide customised training and automated difficulty that matches the requirements and skills of patients while reducing costs

and time. Tresser et al. (2021) argue that self-adaptive systems go beyond adaptation of game parameters at the start of the session, but can provide a dynamic adaptation of virtual game parameters with high potential for upper extremity therapy for children with CP.

Despite advances in therapeutic interventions, there is a need for innovative tools that can enhance therapy outcomes in a playful and engaging manner for children. This study addresses this gap by exploring the design and application of a smart toy specifically made for children with spastic CP. The three key research questions guiding this research are: (1) How to design smart toys that increase motivation and adherence to physical therapy at home for children with spastic CP? (2) What are the effects of self-adaptive play complexity on engagement, motivation, and adherence in hand therapy at home in children with cerebral palsy? In this chapter, we present the case study of the Magic Monster to answer these questions and discuss the lessons learned, advantages and challenges encountered. We answer the first question by elaborating on a design process that led to a fully functional prototype of the Magic Monster. We answer the second question by doing an evaluation following a SCED protocol that included children with CP. This will ultimately help us understand how to design smart toys to increase motivation and adherence to therapy.

This research is a step towards creating innovative and effective solutions that bridge gaps in paediatric occupational therapy.

5.2 RELATED WORK

The everyday use of video games in young populations has increased therapists' interest in using them as therapy tools. Some examples include Nintendo Wii Sports to exercise hand and upper limb movements as an effective supplement to conventional therapy (Sajan et al., 2017), and motion sensors such as Kinect (Zoccolillo et al., 2015; Barth et al., 2023; Sultan et al., 2023) and Leap Motion (Tarakci et al., 2020; Fernández-González et al., 2019) to control commercial and custom video games for upper extremity rehabilitation, stroke rehabilitation, Parkinson's therapy, and such. Willemann Peres et al. (2018) concluded that adding ludic strategies in the therapy programs of children with CP stimulates the improvement of motor skills. Many toys, games and everyday objects are being

used as part of therapy; more specialised technological instruments have also been developed, such as the IREX (Guberek et al., 2009) and Hand Tutor (Levanon, 2013), which contain sensors and actuators. This type of technology provides data collection and storage, motion measurement and analysis, immediate feedback, and customisation. The disadvantage is their high price and complex setting, making them unsuitable for daily practice at home.

A particular category of technology in therapy is smart toys, which gather the characteristics provided by other technological tools with the added value of playful elements while remaining affordable and suitable for the home environment. Smart toys are interactive devices or play objects that incorporate technology such as sensors, connectivity, and artificial intelligence to enhance the play experience (Komis et al., 2021; Kara et al., 2013). Integrating technology into toys transforms the play experience from passive to interactive and adaptive experiences that adjust to the child's individual needs and abilities. This can be particularly beneficial in therapy because children with CP present different degrees of motor impairment. For example, smart toys can record valuable information regarding the movements performed by the users, tracking progress and providing feedback and feedforward. This information can be used to increase engagement and motivate patients to continue exercising while playing. Thus, the combination of sensors, data gathering, artificial intelligence, tangible interaction and play make smart toys appropriate for home therapy for children with CP.

The field of smart toys is progressing through the development of novel and more affordable technologies as researchers explore their potential across diverse domains such as education, entertainment and health. A noteworthy example is the Smart Dolphin "SAM" (Crovari et al., 2019), developed as an educational intervention for people with neurodevelopmental disorders; it uses a set of multisensory stimuli and different interactions with light and sounds within a smart space. Furthermore, therapists can personalise its behaviour to fit the users' needs. Cuddly (Low et al., 2013) is a toy that uses a smartphone embedded in a cuddle toy, using the phone's sensors to create fun interactions like pressing and releasing to create movement and sound for entertainment. For the health domain, Table 5.1 provides an overview of smart toys developed to support therapy. This overview details their stage of development, primary functions, technological features, customisation options, ease of use, context of use, and participant information. As can be observed in the table, the primary function of these smart toys is to support the development of motor and cognitive skills and social

interaction, and they are primarily used in rehabilitation centres and schools, demonstrating the need for tools for the home environment. The examples include both study prototypes and commercially available products, highlighting features such as motion sensors, near-field communication (NFC) tags, and pressure sensors, with varying degrees of user-friendliness and adaptivity in a few of the examples. Most of these applications are still in the research stage and the technology has not been fully developed; therefore, they are not yet available for use beyond laboratory settings or they are available at a high price, making them less affordable for families to use at home. Sometimes, tailored solutions are also too complex to be used outside of the rehabilitation centre. However, this development is very relevant in the context of hand therapy for children with CP if the resulting solutions/innovations are developed with this context in mind. These examples showcase the innovative directions that smart toys have taken, offering tailored solutions for different needs within the paediatric population.

Table 5.1 Smart toys designed for children with cerebral palsy. CA: commercially available; SP: study prototype; CP: Cerebral Palsy; ASD: Autism spectrum disorder; NDD: Neurodevelopmental Disorder; RC: rehabilitation centre.

Article	Stage	Primary Function	Technological Features	Calibration & Adaptivity	Ease of Use	Participants	Context of Use
(Li et al., 2008)	CA	Language, math, cognitive and motor skill development	Sensors and actuators	Manual customisable threshold	Easy to use	2-9y, 7 (CP)	RC
(Gregory et al., 2012)	CA toy modified for the study	Motor skill development	Motion sensors, controllers and connectivity	None	Requires adult setup	N/A	N/A
(Hengeveld et al., 2013)	SP	Language and motor skill development	Sensors	Manual customisable threshold	Easy to use	1-4y, N/A(CP)	RC
(Crisco et al., 2015)	SP	Motor skill development	Motion sensors	Manual customisable threshold	Requires adult setup	5-11y, 20 (nonCP)	RC
(Moraiti et al., 2015)	DIY prototype	Motor skill development	Pressure sensors	None	Requires adult setup	N/A, 8 Therapists	RC

(Ranatunga et al., 2015)	CA	Motor skill development	Camera	Adaptivity	Requires adult setup	N/A, 8 Therapists	RC
(Gabyzon et al., 2016)	CA	Assessment and Motor skill development	Camera and image recognition	Manual customisable threshold	Easy to use	4-8y, 47 (nonCP)	RC, School, Home
(Tam et al., 2017)	SP	Motor skill development	Actuators	Manual customisable affordances	Requires adult setup	5-10y 6 (NDD)	RC
(Mironcika et al., 2018)	SP	Fine motor skill assessment	Motion sensors and connectivity	Adaptable threshold	Easy to use	7-9y, 30 (nonCP)	School
(Kim and Oh, 2019)	CA	Motor skill development and visual motor integration	Actuators	None	Easy to use	7-11y, 30 (ASD)	RC
(Borghese et al., 2019)	SP	Motor skill development	Sensors	Manual customisable threshold	Easy to use	N/A)	Home
(Bian et al., 2020)	SP	Motor skill development	Sensors and actuators	None	Easy to use	5-10y, 5 (CP)	Home
(Minh et al., 2021)	SP	Motor skill development	Motion sensors	Manual customisable threshold	Requires adult setup	2-5y, 4 (CP)	N/A
(Wu et al., 2022)	SP	Motor, speech and geometric cognition skills	Sensors	None	Easy to use	4-8y, 4 (CP)	N/A
(Kuo et al., 2023)	CA	Motor skill development	Sensors	Manual customisable threshold	Requires adult setup	N/A, 37 (stroke adults)	RC

5.3 DESIGN PROCESS OF THE MAGIC MONSTER

Our design process included a broad analysis phase that led to design principles, that were the basis for two design iterations (Figure 5.1). The stakeholders involved in the design process included children, therapists, researchers, and partners from the industry. Therapists' involvement at each stage was crucial to ensure the design of a safe smart toy for children to use during therapy. We have seen that play and motivation are very important elements to design for therapy at home. The Synthesis of Child, Occupation, Performance, Environment in Time (SCOPE-IT) model (Poulsen and Ziviani, 2004) describes the connection between play and therapy. The SCOPE-IT model sees play as one of the four critical domains in children's lives: daily activities, work, rest, and play, respectively, and it emphasises the importance of balancing these domains. This model is designed to establish effective therapeutic programs that fit into the child's context and increase motivation by applying the Self-Determination Theory (Ryan and Deci, 2000). The SCOPE-IT model offers a framework to enrich the therapeutic play experience that benefits children with CP in their development. On the other hand, the Four lenses of play toolkit (Bekker et al., 2014) presents a broad range of playful aspects, such as challenge, control and completion, among others. They emphasise the object, play, and user interaction. This framework will allow us to understand better how playfulness may be employed and to identify the elements required to create new fun experiences for treatment. A scoping review by Pinos Cisneros et al. (Pinos Cisneros et al., 2023) on playfulness and new technologies use the Lenses of Play to identify the play elements that are implemented in hand therapy tools for children with CP; those findings informed the selection of play elements for our toy. Therefore, we use the SCOPE-IT model as a framework for child motivation and therapy and the Lenses of Play as a design toolkit for play to ensure the smart toy's playfulness because it offers a thorough analysis of play that goes beyond standard therapist-centred perspectives.

Approvals from the corresponding institutional review boards were obtained for this research, such as approval of the Ethics Committee of the University of Twente and the Scientific Boards of the Roessingh Rehabilitation Centre and Sint Martenskliniek.

The study did not fall under the Dutch Medical Research Involving Human Subjects Act; therefore, after analysing our protocol, the committee declared that

no approval from the Medical Ethical Committee was needed (dossier 2022-15818). Finally, all participants received information brochures for each activity, and the parents of participating children provided written consent. In the following sections, we will describe the analysis phase and the two design iterations.

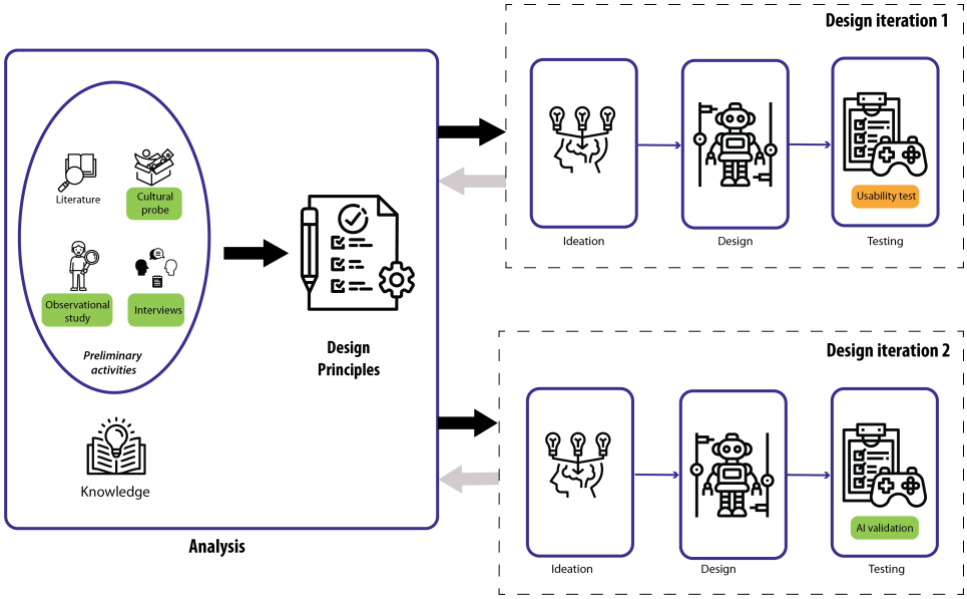

Figure 5.1 Design process of the Magic Monster.

5.3.1 Analysis: Understanding the user

In the analysis phase, we used different methods to understand the stakeholders' context. This section describes the methods used and the results of this phase, which led to design principles.

Methods

Interviews, an observation study, and a cultural probe study were used with different stakeholders. We conducted interviews with occupational and physical therapists who treat patients daily, using a semistructured guide (Appendix B.1). These interviews focused learning more about cerebral palsy and how it affects children and their home environment.

We attended two group therapy sessions at the Roessingh Centre for Rehabilitation for an observation study to learn more about how the children play,

how the rehabilitation programs work, how the therapist and children interact with each other and which tools and toys they use. In the first group, 3 female participants with spastic CP were observed (4-17y). In the second group, 6 children with spastic CP participated in the observation study (3 male, 3 female, 9-17y). Qualitative data were gathered through field notes and therapist interviews, and this information was used to compile and verify a list of therapy characteristics, with an expert providing feedback. We also ran a study with children with spastic hemiplegic CP and their families using a cultural probe (Gaver et al., 1999). The goal was to learn more about the home context of these children and their families. Three families participated in the study by filling out a booklet designed for them. With this approach, we wanted to learn about their routines, the type of exercises they enjoy, their favourite toys, their family composition, and the feelings and problems they experience daily. The data collected were clustered and analysed.

Results

The various methods used with all the stakeholders in the analysis phase provided an overview of the needs of the main users (children with spastic CP) and their context. The SCOPE-IT model served as a framework to categorise the results of the analysis based on the child, motivation, and environmental factors. Table 5.2 summarises the key themes that emerged. The therapist interviews helped us identify issues that the children encounter and further define the problem. For example, constraint-induced movement therapy (mCIMT) (Gordon et al., 2005), which consists of restraining the non-spastic hand with a sling and performing different activities such as play, dressing up, eating lunch, etc., is an essential part of therapy programs observed. However, the interviewed therapists mentioned that it is not recommended to do this type of therapy at home for safety reasons and for the extra pressure it puts on the parents. Instead, it is recommended to have an approach more in line with bimanual training (BiT) (Charles and Gordon, 2006), where children learn to use the spastic hand as an assisting hand in some tasks. Therapists also mentioned the different types of hand movements that children need to exercise and the importance of the opportunity of repetition, which allows motor learning and the importance of practicing daily for approximately 30 minutes. From these conversations, it was decided to focus on using a smart toy to motivate children to exercise dorsiflexion of the affected hand. This idea was later discussed with other therapists as well to ensure that performing such gestures does not pose risks to the children.

Table 5.2 SCOPE-IT model analysis for smart toys design.

Factors	Analysis
Child factors	
Physical factors	The toy is designed in an easy-to-handle way that improves hand movement by playing with it.
Psychological factors	The toy should motivate children to move their hands while playing and it is an empowering object.
Temporal factors	The toy is adequate for the child's age.
Motivation	
Autonomy	The children choose when to play with the toy and for how long.
Relatedness	The toy can provide a shared experience between the child and their family and friends.
Competence	The children feel they can do the activities designed for the toy (game levels, easiness in handling the toy).
Environment	
Temporal environment	The frequency of the intervention does not disrupt the family's routine but can be part of children's play and leisure time.
Physical environment	The toy is designed to be used at home; however, it does not create an extra burden for the parents.
Sociocultural environment	The toy does not replace the therapist, but it is used within a therapy plan set together with the therapist, working towards a goal determined with the child.

In the observation study, we could notice the therapist's role in adapting the game or exercise based on the child's progress, which became one of the key considerations in our design. The children maintained motivation when the exercise was fun, the toys were diverse and when they received verbal encouragement. On the other hand, exercises that were too difficult were demotivating. Figure 5.2 shows a variety of toys used in therapy, such as putty or playdough, which helps children feel different textures and exercise hand strength, Squigz™, a multi-sensory stacking toy that helps practice pinch and grasp, tic tac toe, used to exercise pincer

grip and control, and a variety of video game consoles for gross motor skills of the hand and arm.

Figure 5.2 Picture of observation study, example of toys used during hand therapy.

The cultural probe showed that children have a tight schedule; they attend school, after-school care programs, and sports or cultural activities, some days they have therapy sessions, but they do not have a lot of time, nor energy left to practice exercises at home. When they get home, they want to relax and play with their parents, siblings or alone. The three participating children chose Nintendo Switch as the toy they would like to use to exercise, and two of them chose remote-controlled cars as well. Children mentioned feeling proud when they can do the exercises with their hands. Figure 5.3 shows the response from one of the participants where they drew the hand exercise done that day and how they felt before, during and after. The parents also feel proud and satisfied if their child wants to do the exercises; one of the parents mentioned that they feel very happy when their daughter can do the exercise by herself.

Design Principles and Focus

The related work combined with our analysis led to ten design principles crucial for developing the smart toy, outlined in Table 5.3, which are grounded on the theory provided by the SCOPE-IT and Lenses of Play frameworks, the needs of children with CP, the recommendations from the therapists and the opportunities that new technologies provide. These principles aim to ensure that the smart toy motivates and engages children in therapy by focusing on the home environment, stimulating therapeutic effectiveness, increasing intrinsic motivation and

adherence, providing customisation and a sustainable and affordable alternative for families.

Figure 5.3 Example page of the cultural probe.

Experts from the Roessingh Rehabilitation Centre and the Faculty of Health of the Amsterdam University of Applied Sciences participated as domain experts to set requirements for the design phase. During this stage, stakeholders decided on the platform, media, materials, and a specific hand movement (i.e., dorsiflexion, see Figure 5.4). We chose monsters and magic as a theme for the design based on the findings by Pinos Cisneros et al. (2021) and Hines et al. (2019).

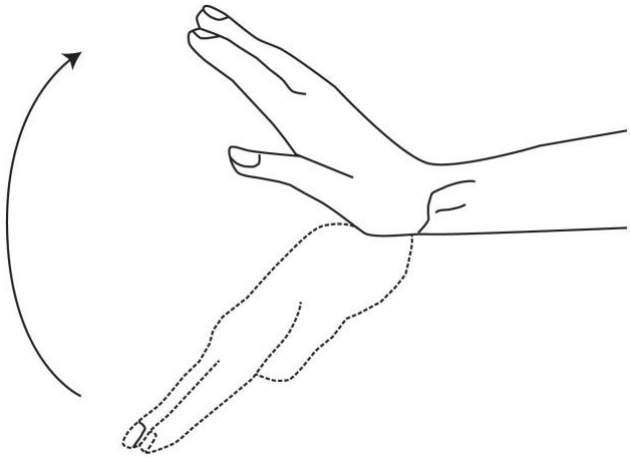

Figure 5.4 Dorsiflexion movement.

5.3.2 First design iteration

The first version of the Magic Monster was developed with designers from IJsfontein (see Figure 5.5). To come to the initial concepts, we organised several brainstorming sessions with all the stakeholders, analysing available technology and considering the previously discussed design principles. The Magic Monster consists of a cuddle toy and an Android mobile app (Figure 5.6). The phone is placed inside the cuddle toy, creating the mouth of the monster. Using a mobile phone ensures a sustainable alternative to custom-designed electronics, as most parents would already have one that can be easily used at home. The sensors used are an accelerometer and a gyroscope, from which data are collected and stored. The Magic Monster is a magic trick assistant. It needs to be entertained; otherwise, he stiffens and falls asleep. A fixed amount of shake movements triggers the start and end of a magic trick. Sounds provide feedback for the player. With the Magic Monster, the child will learn how to do magic tricks, similar to how they are done in the magic-themed hand therapy programs at rehabilitation centres described by Hines et al. (2019). The child holds the toy with their spastic hand and interacts with it by shaking the monster with dorsiflexion movements. This makes the monster dizzy and spits out a box that contains a magic trick. The initial game prototype contains two magic tricks, one with a coin and one with a ball, but new tricks can eventually be added. In the coin trick, the child performs the classic magic trick of making a coin appear and disappear, but instead of disappearing, it turns into a digital coin that will later be turned into a real one again. The child hides one coin between their spastic hand, while they show another coin held in the non-spastic hand. After pronouncing some magic words, they tap the screen with the coin held in the non-spastic hand. A digital coin shows up on the mouth of the monster (screen), this quick movement gives the illusion that the physical coin entered the screen. At the same time, the child hides the coin that was in the non-spastic hand (in their pocket). The digital coin can be moved around on the screen. To create the illusion that the coin comes out of the screen again, the child again says some magic words while shaking the monster with a dorsiflexion movement, while sliding out the coin that was hidden between the spastic hand and the back of the smart toy, and quickly catching it with the non-spastic hand. Figure 5.7 shows the steps of the magic trick with the coin. The ball trick works similarly, but because of the material of the ball and the movements necessary to make it appear, it is of greater difficulty than the coin trick; this trick is unlocked after the child has performed the coin trick 50 times. The gameplay mechanics for the magic tricks were designed to fit the needed exercises.

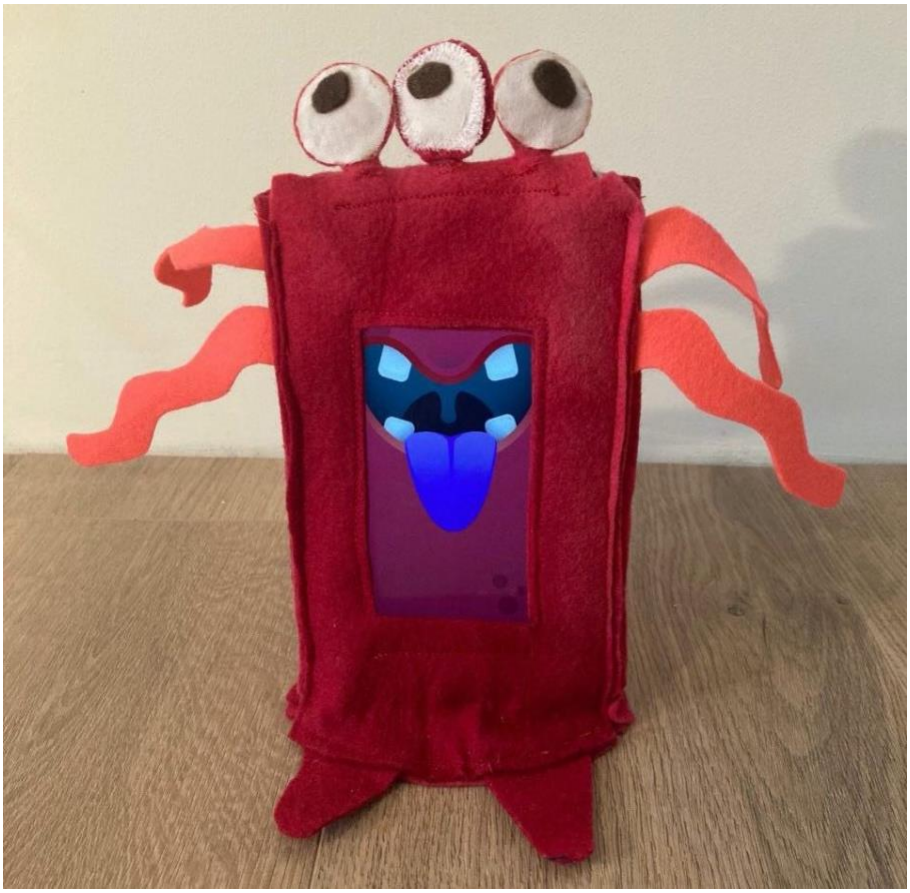

Figure 5.5 First version of the Magic Monster.

Table 5.3 Design principles of the Magic Monster.

Name	Description
Encourage physical play	The toy should motivate children to move their hands, focusing on a specific hand movement.
Open play	The toy should not be regarded as only a therapeutic tool, but as a toy with which the children can have fun.
Off-the-shelf technology	To make the tool accessible to as many children as possible, it should be based on an off-the-shelf technology that can be financially and physically accessible to children at their homes. This should provide robustness and stability.
Bimanual activities	Children with a spastic hand tend to compensate for movements with their non- spastic hand. To prevent this, it is advisable that the new toy allows for both hands to be used so the spastic hand is forced to be exercised.

Physical and digital play	To benefit from the use of technology, the toy should have digital elements like sensors and interactive feedback (sounds, animations, movements, etc.). At the same time, the toy should not focus on being only a digital solution, therefore it will not be a video game, and it should maintain a physical element.
Toy to be used at home	It is important for children to continue exercising at home and not limit their therapy to the moments when they are at rehabilitation centres. Furthermore, with limited access to rehabilitation centres, it is important that children can use this smart toy easily at home.
Social play	A social context can motivate children to perform better in the game. This connects to the need for relatedness.
Play elements	Challenge, completion, control, open play, pretend play.
Feedback and feedforward	Mechanisms that provide information on the performance of a task and that indicate the actions that need to be performed
Customisation and Adaptivity	The toy should adapt to each child's skills.

Evaluation of first prototype

The Magic Monster was first evaluated via usability and acceptance tests with children and an evaluation by three experts. The usability and acceptance tests were done with 22 typically developed children between 7 and 12 years old (13f, 9m). The testing took place in a school for four days. The study's goals were to assess the toy's functionality, acceptance of the toy, and feasibility of performing the magic tricks, as well as to identify errors in the application and with the design of the plush toy. Children received the toy and a list of tasks to do with it; the researcher later interviewed them, the interview questions can be found in Appendix B.2. The interviews with three experts in physical and occupational therapy aimed to analyse the smart toy's functionality and to identify possible risks and improvements. The experts were shown the smart toy and asked questions about its functionality, feasibility, and possible risks of using it in therapy. The questions used in the interview can be found in the Appendix B.3.

Figure 5.6 Screens of the the Magic Monster Android app.

Results

The Magic Monster was well received among the interviewed children; who found it funny, easy to set up, and capable off performing magic tricks. However, ten children found they had to shake the toy too hard, six found the coin trick difficult, and fourteen found the ball trick difficult. Some issues with the app and the material used in the monster were also identified. When asked if they learned anything from playing with the monster, most children responded that they successfully learned how to perform a magic trick. Additionally, most children expressed that they would download the app themselves to proudly show their families that they can do magic tricks. When asked what they would change about the monster, most children suggested changes in its colors and the addition of new tricks. Some children even created new versions of the monster with more tentacles or more eyes, and developed stories about its origin, such as: "The monster's place of residence is in danger, his parents sent him to a strange place and befriended the person who controls the app", and why it teaches magic tricks to kids "It's a magic monster, other monsters don't like magic and that's why he teaches us".

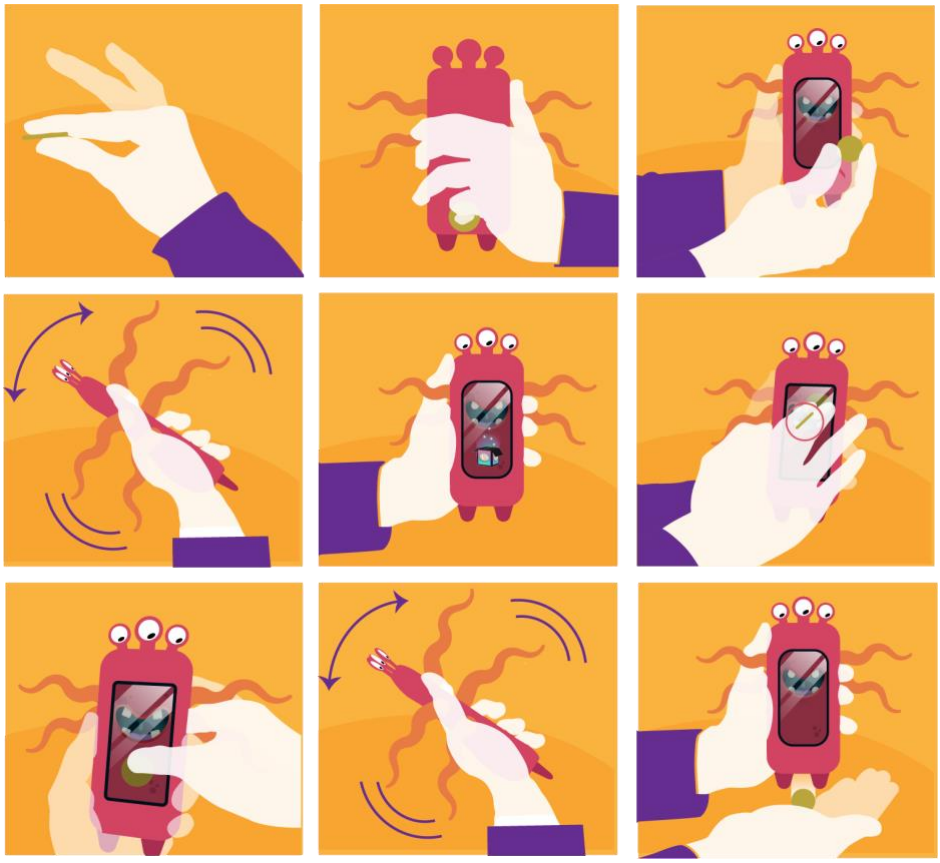

Figure 5.7 Graphic description of the steps of the magic trick with the coin.

All interviewed experts agreed that the Magic Monster is a viable tool for maintaining hand motor practice and does not present risks for the children. It has been designed in a way that is attractive for the children, however, more interactions were necessary to keep them engaged for a prolonged period. Based on the conversations with the experts and the children, we added the following functionalities:

- Hand movement recognition: The toy will be used at home, during playtime with the child when a therapist will not be present, therefore the smart toy should be able to recognise that the child is performing the correct hand movement. The smart toy will include a movement recognition AI algorithm to determine whether the correct hand movement has been performed.

- Self-adaptiveness: Children with CP differ from each other; the complexity of the exercises must adapt to the child's skill, providing a personalised play experience.
- Challenges: The children receive new challenges depending on how much they have played and how well they can do the hand movement.
- Material: Durable fabric will be used that allows for repetitive use of the toy and for the sponge ball to slide easily.
- Look: The monster will be offered in different colours.
- Adjustable toy: The spastic hand of the children is often thinner and weaker than the non-spastic hand. It is difficult for them to grab the toy; the toy should have bands that provide a better grip.

5.3.3 Second Design iteration

Based on the insights from the first version, a second version was made. The most significant change in this version was developing and implementing a machine-learning-based recognition model to identify the dorsiflexion of the hand and provide calibration and self-adaptation for the game. Adult volunteers trained and evaluated the model using an arm brace with different bending degrees to simulate spasticity. Prior work by Schoorl et al. (2024) proposed a machine-learning model for wrist-movement classification for an adaptive mobile phone-based rehabilitation system, which we used in our application. The software tracks the motions and uses thresholds for speed and range of motion for the dorsiflexion movement that must be met before the child can play the magic trick. Challenges were added to encourage the players to exercise according to their skills. The smart toy can be played in two modes: manual, where the threshold of speed and range of motion is set manually, and the AI mode, where an automatic calibration is performed. If the AI model detects that the difficulty of the shaking movement (dorsiflexion) is too high for the child, it self-adapts the play complexity, lowering the threshold. Likewise, if it detects that the movement is too easy for the child, it asks them to shake it harder, increasing the threshold. This self-adaptive functionality of the smart toy determines whether the children can receive a new challenge to shake the monster more, less, slower, or faster, providing feedback and feedforward mechanisms to indicate the children's performance and the needed actions. However, the child can decide whether to accept the challenge at that moment, giving them autonomy and control. The app also tracks the game's usage and difficulty level. Regarding the physical design of the smart toy, different

materials were tested, and the toy was remade with more durable fabric (Figure 5.8), a plastic cover to protect the telephone (Figure 5.9) and a band for support.

Figure 5.8 The development of the second version of the Magic Monster.

Evaluation of second prototype

After implementing the AI model in the Magic Monster, an interview, a questionnaire, and data analysis were used to validate the AI functionality, usability, and acceptance of the Magic Monster with eight children with spastic CP (2 male, 6 female, aged 7-12, Manual Ability Classification System 1 to 3) and their therapists. The children played with the Magic Monster for three minutes, which provided enough data to analyse if the AI algorithm could properly detect dorsiflexion. A video was recorded and later manually annotated by two researchers using the ELAN software (Brugman et al., 2004) and compared with the data from the phone to verify that the AI model correctly identified the dorsiflexion movements. Accuracy, precision, recall, and F-scores were also computed. The new design and material of the Magic Monster were assessed via an interview and questionnaire with the children (Appendix B.2), and therapists also evaluated the toy by reflecting on the calibration of the toy and the feasibility of using it in therapy (Appendix B.5).

Results

Regarding the usability and acceptance of the smart toy, the changes made in the material of the toy were well received, especially the addition of a band for support. Only one child needed to use both hands to be able to shake the monster. The children mentioned that the monster looked “leuk” [nice] and “wat gaaf” [how cool] and were enthusiastic about playing with the Magic Monster. Three children mentioned that they would like to take the Magic Monster home and play with it. One child found new ways to play with the toy besides the magic tricks by making it fly around and dance in the room. Another child mentioned that they would like to play with the toy at last twice per week. The magic trick created surprise reactions; a child’s comment was, “Wow! Hoe dan?!” [Wow! How is it possible?] and all children showed eagerness to learn to perform the trick. Overall, children were positive about the design and functionality of the Magic Monster. They showed curiosity and enthusiasm in each design iteration, and they particularly liked the sounds of the monster and the surprise element of performing a magic trick. A suggestion from a child was to make it speak to understand better what it wants.

Figure 5.9 The final version of the Magic Monster.

Therapists indicated that dorsiflexion, the movement needed to play with the Magic Monster, was beneficial for most children; in some cases, the child would also benefit from doing another type of movement, like wrist rotation. Additionally, therapists observed that, in some cases, spasticity made it more difficult for some children to grasp the toy. Finally, they highlighted the importance of calibration for the children to do the exercises, noting a marked difference between a calibrated setup vs. a non- calibrated setup. The metrics evaluated to validate the AI model that detects dorsiflexion gave good results, with high accuracy (0.948), precision (0.929), recall (0.846), and F-scores (0.885). The recall is slightly lower than precision, indicating that not all dorsiflexion movements are identified as such. However, the results show sufficient accuracy in recognising dorsiflexion movements during rehabilitation.

5.4 FIELD EVALUATION OF THE MAGIC MONSTER

This study (See Figure 5.10) had a randomised, non-blind, multiple-baseline single-case experimental design following the single-case reporting standard SCRIBE (Tate et al., 2016) as is customary for small test samples (Krasny-Pacini and Evans, 2018). Cerebral palsy is a diverse disorder with considerable variation among individuals. A single-case experimental design (SCED) enables a thorough study of each participant's response to the intervention. SCED research typically begins by collecting a baseline phase through repeated measurements to give a basis for comparing changes in behaviour or outcomes following the introduction. In this way, the participants act as their own control group, which allows us to personalize and test self-adaptiveness in this group. SCED designs are increasingly being employed in clinical intervention research, especially when sample size is limited (Tanious and Onghena, 2019). The duration of the study was three weeks, and it consisted of two phases during which the children played with the smart toy Magic Monster v.2. To further limit challenges to internal validity, in a randomised SCED design, each participant's time in Phases 1 and 2 is randomly distributed. Phase 1, or baseline, had a randomised duration between one and eight days, and Phase 2 or intervention phase, had a duration of three weeks minus the baseline duration. The baseline acted as a control and was compared to the intervention phase.

The recruitment of participants was done through two rehabilitation centres in the Netherlands: Roessingh Rehabilitation Centre, Sint Martenskliniek

and UMCG Centre for Rehabilitation. Recruitment started in June 2023 and ended in December 2023. The therapists of the paediatric departments received information about the study and proceeded to select the participants who fit the inclusion criteria. We stated the following inclusion criteria: children with a diagnosis of Cerebral Palsy, aged between 7 and 12, with a Manual Ability Classification System (MACS) levels I-II, having a goal relating to improving hand/wrist function, dominantly spastic presentation, normal or corrected-to-normal vision and hearing, able to cooperate, understand, and follow simple instructions for gameplay. Potential subjects who met any of the following criteria were excluded from participation in this study: a visual, cognitive, or auditory disability that would interfere with play, unable to commit during the three weeks of the duration of the study.

The introductory meeting was held in the rehabilitation centres in the presence of the child (the main participant), the professional therapist and a parent or caregiver of the child. The child was given the smart toy with an instructional video that showed the magic trick and a live demonstration. In addition, a paper manual was provided as more detailed instructional material. Other accessories included coins and balls for the magic trick and a magician's costume for a final performance. The researcher established an initial manual setting of the game's difficulty with the therapist. The parents and children received information on how to charge the phone, place it inside the cuddle toy and activate the application. An initial motivation and engagement assessment was done during the introductory meeting. The children then took the smart toy home with the recommendation to play with it every day. At the end of the baseline period, the researcher visited the home to extract the data, filmed a short video of the child playing with the toy and filled out a questionnaire with the children and parents. Finally, the researcher started the intervention phase by activating the AI functionality of the smart toy. A status update conversation and a follow-up questionnaire were carried out at the end of the second week and at the end of the intervention, respectively. Participants were able to contact the researcher in case of issues or questions about the prototype throughout the study. To ensure procedural fidelity, the same researcher gave the instructions to all participants following the already established protocol, which contained the steps to be followed in each stage of the study and the questionnaires for the participants.

The children had the opportunity to play with the toy for 21 days. It was necessary to change some of the dates and locations of meetings (from onsite to

online) for some of the participants (child1, child 3 and child5) due to conflicting schedules with children's or parents' activities or family issues that arose during the intervention. The toy's strap and amount of filling were adjusted to increase the comfort of use for the children.

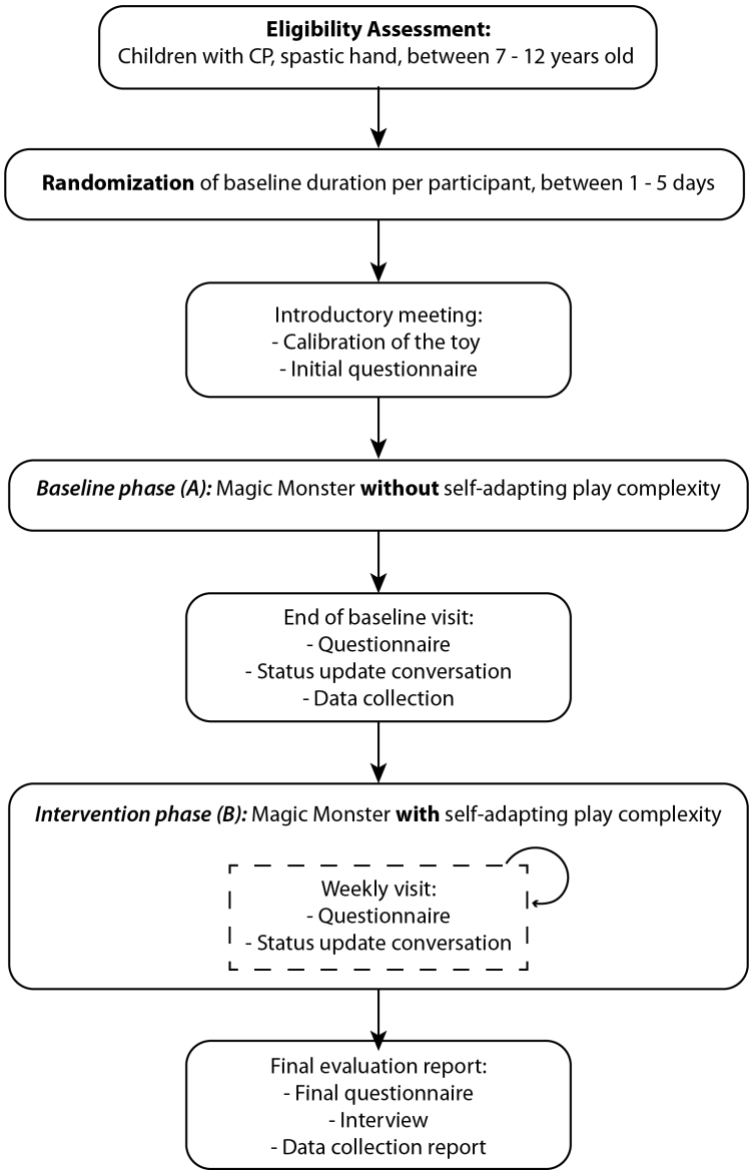

Figure 5.10 Study design.

5.4.1 Procedure

During the baseline period, the smart toy did not have the AI functionality activated and was used as a regular smart toy. When the baseline period ended, the main researcher extracted the range of motion recorded by the smartphone (calculated with the accelerometer and gyroscope) and the game data (play level and duration of the game), activated the AI, and the smart toy was calibrated. This means that the smart toy was now using self-adapting play complexity. At that time, the children and at least one of their caregivers were interviewed, and a video of the child playing with the smart toy was recorded for qualitative analysis. In both phases, quantitative data was recorded every time the children played with the smart toy. The main researcher met with the child and family again during the remaining weeks to extract the new data from the smart toy and conduct another status update conversation. At the end of the three weeks, the researcher retrieved the smart toy, gathered all the remaining data, and conducted a final conversation with the participants. This study was replicated across five participants.

Measurements

The adherence, engagement, and motivation to do hand therapy were measured during the baseline, between the two phases, during the intervention and at the end of the intervention via the use of sensors, questionnaires and status update conversations. We recorded the duration and frequency of the play sessions (exercise time) per participant to measure adherence. These two variables were automatically recorded by the mobile application of the Magic Monster and registered in a log file with corresponding timestamps. We extracted 21 timestamps per participant on average. The questionnaires and status update conversations provided information to measure engagement and motivation. The questionnaires were developed based on the Twente Engagement with eHealth Technologies Scale (TWEETS) (Kelders et al., 2020) and the Core Elements of the Gaming Experience Questionnaire (CEGEQ) (Calvillo-Gámez et al., 2015). The TWEETS questionnaire consists of nine items measured on a 5-point Likert scale that varies between strongly agree and strongly disagree and it measures behavioural engagement, cognitive engagement, and affective engagement. For the purpose of this study, the items of the TWEETS questionnaire were adjusted to reflect the specific content and features of the smart toy prototype. The total engagement scores range between 8 (not engaged) and 40 (highly engaged). The CEGEQ questionnaire was used to understand and measure various dimensions of the gaming experience such as enjoyment, puppetry, facilitator, ownership, video-game, environment and

game-play. The total CEGEQ scores range between 13 (not engaged) and 65 (highly engaged). We also included open questions for the questionnaire done at the end of baseline phase (Q2), the status update conversation on week 2 (Q3), and on the final questionnaire on week 3 (Q4). Annex 1 shows the full list of questions per questionnaire and the corresponding construct (TWEETS) and dimension of the gaming experience (CEGEQ), as well as the open questions used. During the status update conversations, we discussed the activities performed with the smart toy, the issues that arose, and the overall experience and participation of family members.

Table 5.4 Basic information on participants

Participant	Age	Gender	Affected hand	MACS[1]
child1	7	Female	left	II
child2	7	Female	left	II
child3	7	Male	right	II
child4	8	Female	left	II
child5	12	Female	right	II

[1]Manual Ability Classification System.

Participants

Five children (4 female, 1 male - Figure 5.11) with cerebral palsy participated in the study; Table 5.4 lists the characteristics of the participants. Figure 5.12 shows the CONSORT flow diagram for recruitment of participants.

Figure 5.11 Participants playing with the Magic Monster.

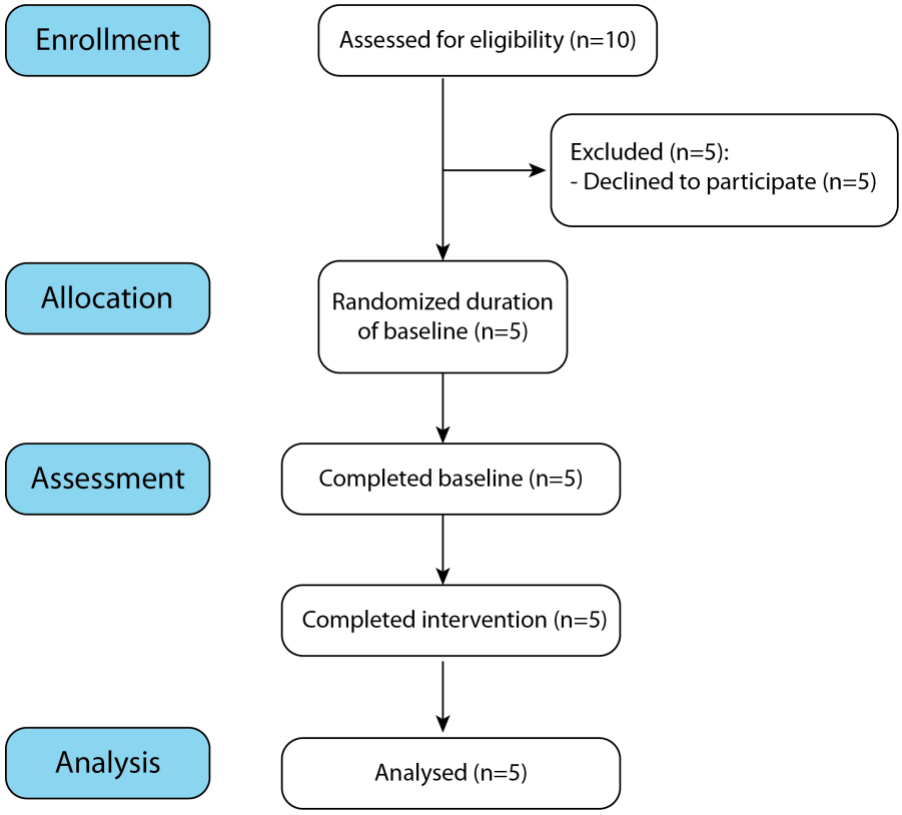

Figure 5.12 CONSORT flow diagram Standardized recruitment flowchart depicting the number of screened, enrolled, allocated, assessed, and analysed participants.

5.4.2 Data analysis

Our data analysis included both quantitative and qualitative methods providing a broad understanding of the participants' experiences.

Quantitative analysis

The primary data analysis strategy was a visual inspection of the time series data, a standard for single-case research (Kazdin, 2019). We analysed changes in the data across the two phases. To analyse adherence to the therapy, we looked at the total duration of playtime per day and the total number of play sessions.

Qualitative analysis

For the qualitative analysis, we used data from the open questions of the questionnaires filled in by the children and their parents, as well as data from the video recording of the status update conversations. The status update conversations were transcribed and translated for post-analysis with ATLAS.ti 24. Key responses were clustered into identified themes following a deductive analysis approach (Braun and Clarke, 2006). We analysed our data to find what children and their parents said about the themes of the questionnaires and status conversations. The first author generated an initial set of codes based on the themes, and applied them to the identified quotes, the codes and themes were reviewed by a second author.

5.4.3 Results

Table 5.5 summarises how each child used the Magic Monster. From Table 5.5, we can see that participants varied in the number of days they used the toy (5-10 days in 21 days) with an average of 7.8 days. During that period, there was an average of 29.6 play sessions. We can observe a variation in adherence, shown by the variation in the number of days played and the frequency of sessions among participants. Child5 was the most consistent participant in playing sessions across more days with the highest total sessions played, whereas child2 played on fewer days with a lower frequency of sessions. The average of daily sessions shows the intensity of play, where child5's average (2.2) suggests that this participant engaged more intensively compared to child3 and child2 with 0.9 and 0.6 averages respectively. Furthermore, child4 and child5 played on average for an amount of time similar to the 30 minutes recommended by the therapist for home therapy. No adverse events were reported during the study.

Table 5.5 Summary of usage of the toy.

Participant	Total days played	Total sessions played	Ave. daily sessions	Ave. time played (min)
child1	10	34	1.6	19.64
child2	5	18	0.9	18.03
child3	8	12	0.6	21.87
child4	7	37	1.8	35.86
child5	9	47	2.2	33.53

Quantitative data

In Figures 5.13-5.17 the use of the Magic Monster over time of the study is plotted for each child separately. These graphs were used for visual analysis and to determine differences between the baseline and intervention phases.

Child 1:

The baseline duration was 5 days, and the intervention was 16 days. Visual inspection of Child 1's data (Figure 5.13) shows high use of the smart toy during the baseline period, with 12 play sessions during the first day and a fluctuation between 20 and 40 minutes of playtime during the same period. During the intervention phase, we observed that the frequency of play sessions dropped to 0 for several days, except for days 9, 10, 19, 20, and 21. The average frequency of play sessions during the intervention phase is approximately 1.1 sessions per day, and the average time spent playing is around 6.5 minutes per day.

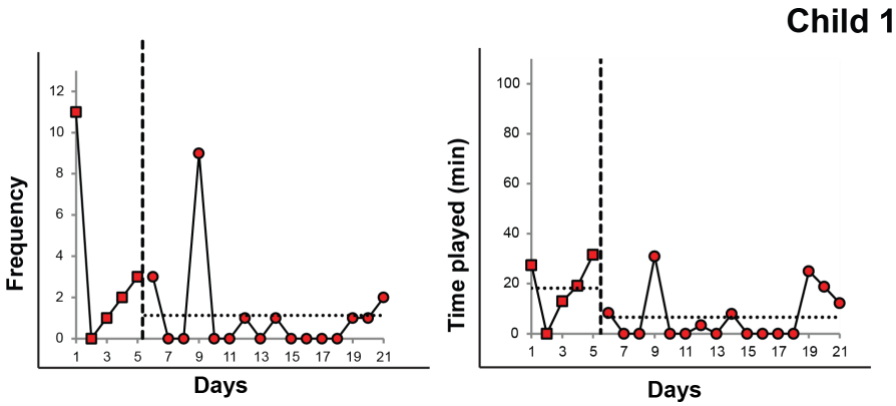

Figure 5.13 Child1's frequency of use and time played.

Child 2:

The baseline duration was 8 days, and the intervention was 13 days. Visual inspection of Child 2's data (Figure 5.14) shows a high frequency of play sessions during the start of the baseline period, with 12 sessions on the first day and 2 sessions on Day 8, the other days there was no interaction with the smart toy. The time played fluctuated between 10 and 40 minutes, with a peak of 40 minutes on Day 1. During the intervention phase, the frequency of play sessions dropped to 0 for most days, with minor increases on day 9 (7min) and day 20 (25min). The average

frequency of play sessions during the intervention phase was approximately 0.3 sessions per day, and the average time played was 2.5 minutes per day.

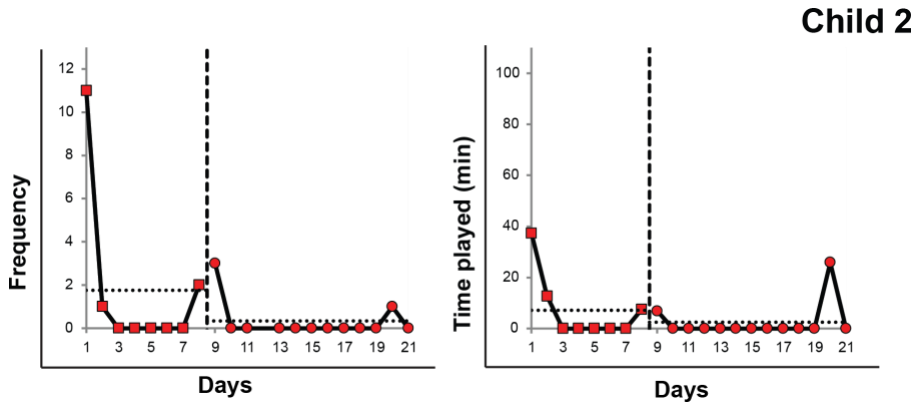

Figure 5.14 Child2's frequency of use and time played.

Child 3:

The duration of the baseline was 2 days, and the intervention was 19 days. Visual inspection of Child 3's data (Figure 5.15) shows an initial use of 2 sessions on the first day. The time played was around 46 minutes during that period. During the intervention phase, the frequency of play sessions varied. The highest frequency was four sessions on day 3. The time played also fluctuated during the intervention phase, with peaks at 30 minutes on day 3, 25 minutes on day 5, and a decrease on the following days with an increase of 25 minutes on day 15. After that, the frequency decreases to 0 on the remaining days. The average frequency of play sessions during the intervention phase was approximately 0.53 sessions per day, and the average time played was 6.8 minutes per day.

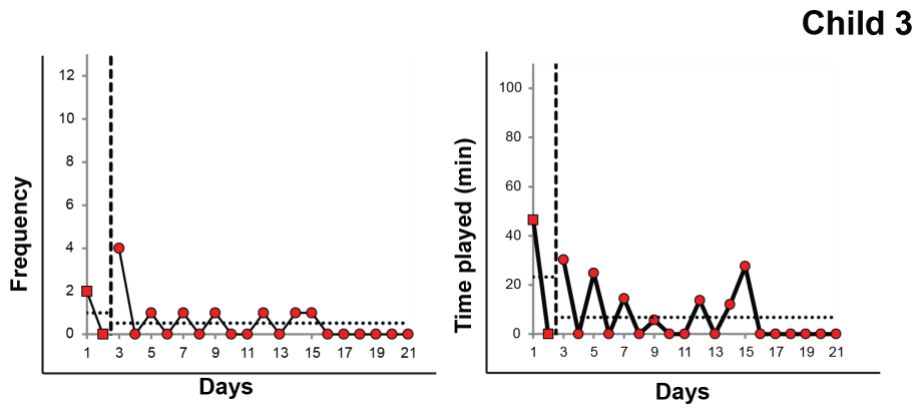

Figure 5.15 Child3's frequency of use and time played.

Child 4:

The duration of the baseline was 2 days, and the intervention was 19 days. Visual inspection of Child 4's data (Figure 5.16) shows a high frequency of play sessions during the baseline period, with 12 sessions on the first day and a total of 21 sessions in this period. The time played started at 109 minutes on Day 1 and then declined to 49 minutes. During the intervention phase, the frequency of play sessions decreased steadily and finally reaching 0 on Day 12. The average frequency of play sessions during the intervention phase was approximately 0.84 sessions per day, and the average time played was 5 minutes per day.

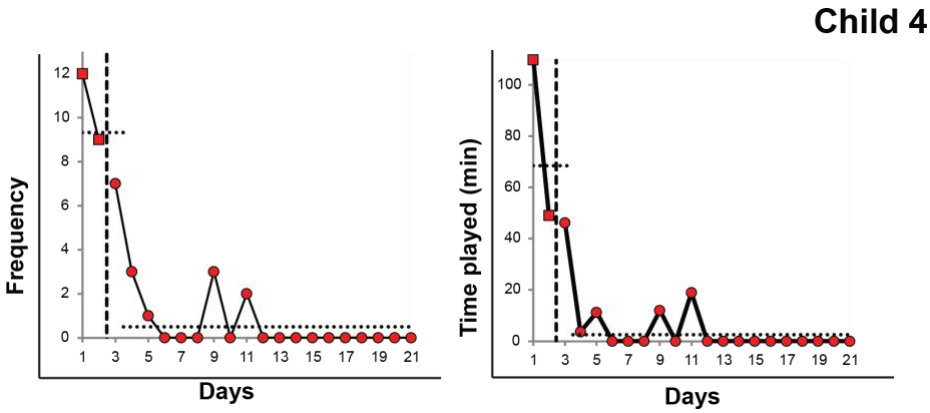

Figure 5.16 Child4's frequency of use and time played.

Child 5:

The duration of the baseline was 1 day, and the intervention was 20 days. Visual inspection of Child 5's data (Figure 5.17) shows a high number of play sessions during the baseline period, with 6 sessions on the first day. The time played started at 45 minutes on Day 1. During the intervention phase, the frequency of play sessions was variable, with peaks on Days 3, 12 and 19 and 21. The other days the frequency was low. The average frequency of play sessions during the intervention phase was approximately 2.15 sessions per day, and the average time played was 12.8 minutes per day.

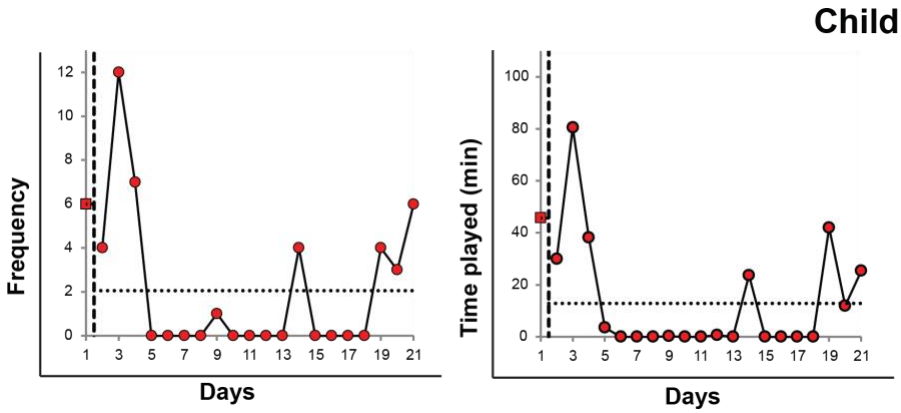

Figure 5.17 Child5's frequency of use and time played.

All the participants completed at the beginning of the study (T0) and at the end of the study (T1) the TWEETS questionnaire, which measures engagement with eHealth technologies and the CEGEQ questionnaire, which evaluates the gaming experience. Table 5.6 shows the overall TWEETS and CEGEQ scores per participant. Engagement remained the same for child1 and child5; there was a decrease in engagement for child3 and child4 and an increase in engagement for child2 between T0 and T1. The gaming experience increased between T0 and T1 for all children.

Table 5.6 TWEETS (min 8, max 40) and CEGEQ (min 13, max 65) scores for each child at two time points (T0 and T1).

	TWEETS		CEGEQ	
Child	**T0**	**T1**	**T0**	**T1**
Child1	36	36	51	57
Child2	32	35	52	56
Child3	35	31	51	56
Child4	36	34	58	59
Child5	38	38	55	62

5.4.4 Qualitative data

Motivation and engagement

The descriptive analysis of the status update conversations and questionnaires focused on four main themes regarding motivation and engagement: usability, challenges, perceived benefits, and recommendations.

Theme 1: Usability and game perception

This theme summarises the ease of use, setup of the Magic Monster and the perception of the game that the participants had during the study. Several points were relevant to this theme; the most notorious was the impact of the size and weight of the toy. Child5's mother reflected on the physical challenges of the toy "I think it's just a little too big for her, is too heavy for her hand actually". The other participants shared this sentiment. However, adding one or two elastic bands helped the children hold the smart toy and improved the comfort and ease of use. While three children had no problems setting up the smart toy to play, two children did encounter issues. Child3's father acknowledged the child's need with assistance, showing limited independence "I had to do it, while he can usually start an iPad by himself". In the case of child1, who needs to use a splint on her hand for support, she found it easier to play with the monster when she removed the splint, but that required assistance from her mother to remove it.

Another relevant point for our study was the difference between the play experience when the AI was deactivated vs the play experience with the AI activated; child5's mother noticed a change when the AI was activated "The very first time; it was still a bit difficult for her. I think you just tweaked it a bit; then it became a bit easier for her". However, the other parents and children did not made mention of such a difference.

All parents agreed that it is a nice product, and they and the kids like the colours, shapes, sounds and graphics of the monster. For example, the mother of child1 said "I also really like the decoration itself, it is attractive to children" and child4 said "I thought it has funny sounds". However, child3's father reflected on the complexity and limitations of the activities that the child can do with the smart toy "on the one hand, he liked the game with the coin, with the ball, but in the other, of course, you know, it does serve a certain obstacle to him wanting to do a little more with it". Parents of child1 and child3 indicated the need to add variation in the game. Despite the need for extra activities, parents saw the potential of such a toy and the children were saddened for the departure of the toy and expressed interest in testing future prototypes.

Theme 2: Challenges

This theme collects the difficulties faced by children and parents during the duration of the study. During the status update conversations, a few reasons for the small playtime were given: the children had busy schedules, there were other

games or activities that competed for attention, parental support needed and decrease of interest. Three kids (child1, child2 and child3) joined the study at the start of the summer, while the other two joined the last week of summer which included an intense week of hand therapy at a rehabilitation centre. For child4 the test coincided with the start of the school year and after school activities, so she felt too busy. “This week was very busy. Yes, we pick her up at 5 o’clock. And then we go to dinner, then we often don’t have time to play a game and then she goes to bed”. Child2 preferred to play outside during that period and during the second week she preferred to play with other toys. Child1 had an important end of the school year test during the second week that kept her busy and later it was no longer possible to play "because the time she wants to play it is bedtime "[father child1]. Child4 mentioned that she did not play much during the last week because a friend was visiting, and she also forgot because she was at school. The father of child3 is the person who usually helps him with his exercises; child3 stopped playing with the toy towards the end of the study because his father had to travel abroad, and he felt that he could not do it by himself for fear of damaging a phone that did not belong to them. Furthermore, child3 is used to play with the ipad often and has a lot of experience with video games, his father mentioned that “keeping him motivated on it is a bit difficult [because] if it doesn’t function as expected then it’s like ohh no then [he] puts it down” which made him prefer to play games on the ipad. Regarding interest, parents also observed that during the first days the children did not need to be reminded to play with the toy, in the case of child1 her mother mentioned “I did not need to remind her for the first two days, after that I had to”.

Theme 3: Perceived benefits

This theme describes the perceived benefits of incorporating the Magic Monster as part of a home therapy, this includes factors that motivate children to engage with the Magic Monster, the improvements in motor skills and the enjoyment derived from the toy. Children and parents were enthusiastic about the use of the Magic Monster throughout the three weeks of the study. When asked if she wanted to perform a magic trick during the last conversation, child1 felt proud and with a sense of empowerment, she took the role seriously and performed the trick as if she had a big audience. She later mentioned that she wanted to keep it the whole year. Which demonstrates a strong attachment to the toy, with a desire to keep it for an extended period. Child2 mentioned during the second visit that she had given the Magic Monster the name “Schatje” which indicates a closer connection with the toy. At the end of the study, she was reluctant to return it. The mother of child5

mentioned at the end of the study “My daughter found the Magic Monster fantastic! She thoroughly enjoyed the Magic Monster for 3 weeks!!!!”, while her child5 enthusiastically asked “When will the Magic Monster be available to download on our phone?”. Child4 mentioned that she liked the Magic Monster a lot. Regarding the improvement of motor skills, the mother of child1 said “I do notice that it really really stimulates hand movement.

Yes, because she really needs it for that exercise.”. Child3’s father also noticed a difference in the quality of the hand movement “So when he’s sitting there and he moved his wrist like he should have, which I think is super!”.

Theme 4: Recommendations - looking towards the future

This theme gathers recommendations, functionalities, and visions of the future of the Magic Monster. Regarding the monster’s design, the parent of child3 suggested to “Add more challenges, and points, [because] the sense of competition works well with child3.” Child1 and child2 would like to hear the Magic Monster talk and give more details of what is happening. To use a smaller phone or device that fits better in the child’s hand was a request from all the participants. Parents and children would like to see other types of hand movements like wrist rotation, individual finger movement, grip and other movements to encourage fine motor skills and to gain strength. Although this toy was designed for children aged 7 to 12 years old, parents already started to wonder how they could continue to use it when their child is older, the parent of child 5 suggested to add “different sounds and other magic tricks for other age groups”. Child3 found it necessary to have a score or counter in the screen to indicate how many more times he should shake the monster in order to get a challenge or a new trick. He gave us ideas on how to improve the interface to be able to see that “And it’ll tell you how. You can put how many times you did it and how [many you need], like on the left side top, you actually get how many you’re supposed to get, [and] on the right top it shows you how many [coins] you have”. Throughout the study he showed a strong interest in gamification, control and goal settings.

5.5 DISCUSSION

This study explored the design and evaluation of the Magic Monster, a smart toy aimed at increasing motivation and adherence to hand therapy at home for children

with spastic cerebral palsy (CP). This discussion examines two main aspects: first, the design considerations necessary to create an engaging therapeutic tool, and second, the impact of self-adaptive play complexity on engagement and adherence. By reflecting on these findings, we highlight key takeaways for future research and the development of interactive rehabilitation technologies.

5.5.1 Designing Smart Toys for Motivation and Adherence

Looking back on our research, we reflect on the insights gained from our study, drawing lessons for the design of smart therapeutic toys and their impact on therapy engagement.

Integrating Design Methods into Principles

Diverse research and design methods ensure a multifaceted understanding of user needs, making the design process deeply user- centric. The methods used should be tailored to the participants, while keeping a clear goal of the activity. For example, using a theoretical framework like the SCOPE-IT model gave us a starting point to identify informed requirements in the design of therapeutic interventions. The observation study and interviews with the therapists helped us get a first-hand understanding of the therapy process, the therapist's role and the children's expectations. The cultural probe method gave us a deeper understanding of the children's home environment, which allowed us to analyse how feasible it could be for them to use a smart toy for therapy at home. These methods informed key design principles, such as adaptability, playfulness, and accessibility, which were embedded in the final prototype.

Engaging Stakeholders in the Design Process

It is well known that a user-centred design approach leads to a deep understanding of the problem and a better solution. However, it is not always possible to have access to the target group, especially when it is a vulnerable group like children with disabilities. What can be done in those cases is to identify which other stakeholders can provide relevant information and which are the most suitable activities according to them. Therapists know the problem in-depth and can be a starting point with a broader view; parents witness daily the joys and struggles of their children, so they can provide more specific information. A similar group, such as children without disabilities but in the same age group, can provide information about the type of toys and themes enjoyed by children of that age group. They can also help us test the prototype for likeability and functionality. However, we need to

be mindful about which aspect of the research will be evaluated by whom. In the end, there are aspects that only the target group can help us identify, as there can be physical and cognitive differences between them and other participants.

Adaptability and adaptivity in Therapy

When children are part of therapy programs, the expert eye of the therapist identifies when a child is ready to use a different tool or how to modify a toy to increase the challenge of the exercise. When children are at home, they may not be able to have that feedback. Although there are well-known scales used to classify how children with CP use their hands in daily activities, such as the manual ability classification system (MACS) scale (Eliasson et al., 2006), each child is different and each child has a different level of spasticity. With sensors and data collection, a machine learning-based model can identify the child's level and self-adapt the difficulty level. Therefore, it is necessary to design solutions that can adapt at an individual level. During our design process, we kept this in mind, not only in the use of sensors and data that measure the angle of rotation of the wrist and speed of movement while doing dorsiflexion, but also in the toy's design by adding extra bands or removing padding to make it comfortable and easier to use. Since these pertain only to modifying the plush toy cover and not to the phone application, they are easy to perform. Customising the intervention to the user will provide a more comfortable and effective experience.

Play as an Intrinsic Motivator

The interest in using play for health has existed for some time. Therapists see the potential to use the engaging elements of play to motivate their patients because play can be active, sociable, meaningful, and enjoyable. Playful objects that can be used for therapy contribute to creating an impact on the player that goes beyond entertainment (which is highly valuable as well) and positively impacts the player's real world. Children with disabilities need to be children and enjoy a fun and relaxing activity with family and peers. Designing playful activities that can also positively impact their motor ability, in the case of children with CP, allows them to enjoy their free time without the burdensome pressure of doing another therapeutic exercise. The Magic Monster incorporated game principles such as challenge (adapted according to the player's skill), completion, feedback, and feedforward. The Magic Monster reacts with sounds and movements, giving feedback on the actions performed. Furthermore, it has feedforward mechanisms in the shape of challenges to encourage and motivate children to continue exercising based on a

personalised analysis of the child's skills. The use of metaphors (framing exercises as magic tricks) encouraged playful interactions and helped reduce the burden of repetitive therapeutic movement. Starting from play principles (Bekker et al., 2014) helped define the functionalities of the smart toy. Our findings align with previous research suggesting that embedding play in therapy increases adherence by making exercises more enjoyable and less task-oriented.

5.5.2 Effects of Self-Adaptive Play Complexity on Engagement and Adherence

Factors Influencing Adherence

The field evaluation of the Magic Monster presented in section 4, showed that participants' involvement levels varied, with some children engaging more intensively over fewer days and others less often. Although none of them played every day of the study, which was expected given that children in general do not tend to play always with the same object, and the novelty decreases. Individual preferences, scheduling restrictions, even weather and the need for parental assistance all had an impact on these disparities. There was also the fear of using a phone that did not belong to them, if in the future they could download the game in their own phones they might feel more comfortable about the way they play with it. While the questionnaires and conversations found that children and parents generally liked the toy's design and interactive elements, issues such as physical comfort and simplicity of game interactions were reported, limiting playing for certain participants. The quantitative analysis shows that the benefits of AI only do not suffice to maintain adherence to the therapy if the novelty of the smart toy decreases and if there are not enough interactive elements to maintain interest. Besides having a machine learning algorithm, the smart toy should provide a wider option of games and fun interactions for the player.

Engagement

Looking at the scores of the questionnaires, a noticeable finding is that engagement was rather high throughout the research. Considering the answers from children and parents, we could attribute this high score of engagement to the need to incorporate a new type of toy for therapy. However, some challenges—such as comfort issues and limited game variety—highlight the need for continuous refinement. Our results suggest that while adaptive difficulty can enhance

engagement, supplementary features such as expanded game modes and additional interactions could further improve the therapy experience.

5.5.3 The Magic Monster as a tool for therapy

Therapy and therapeutic goals

A good understanding of the therapeutic aspects of the intervention is essential for properly developing therapeutic tools; this is also reflected in the work by Perera and Ranasinghe (2018), where they use a similar multidisciplinary and iterative approach to designing assistive products for children with CP. By starting with understanding the context and selecting therapy principles, the design can have a clear direction. Our therapy principles include using bimanual activities to prevent compensatory hand movements, focusing on hand movements like dorsiflexion, promoting repetitions, and adapting to the player's skill level. Defining a clear goal for the toy, like working on a specific hand movement, can help focus on designing interactions that contribute to the therapy. However, it can also limit the diversity and number of interactions that the toy has, thus potentially reducing the amount of entertainment and keeping the child engaged.

In the Magic Monster, we included the lessons from our design process and other existing smart toys to provide not just a tool for therapy but a toy that children can play with and enjoy, with the added value of exercising their hands. The Magic Monster also has some further advantages. For example, it uses a mobile phone, an off-the-shelf technology that is an accessible and sustainable option for most families and easy to set up at home. It promotes bimanual activities by encouraging children to hold the Magic Monster with the affected hand and a coin or ball with the non-affected hand. In this way, it prevents children from using only their non-affected hand, as they commonly do in most activities. The Magic Monster has physical and digital elements, providing multisensory stimulation that helps develop sensory integration skills. Haptic feedback of a physical object, in combination with the digital aspects of the toy, provides extra interactions that make the play experience engaging and motivating. The Magic Monster's machine learning-based recognition module has been trained to detect dorsiflexion. An initial calibration phase sets the difficulty level of the smart toy; after some repetitions and assessment of movement, the difficulty increases or decreases to fit the player's skill, providing a customised play experience. The Magic Monster allows children to perform a magic trick for themselves or an audience. Making this

a shared activity also gives them a sense of pride and empowerment because a social context can motivate children to perform better.

5.5.4 Challenges

Challenges and considerations during the development phase were plenty. The main challenge was the limited access to the target group; initial tests had to be done with children and adults without CP. However, we see that this is a common challenge in similar studies (Li et al., 2008; Bian et al., 2020; Minh et al., 2021; Wu et al., 2022). The machine learning model was initially trained with adult data, which was later validated with children with spastic CP. Another challenge was the size and weight of the mobile phones used. Most available phones in the market are getting bigger and heavier to provide more memory, storage, and camera functionalities, and proved to be too heavy for the hands of children with spastic hemiplegic CP who already have a more impaired upper arm; this was solved in the design by adding extra bands for support and removing some of the padding. Something to consider in the case of children with CP is that they often use a splint on their hand for support; this was the case of child1; this type of support can affect the intended use of the toy, and removing it can hinder the autonomy of children to start to play because they would need assistance from a caregiver to remove the splint and put it back once they finished playing.

We have identified some areas of improvement, including developing an open platform to create mini-games or other types of interactions that can be adjusted to children's preferences. Another point for further work is to develop a family of monsters guided by therapists; children can choose depending on their therapeutic goals. Each monster can help train different hand movements. An example of such a toy is the Squid monster (Alberts et al., 2022). Another possibility is to develop the toy into a digital companion for enacting behaviour change. We also see the need to create a platform for therapists to monitor the therapy's evolution remotely.

5.5.5 Future work

Our ongoing research and future developments of smart toys for therapy aim to improve and validate adaptability, adaptivity, engagement, and impact in supporting therapy programs for children with cerebral palsy. To achieve this, future work should continue to prioritize a participatory design approach with diverse stakeholders such as children, parents and therapists. However, because

children, the primary users, develop in a family context, further exploration is needed into tailored designs that integrate the families' preferences and routines and the therapists' advice. Moreover, incorporating real-time monitoring and data collection could improve the precision and reliability of SCED methodologies in evaluating therapeutic tools. Future iterations of smart toys for therapy should explore advanced AI algorithms for better personalisation, including more nuanced calibration and thresholds for hand movements and the ability to detect and adapt to different therapeutic goals, such as dorsiflexion vs. wrist rotation. Finally, given the utility of SCED for small sample sizes, future research could broaden its application by including more diverse participants and longer evaluations that explore the effects of different toy functionalities such as types of feedback and feedforward, comparison of modalities and varying play modes.

5.6 CONCLUSION

This research presents the design process, evaluation and main insights of a smart toy that aims to become a companion for children that encourages exercise while playing. From this process, we can conclude that home therapy using smart toys has the potential to be motivating for children with spastic CP and, therefore, have a positive impact on the treatment of motor impairment and well- being. Designing smart toys for therapy is an intensive process requiring different stakeholders' involvement with design methods that align with their needs and wants. Our process successfully achieved this by integrating design principles, user feedback, and technological elements to create a smart toy that aligns with therapeutic goals and enhances children's engagement in hand therapy while elevating their play experience. Although a therapeutic smart toy is not a replacement for a therapist, a smart toy like the Magic Monster can be part of the therapy program focusing on the home environment. Our research underscores the importance of user-centred design, stakeholder collaboration, and iterative development in creating effective therapeutic tools.

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Chapter 6

WRIST MOVEMENT CLASSIFICATION FOR ADAPTIVE MOBILE PHONE-BASED REHABILITATION OF CHILDREN WITH MOTOR SKILL IMPAIRMENTS

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Rehabilitation exercises performed by children with cerebral palsy are tedious and repetitive. To make them more engaging, we propose to use an exergame approach, where an adaptive application can help the child remain stimulated and interested during exercises. In this paper, we describe how the mobile phone sensors can be used to classify wrist movements of the user during the rehabilitation exercises to detect if the user is performing the correct exercise and illustrate the use of our approach in an actual mobile phone application. We also show how an adaptive difficulty system was added to the application to allow the system to adjust to the user. We present experimental results from a pilot with healthy subjects that were constrained to simulate restricted wrist movements, as well as from tests with a target group of children with cerebral palsy. Our results show that wrist movement classification is successfully achieved and results in improved interactions.

6.1 INTRODUCTION

Children with cerebral palsy often need to perform repetitive movements during these therapy sessions. It can be a difficult task to keep them motivated to continue doing these exercises regularly, especially when these need to be performed at home in between sessions with their therapists. When they are intrinsically motivated, they participate in therapy for their own satisfaction and are more likely to improve and keep up with their therapy sessions and exercises (Ryan & Deci, 2000). Moreover, children with cerebral palsy might often encounter frustrating moments and failure during their therapy, which underlines the need for keeping therapy as motivational and engaging as possible to minimise frustrations and uphold motivation (Fikar et al., 2018). It is therefore important for a therapist to accommodate an environment that both enhances self-directed engagement in therapeutic exercises and also provides intrinsic motivation to perform the therapy exercises at home.

Since the exercises recommended for cerebral palsy are often not inherently experienced as being enjoyable, applied games can be a powerful tool to motivate children to gain more intrinsic motivation, and can contribute to a higher degree of personalization and adaptivity to accommodate their individual needs (Pinos Cisneros et al., 2020; Salah et al., 2014). Digital developments make different types of learning incorporated into video games possible, allowing for games that are both engaging to play and can help children to learn (Williamson et al., n.d.). They can help decrease the negative aspects of therapy, such as frustration and boredom, and increase the positive aspects, such as happiness and enjoyment, and can therefore be a suitable tool for providing intrinsic motivation for children to perform their therapeutic exercises.

The hand and wrist rehabilitation of cerebral palsy patients focuses on a type of movement called “dorsiflexion”. The dorsiflexion of the wrist and hand involves bending the hand upward towards the top of the forearm; the downward bending movement towards the bottom of the forearm is called “palmar flexion”. The main exercise for the patients is shaking the hand up and down, moving between dorsiflexion and palmar flexion repeatedly. The mobile rehabilitation application requires such movements for successful completion of its tasks.

In this cahpter, we describe how a mobile application that has been developed for facilitating hand therapy can be extended to become adaptive by

classifying hand and wrist dorsiflexion movements of its users on the fly. For this purpose, we test the suitability of a small number of classifiers, based on the sensors on the phone. We test and refine our approach first on a pilot study with healthy subjects, whose wrists we constrain in several ways to simulate patient conditions. Our original target group for this application is children from ages 7 to 12, who have hemiparesis as a result of cerebral palsy and are within level I or II on the Manual Ability Classification Scale or MACS (Eliasson et al., 2007). After the pilot, we also conduct an experiment with eight children with cerebral palsy and present our results.

We briefly introduce the mobile phone based exergame application here, which serves as our experimental platform. The phone is inserted in a soft, animal-shaped sheath, and the phone display becomes the face of the animal, which is capable of expressing emotions, as can be seen in

Figure 6.1. In the game, the animal is an assistant for performing magic tricks and comes with a separate booklet in which the magic tricks are explained. The performing of the trick requires some dexterity, and wrist movements are performed during the procedure. The mobile application core used for this research has been previously developed by a gaming company using the Unity3D game engine and runs on Android phones.

Figure 6.1 The monster case used for the Magic Monster application and a screenshot from the mobile app.

In this study, we implement a movement recognition system to accurately recognize dorsiflexion movements during the use of this mobile application, as well as an intuitive adaptive difficulty system. Since the patients need to perform specific movements as part of their hand therapy, the accuracy of these movements needs to be assessed to evaluate therapy progression. Also, different patients have different needs and might not have the same range of motion in their wrists as other patients. Consequently, it is necessary that the application should adjust to the user, and keep adjusting if the capabilities of the user change over time.

The remainder of the chapter is structured as follows. First, we discuss related research in Section 6.2. Next, we present our data collection approach for the movement classification system in Section 6.3. In Section 6.4, we describe the features we use and the approaches tested for the classification of dorsiflexion. The experimental results are summarised in Section 6.5. In Section 6.6 we present the adaptive difficulty system introduced to the application. Section 6.7 reports results obtained with the target patient group. Finally, we provide a discussion and conclusions in Section 6.8.

6.2 RELATED WORK

The potential of personal informatics (PI) systems for people with motor disabilities has been discussed in (Motahar & Wiese, 2022). Here we focus on games that target children with motor skill impairments specifically, as well as provide some references for mobile phone based activity recognition, which is a very broad area due to the potential richness of the activities that can be detected. This chapter, however, is the first for detecting dorsiflexion movements in the literature.

6.2.1 Games targeted at children with motor skill impairments

While many applied games in the field of health have been developed in the past, the selection of applied games that specifically target children with motor skill impairments is not as substantial (Ayed et al., 2019; Page et al., 2017). In Gürbüzsel et al. (2022), a number of smart toys and game applications are listed to monitor and enhance fine motor skills of children, but these are not geared towards rehabilitation. Researchers from the University of Amsterdam and the Amsterdam

University of Applied Sciences developed a game for detecting delays in motor skill development on a commercially available toy called the *Futurocube (Sander et al., 2017)*. Using this game, they were able to predict the degree of motor skill impairment in the participants with increasing accuracy as the difficulty of the game rose. More recent work with the Futurocube has focused on using different machine learning techniques for classifying children with motor skill impairments (Brons et al., 2021).

Mironcika et al. (2018) developed a smart toy for motor skill assessment in form of a board game. The goal of this game is to move tokens (depicting mice) across the board and turn them around as carefully as possible so as to not wake up 'the cat'. The tokens contain accelerometers, which are used to assess the smoothness of movements by computing the mean-squared jerk feature. The results show that children with better fine motor skills can move the tokens more smoothly using one hand, making the game suitable for detecting motor skill impairments. Moreover, the game was perceived as fun and exciting to play by the children participating in the experiment. More recently, Naya et al. (2021) presented a mobile application for analysing the fine motor performance in children based on a similar idea, by making them move an object along several paths, varying in difficulty from straight to zigzag-shaped.

A smart toy that was developed for practising fine motor skills in (Serpa-Andrade et al., 2021) encompassed several different exercises to practice different types of movements: tracing a path while holding a pen, placing clothespins on colored fabric, and carrying a metal ring from left to right while avoiding touching the filament, respectively. In most of these applications, the difficulty of the game is adjusted by having multiple challenges with different difficulty levels. In this chapter, however, we measure and adapt the difficulty to the child. Measuring performance has the double purpose of observing rehabilitation progress longitudinally.

6.2.2 Human activity recognition using smartphone sensors

A modern smartphone contains a variety of sensors, including an accelerometer, a magnetometer, and a gyroscope, which can be highly useful for recognizing the activities of a user (Peng et al., 2018; Ravi et al., n.d.; Shoaib et al., 2014). Previous research has largely focused on human movement recognition using the sensors available in smartphones (Micucci et al., 2017; Nweke et al., 2018, 2019; Pires et al., 2016). The most common application is the detection of everyday activities

including sitting, walking, and walking up the stairs. For these types of applications, the phone is usually passively carried around. Some of these applications addressed disabilities or pathologies impairing movements of the limbs, such as gait (Zhang et al., 2019).

Deep learning methods have become widely used for activity recognition in recent years (Bozkurt, 2022). Some examples of different types of networks previously used for activity recognition include basic multilayer perceptrons (MLPs) (Wang et al., 2019), convolutional neural networks (CNNs) (Ignatov, 2018) and recurrent neural networks (RNNs) (Murad & Pyun, 2017).

CNNs are mostly used for visual data, such as images and video, but have also been used on time series data such as sensor data collected using smartphone sensors (Ignatov, 2018; Wang et al., 2019). One study proposed the use of CNNs for activity recognition using the accelerometer in a mobile phone (Ignatov, 2018). As input for the network, they used both the raw accelerometer data and a selection of extracted basic statistical features that describe the global properties of the time-series data. The combination of both seemed to achieve the best performance. For mobile phone applications, shallow architectures and lower computational costs are desirable, as battery life is an important consideration.

For supervised activity recognition tasks, the temporal dimension is important, as a large part of the challenge is to properly segment the activity boundaries and to provide continuous class labels. For this purpose, RNNs (Murad & Pyun, 2017) and long short-term memory (LSTM) networks were used (Chen et al., 2016). LSTM layers can also be combined with convolutional layers to create more complex models for human activity recognition using raw mobile phone sensor data (Xia et al., 2020).

In our application, we examine a range of simple to complex models to classify dorsiflexion movements. What is more important than the selection of the machine learning approach is the insights into how a cerebral palsy patient would handle a mobile phone during the exergame, and how that will affect the performance of the classifiers. We first deal with the problem of data collection, as most ML approaches need as much data as possible to provide good classification results.

6.3 DATA COLLECTION

To train a model for distinguishing dorsiflexion from other types of hand movements, we collected data for a variety of movements, as well as dorsiflexion movements from different starting positions. We have defined 28 distinct movement classes: the first 10 classes describe dorsiflexion movements from different starting positions, and the other 18 classes describe other kinds of movements and non-movements which function as the true negatives in the dataset, including rotations, shaking, and the phone sitting still. We use the accelerometer and the gyroscope to record the data along three perpendicular axes (x, y, z). The phone that was used for data collection, and all subsequent training and evaluation, was a Samsung Galaxy A52.

We have created a custom mobile application for data collection, where the user is shown an animation showing how to perform a movement, along with auditory instructions and a text description of the movement. This interface selects ten movement classes per session randomly for each user. Additionally, we recorded the hand movements of the user using an external video camera, for improving annotation quality. A total of 37 data collection sessions with 20 unique subjects were completed. Before participating in the experiment, the subjects were informed of the purpose and methods of the study and signed a written consent form. The data collection and storage procedures were reviewed and approved by a medical ethics review committee (dossier 2022-15818).

Two annotators manually annotated the beginning and end times of the movements using the annotation tool ELAN (Brugman & Russel, n.d.) Only a binary label was introduced (i.e. dorsiflexion vs. no dorsiflexion) during the annotations.

The resulting dataset consists of a total number of 337 segments, out of which 113 are classified as dorsiflexion movements. The dataset is divided into a training (15 subjects) and test (5 subjects) set for model training and evaluation purposes. The test set contains 53 segments, representing 15.7% of the total dataset.

Figure 6.2 and Figure 6.3 show two examples of what the data looks like, for one dorsiflexion movement and one non-dorsiflexion movement (i.e. rotating the phone), respectively. The collected accelerometer and gyroscope data are plotted for each of the three axes. From these plots, it can be seen that the recorded

sensor data for these movements look similar at first sight, especially when looking at the gyroscope data.

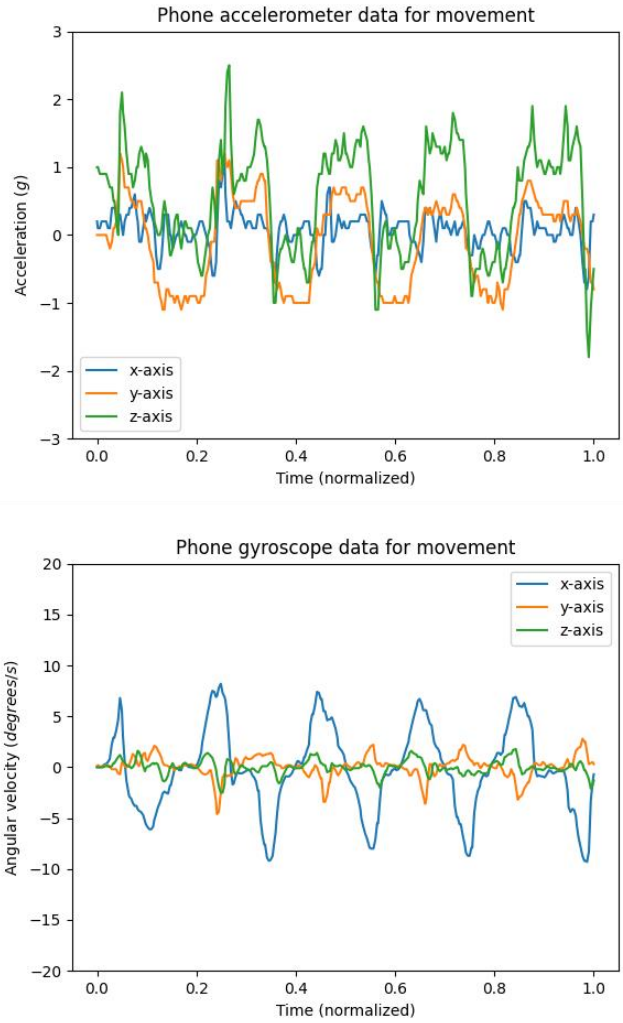

Figure 6.2 Recorded sensor data for movement class 1: dorsiflexion with the phone upright and the screen turned away from the hand palm.

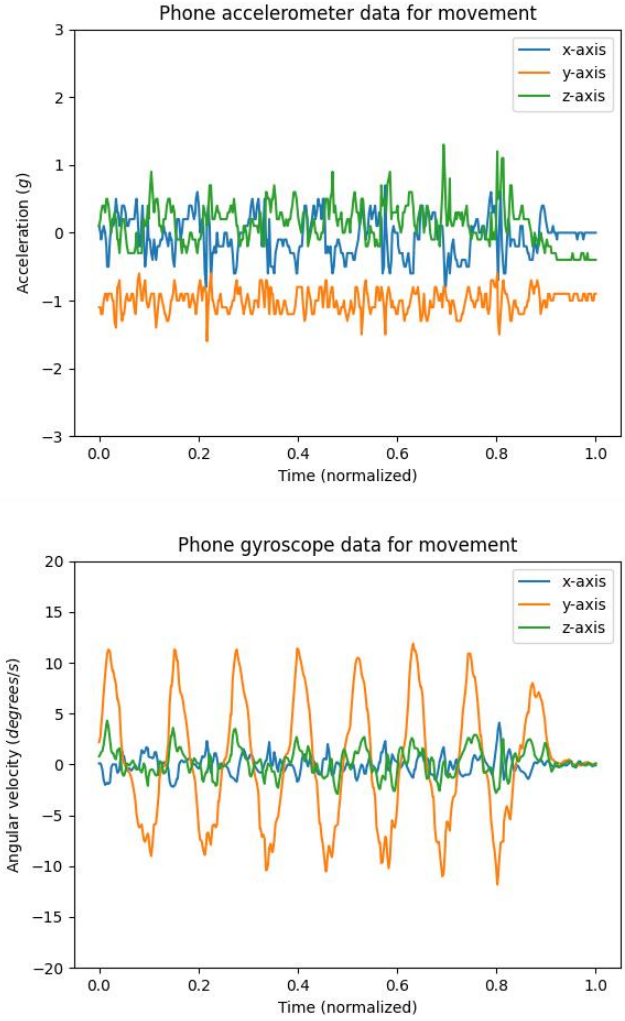

Figure 6.3 Recorded sensor data for movement class 21: rotating the phone to the left and right side alternately, with the phone held horizontally and the screen turned upward.

6.4 CLASSIFICATION OF DORSIFLEXION

6.4.1 Feature extraction and selection

We investigated both feature extraction and feature selection to train the machine learning models. For the former, we extracted seven low level descriptors (i.e. mean, min, max, standard deviation, variance, skew, and kurtosis, respectively) from each of the axes of the sensors, resulting in 6 × 7 = 42 features. Each feature was normalized using min-max normalization.

For feature selection, we used the Minimum Redundancy Maximum Relevance (mRMR) algorithm (DING & PENG, 2005). This method attempts to find an optimal number of features by eliminating redundant features. For each feature, a score is computed based on the maximum relevance with regard to the output variable, and minimal redundancy with regard to the already selected features. The algorithm iterates until k features have been selected. One advantage of mRMR is the explainability of the selected features, which is important because we want to be able to explain the logic behind the selected thresholds for the dorsiflexion movements.

There are various options for score functions to use with mRMR, and we used a function that combines the F-test statistic and the Pearson correlation coefficient to compute a score for each feature (Zhao et al., 2019). This method is simple and fast, yet provides comparable results to other implementations of mRMR. The relevance of a feature is computed as the F-statistic between the feature and the target output. The redundancy of the feature is computed as the average Pearson correlation between the feature and the features selected during previous iterations.

6.4.2 Classification

We tested and compared several machine learning approaches of different complexity for solving the classification problem. Since the mobile phone presents a limited energy budget, simple approaches are preferred to computation-heavy approaches. We tested k-nearest neighbors (k-NN), support vector machines (SVM), multi-layer perceptrons (MLP), convolutional neural networks (CNN), long-short-term-memory (LSTM), and Bidirectional LSTM, respectively. To evaluate the results, we used classification accuracy, precision, recall, and the F-score.

A basic k-NN classifier is used as a baseline algorithm with the 42 features obtained via feature extraction, as described earlier. We used the Euclidean distance as the distance function, and leave-one-out cross-validation on the training partition was used to select the value for k that provided the highest accuracy, which was set as 1.

Next, we performed mRMR to determine the features to be used for the final model. The highest training set accuracy was observed when using 21 features out of 42, ultimately resulting in an accuracy of 0.997 on the training set for k = 1 and 21 features. Therefore, these are the values that are used for evaluation on the test set. We have tested dynamic time warping (DTW) in conjunction with kNN, but DTW is too time-intensive to use in a real-time application and was not taken into further consideration.

The second model we trained is a support vector machine (SVM) with a linear kernel, using the same features that were used with 1-NN. Using mRMR on the training set resulted in the selection of only 2 features out of the 42, with a cross-validation accuracy of 0.993. We also trained four neural network (NN) models.

Multilayer perceptron (MLP)

The first NN we have trained is a multilayer perceptron, with two hidden layers (with 128 and 256 neurons, respectively), a dropout layer, and a classification layer. This network takes as input the same features that are also used for the k-NN and the SVM. We first used mRMR to select the appropriate number of features, computing the accuracy using leave-one-out cross-validation on the training set for each possible number of features. The network was trained with the ADAM optimiser for 100 epochs max (Kingma & Ba, 2017).The highest scoring number of features was 37, with an accuracy of 0.958.

Convolutional neural network (CNN)

While CNNs are most commonly used for image recognition and classification tasks, they can also be applied to activity recognition tasks using sensor data. The network structure we used was based on a CNN used previously for activity recognition (Ignatov, 2018). The first layer is a 1-dimensional convolutional layer with 196 filters. The kernel size used is 1 × 16. This convolutional layer is followed by a max pooling layer with pool size 4 and a flattening layer. Next is a dense layer with 1024 neurons, followed by the classification layer.

Long Short-Term Memory

We tested an RNN with LSTM layers (Hochreiter & Schmidhuber, 1997). LSTMs have been shown to benefit from at least two or more LSTM layers, which is why our model had two LSTM layers, with 128 and 256 nodes respectively. They are followed by a dropout layer and the classification layer.

Bidirectional Long Short-Term Memory

The BLSTM was constructed similarly to the LSTM, but instead of two LSTM layers, it contains two BLSTM layers, also with 128 and 256 nodes, respectively (Schuster & Paliwal, 1997). Similar to the LSTM, the BLSTM layers are followed by a dropout layer and the classification layer.

6.5 EXPERIMENTAL RESULTS

The experimental results of each trained model can be seen in Table 6.1. The accuracy, precision, recall, and F-score are shown for each of the models, reported on the independent test set. The precision, recall, and F-score are also shown for each class separately. The highest scores are shown in bold text for clarity.

The CNN model performed well overall, but the precision and recall results indicate that most of the time dorsiflexion movements are indeed classified as such, but there are also false positives. This is made evident by the fact that the F-score for these models is lower. The more complex NN models show more balanced scores and higher F-scores, with CNN scoring the highest overall, suggesting that it is a suitable machine learning model for classifying dorsiflexion in a binary classification task.

6.6 ADAPTING THE GAME TO THE USER

When a movement has been positively identified as a dorsiflexion movement, we want to check at what level the user is shaking the phone, using an adaptive difficulty system. The mobile application is supplied with two indicators for this purpose, namely, the range of motion and speed. To achieve adaptive difficulty, the application needs to be able to adjust the sensitivity to the user with regard to these two measures, and slowly decrease the sensitivity to make it harder to get the

correct movement. This feature helps to get the user to progress in their therapy and improve their motor skills.

Table 6.1 The accuracy, precision, recall, and F-score for dorsiflexion recognition per model on the test set.

		*KNN**	*SVM**	*MLP**	*CNN*	*LSTM*	*BLSTM*
Overall	**Accuracy**	0.943	0.925	0.962	**0.970**	0.961	0.964
	Precision	0.932	0.913	0.952	**0.963**	0.949	0.953
	Recall	0.956	0.941	**0.971**	**0.971**	0.968	**0.971**
	F-score	0.940	0.921	0.960	**0.967**	0.957	0.961
Dorsiflexion	**Precision**	0.864	0.826	0.905	**0.938**	0.903	0.911
	Recall	**1.000**	**1.000**	**1.000**	0.974	0.991	0.991
	F-score	0.927	0.905	0.950	**0.956**	0.945	0.949
Non-dorsiflexion	**Precision**	**1.000**	**1.000**	**1.000**	0.987	0.995	0.995
	Recall	0.912	0.882	0.941	**0.968**	0.945	0.950
	F-score	0.954	0.938	0.970	**0.977**	0.970	0.972

* uses extracted features as input, as opposed to raw sensor data

6.6.1 Rule-based adaptive difficulty

We implemented two decision rules to determine at which points the thresholds for both the range of motion and the speed should change. To determine when to change the difficulty, the past performance of the player and the percentage of correct movements over the last 10 registered shakes is analysed. If at least 90% of the movements reached the threshold, the threshold increases; if no more than 60% of the movements remained under the threshold, the threshold decreases.

6.6.2 Calibration

Since we wanted to adjust the dorsiflexion recognition sensitivity to the user, the application first goes through a calibration phase when it is used for the first time. During this step, the player performs dorsiflexion to activate the different stages of the 'magic trick', and the adaptive system uses the first five movements to determine the thresholds for both the range of motion and the speed. Besides the automatic calibration, the user can also reset the thresholds and restart the calibration from the settings screen, or adjust the thresholds manually if they wish. This is a precaution against the application not functioning according to the preferences of the user, who may prefer easier or more challenging settings.

6.6.3 Range of motion

In order to train the system, a pilot was conducted without accessing the target patient group.

Children with hemiparesis as a result of cerebral palsy often wear an arm brace to support their wrist, such as the one shown in Figure 6.4. However, besides supporting the wrist, this arm brace also restricts the movement of the wrist. Subsequently, we used arm braces to simulate restricted wrist movements for different ranges of motion.

Data were collected for the following conditions of dorsiflexion, all from the same starting position to make comparing the movements easier:

- Free movement without the arm brace
- Half-restricted movement with a plastic ruler inserted in the arm brace, resulting in the range of motion seen in Figure 6.4
- Fully-restricted movement with a metal ruler inserted in the arm brace, resulting in the range of motion seen in Figure 6.5

These three degrees of movement are considered the three different movement classes. For each of these movements, we recorded 20 samples. We performed feature extraction and selection as with the previously described experiments. The idea is to obtain features that are suitable to recognise varying strengths of dorsiflexion, which can be used to set a threshold to determine the range of motion of the dorsiflexion movement.

Figure 6.4 Dorsiflexion while wearing an arm brace with a plastic ruler inserted.

Figure 6.5 Dorsiflexion while wearing an arm brace with a metal bar ruler inserted.

A visualization of some of the collected sensor data, for each level of restriction, can be seen in Figure 6.6, Figure 6.7 and Figure 6.8.

We have considered the mean absolute error (MAE), mean squared error (MSE), and root mean squared error (RMSE) to measure the performance of regression models. RMSE is expressed in the same units as the original y values, and penalises higher error values more compared to MAE. Therefore, we have used RMSE for evaluating the models.

For each set of features, leave-one-out cross-validation was used to compute the RMSE for that number of features. Using a single feature (namely, the standard deviation of the x-axis of the gyroscope) ultimately results in the lowest RMSE. On the test set, the model results in an RMSE of 1.419. Since a single feature is powerful enough to determine the range of motion for the most part, the adaptive difficulty system was linked to this indicator, together with the simple threshold adjustment rules described earlier. This provided a simple and reliable method for evaluating the range of motion of the user.

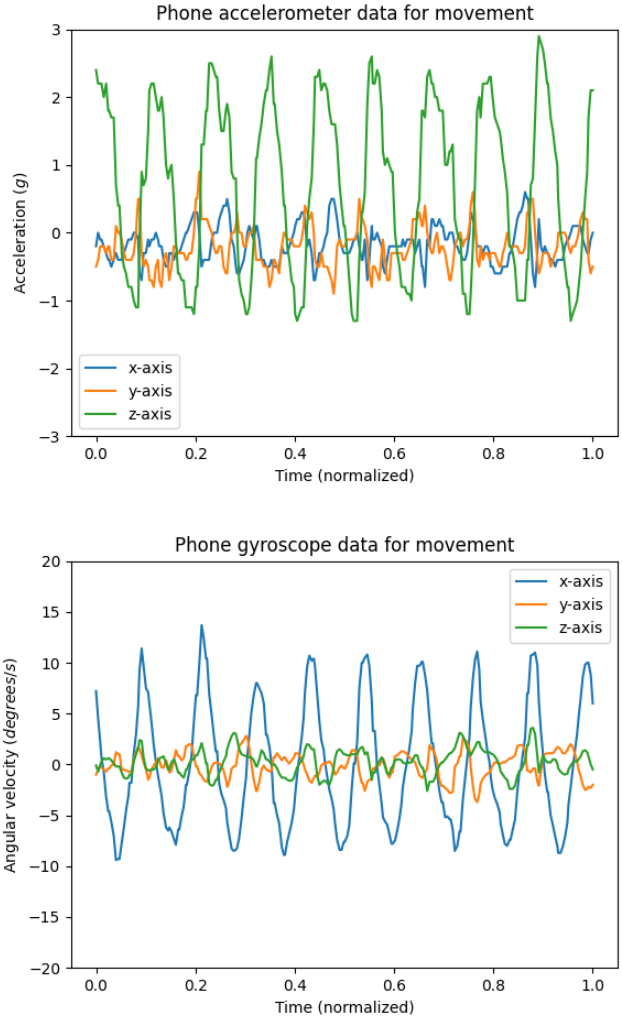

Figure 6.6 Sensor data for dorsiflexion, with the wrist unrestricted.

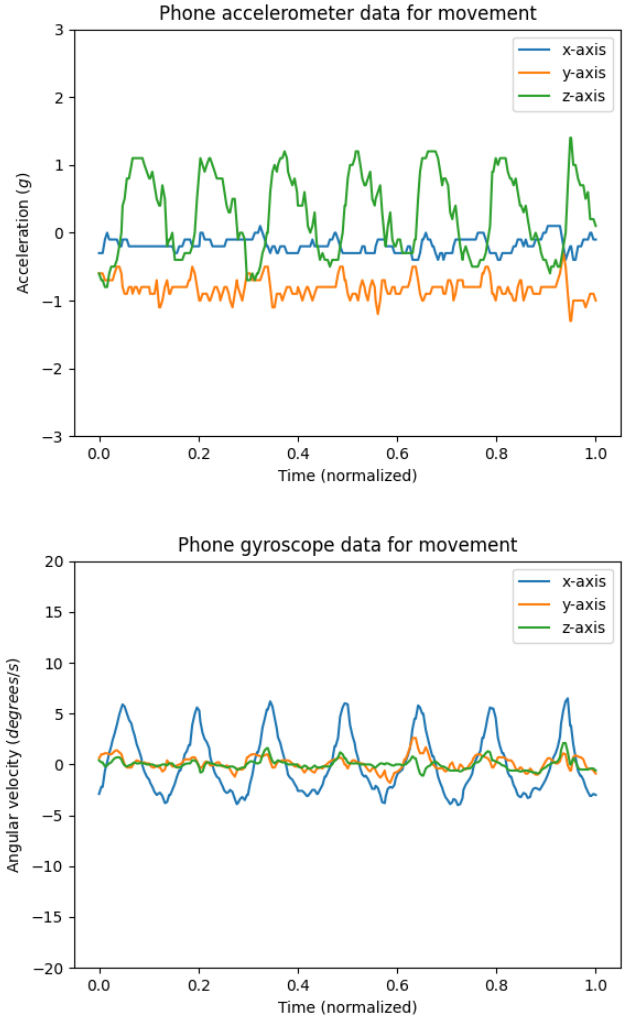

Figure 6.7 Sensor data for dorsiflexion, while wearing the arm brace with a ruler inserted.

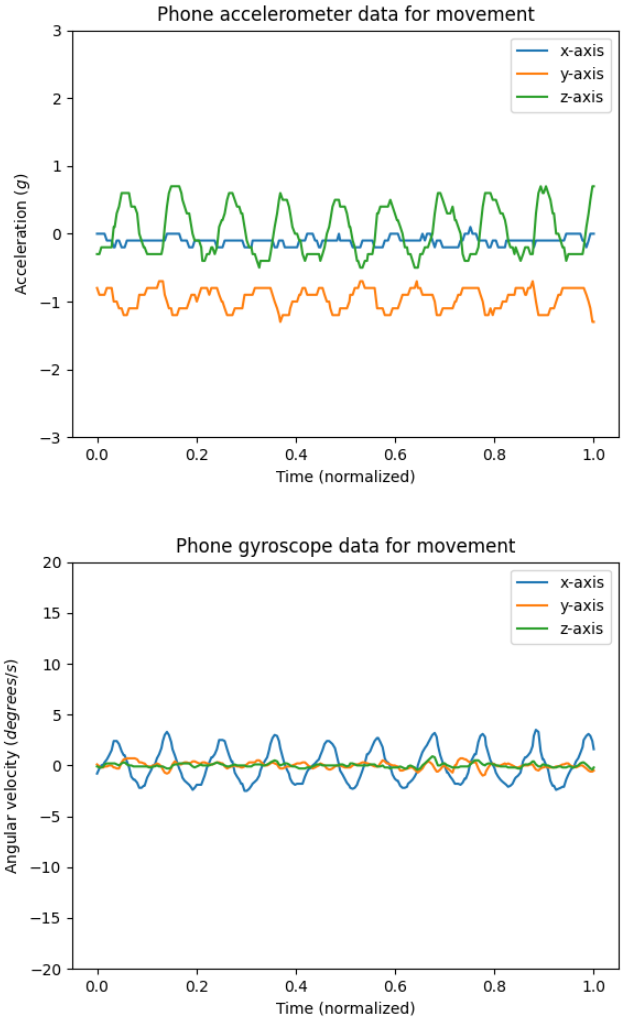

Figure 6.8 Sensor data for dorsiflexion, while wearing the arm brace with a metal bar inserted.

6.6.4 Speed

We collected data for dorsiflexion movements with the phone upright for three degrees of speed, classified as slow, medium, and fast, respectively. These classes were used to provide some qualitative insights, and examples of the collected sensor data can be seen in Figure 6.9, Figure 6.10 and Figure 6.11. A clear difference can be observed between different movement speeds. Most notably, the maximum amplitude of both the accelerometer and gyroscope signals goes up as speed

increases along the axis on which the movement occurred. As can be observed, the signals are similar to the different ranges of motion as seen in Figure 6.6, Figure 6.7 and Figure 6.8. However, what sets the speed apart from the range of motion, is the frequency at which the minimum and maximum amplitudes alternate.

To compute the frequency, there are some different options, including:

- Computing a fast Fourier transform (FFT) and taking the lowest frequency.
- Calculating the number of zero crossings or the number of times the sensor value oscillates about 0. The faster the sensor value oscillates around 0, the higher the frequency.

In our implementation, we used the number of zero crossings for the speed. While this is a rigid scale and does not allow for a gradual increase in difficulty, it does provide clear levels for the user to achieve, and it is intuitively interpreted.

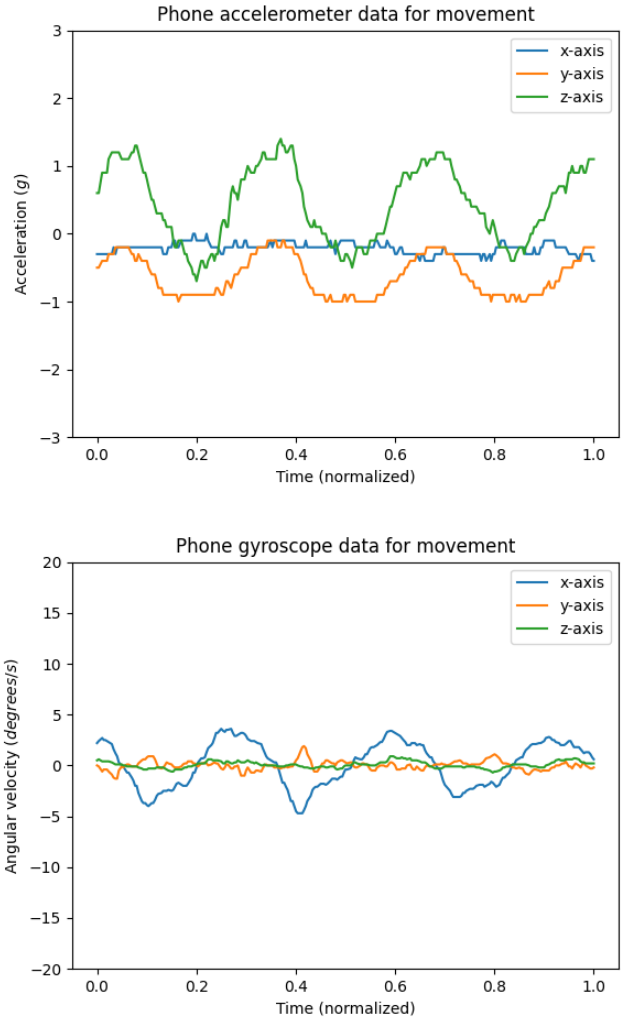

Figure 6.9 Sensor data for dorsiflexion, performed with low speed.

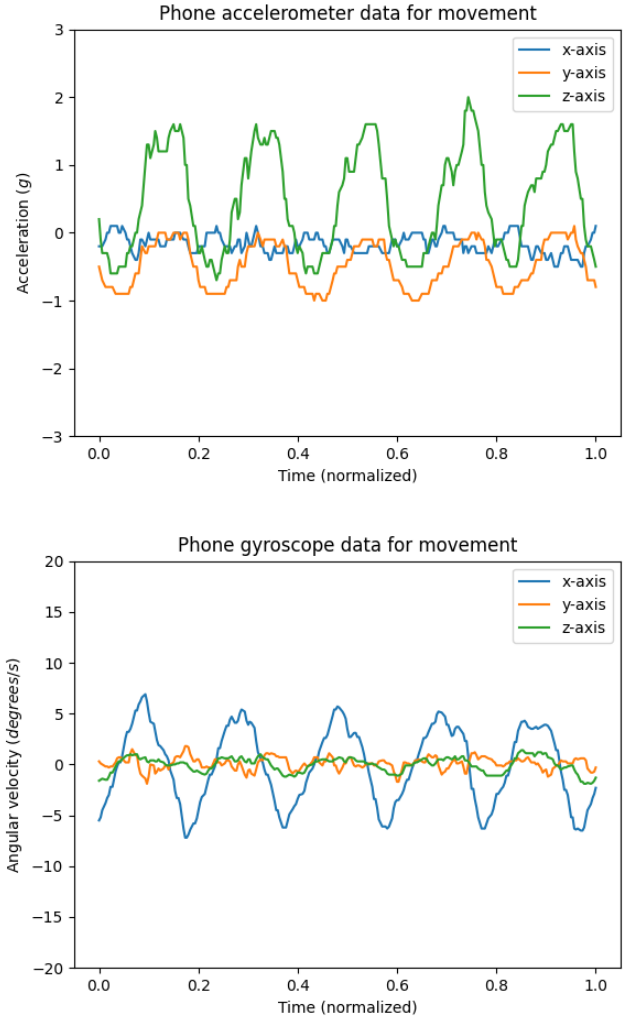

Figure 6.10 Sensor data for dorsiflexion, performed at medium speed.

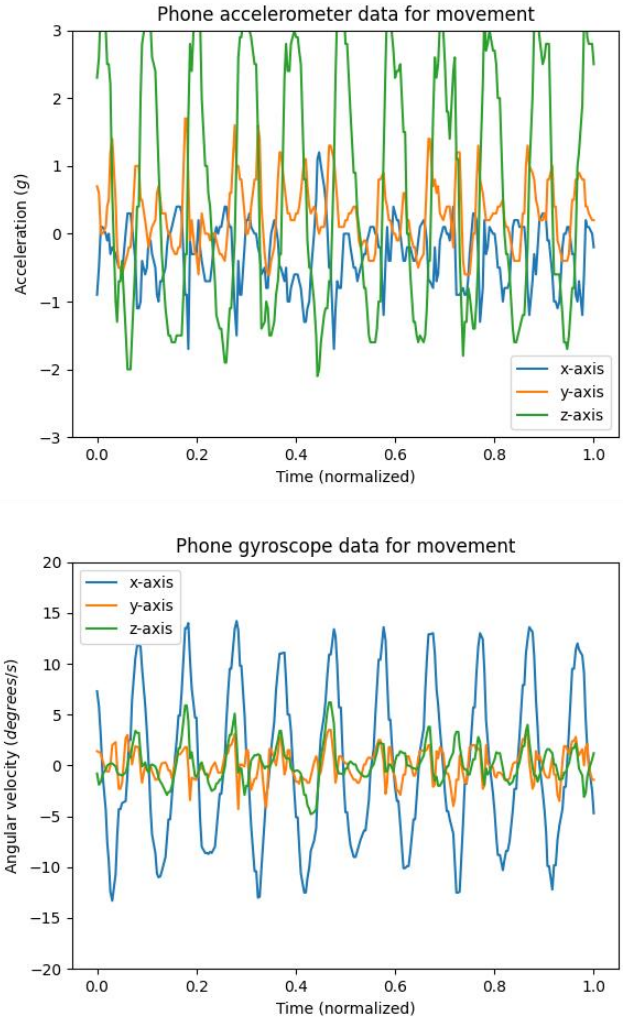

Figure 6.11 Sensor data for dorsiflexion, performed at fast speed.

6.7 TESTS WITH THE TARGET GROUP

Using the implemented dorsiflexion recognition and adaptive difficulty systems as described above, we performed an evaluation test with the target group to check the accuracy of the dorsiflexion recognition system. We collected data from eight children with cerebral palsy during therapy sessions at two clinics that specialise

in treating posture and movement-related disorders. We travelled to the clinics and performed one-on-one sessions with each participant. Each participant was given a demonstration of how the magic monster is supposed to be used and was then asked to play with the magic monster application for three minutes. We obtained ethical approval from the Twente University and the rehabilitation centres prior to the study. The sessions were recorded using a video camera. The parents of the children gave written consent before the session with the magic monster, after informing them of the purpose and data collection procedure of the experiment.

One of the findings of this study, besides the data collection, was that the magic monster can sometimes be difficult and too big to hold for children with cerebral palsy. This is why a strap was added to the back of the monster, which wraps around the hand to hold the monster in place. This strap was added to the monster halfway through the testing phase and could potentially have influenced the results.

Similarly to the previous data annotation that was done for training the machine learning algorithm, two people manually annotated the beginning and end times of the recorded movements in all of the recorded videos using ELAN (Brugman & Russel, 2009). The annotated dorsiflexion movements were then manually compared to the sensor data recorded using the phone. The mobile application checks if it detects dorsiflexion once per second to prevent performance issues by checking more often. The ground truth is obtained by inspection of the videos. The confusion matrix can be seen in Table 6.2.

Table 6.2 Confusion matrix for the binary dorsiflexion recognition.

		Annotated (real) values	
		Positive	Negative
Predicted by AI	Positive	252	10
	Negative	35	931

To further evaluate the results, we computed the accuracy (0.948), precision (0.929), recall (0.846), and F-scores (0.885). Overall, the scores are high, with recall being lower than precision overall, meaning that not all dorsiflexion movements annotated as such are indeed being recognised as dorsiflexion. One limitation is that the target group is very small, and it is difficult to obtain data from

children with cerebral palsy. Our training set did not completely reflect the variation in the target group and was collected from adult subjects.

6.8 CONCLUSIONS

In this study, we proposed a simple approach to detect dorsiflexion movements, and incorporated it into an application for hand and wrist rehabilitation of children with cerebral palsy. Our approach uses accelerometer and gyroscope data and uses a convolutional deep neural network on simple features extracted from these sensors to classify dorsiflexion movements.

Based on the classifier's output, the speed and range of motion were computed into simple indicators, which were added to the exergame to let it adapt to the user. We performed a series of experiments to measure the efficacy of the approach, and also tested the adaptive exergame on children with cerebral palsy.

The study has several shortcomings. More extensive data collection is needed for understanding the user experience aspects with the target group. This could be done with either the data collection application developed for this study, or with the magic monster application itself. While application data can be collected relatively easily, the video data that need to be collected for annotation and quality assessment purposes is much more difficult to obtain, and more sensitive to handle. However, once the annotations are completed, the video data can be destroyed, and only the anonymous gyroscope and accelerometer data can be shared with the annotations.

The data collection was mostly focused on training an activity recognition model, and the adaptive difficulty adjustment of the system was developed with much less data. However, the logic of adaptation is fairly simple, and in general, less data will be sufficient for its development. Nonetheless, there is a need for a longitudinal user study, since the effects of having an adaptive difficulty can only be measured if the application is used for a longer period of time, and against a control group that uses a non-adaptive version of the application. Longitudinal studies can also assess the appeal of the application, and find out whether the novelty wears off, or whether the application loses its likeability after the magic trick is fully mastered.

The current data collection and evaluation were done using only one phone model. For future research, it would be fruitful to collect data using different models and compare the results, since the gyroscopes included in different phones might show slightly different behaviours. An additional shortcoming of the evaluation tests with the target group is that a strap was added to the back of the monster halfway through the data collection, potentially influencing the results.

We have not explored data augmentation strategies, but since data collection is both costly and time-consuming, data augmentation might help increase the number of available data points and increase the versatility of trained models. Data augmentation could potentially help increase the performance and reliability of the trained models when applying them to real-time applications.

Children with cerebral palsy stand to benefit from innovative solutions for aiding them in the arduous rehabilitation process. We believe the developed application can serve as a valuable tool, and the sub-modules can be integrated into other applications.

6.9 ACKNOWLEDGMENTS

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Chapter 7

THE SMART TOY - CTT: DESIGNING FOR CHILDREN'S WELLBEING IN HOME-BASED THERAPEUTIC PLAY

This chapter is based on the article submitted to DSR2026:

> Pinos Cisneros, T., Kröse, B., Schouten, B., & Ludden, G. (2025). Smart Toy - CTT: A Process Framework for Developing Smart Toys for Home Therapy.

Abstract

Integrating play into therapeutic interventions enhances engagement and adherence, particularly for children. However, technology-based therapies primarily focus on video games, limiting applicability for specific physical therapy exercises. This paper introduces the Smart Toy-CTT (Context, Theory, and Technology) framework for developing therapeutic smart toys. Developed through a Research through Design approach, the framework addresses therapeutic design complexities by integrating three layers: context (therapeutic environment, family, and goals), theory (motivation, play, and behaviour-change techniques), and technology (sensors, data collection, and AI-driven adaptability). A workshop evaluation with designers and researchers, along with a case study with children with cerebral palsy, demonstrates how stakeholder collaboration guides the adaptive, engaging design of smart toys. Findings reveal that simultaneously considering context, theory, and technology enhances therapeutic relevance and engagement. The Smart Toy-CTT framework provides practical guidelines for designing effective, playful, and motivating therapeutic tools suitable for home-based interventions.

7.1 INTRODUCTION

Effective home-based physical and occupational therapy for children requires creative strategies to counteract the monotony and disengagement that arise from repetitive activities. Integrating interactive and playful design elements presents a promising alternative to increase motivation and adherence. Fiss et al. (2023) found that incorporating play into (physical) therapy enhances engagement and adherence, especially for children. While traditional interventions often rely on the therapist's encouragement and toy or play suggestions, more novel alternatives propose using video games to make therapy more engaging (Alrashidi et al., 2022; Howcroft et al., 2012; Sajan et al., 2017; Vezér et al., 2024). However, the primary focus on (on screen) video games rather than physical toys limits the applicability of using technology in therapy for specific therapeutic exercises. This may be due to difficulties and frustrations arising from working with a virtual environment (Guberek et al., 2009), but could also be attributed to the limited interaction opportunities these environments offer. Smart toys, which blend play and technology, provide a promising alternative by incorporating physicality and real-time feedback. It also offers the opportunity to tailor the interaction to children's individual skills via AI-driven adaptability, adjusting difficulty, and providing feedback and feedforward to individual needs. Such responsive behaviour could enhance motivation and thus should be explored for personalised home-based therapies.

Although (smart) technology offers many opportunities, (design) innovation in the medical context is challenging. Designers and developers need to understand the complexities across multiple domains: illness characteristics, treatment requirements, policy context, regulatory issues, home environment, potential of the technology, ethical considerations, and the practical challenges of shaping and implementing healthcare innovations. The COVID-19 pandemic struck at the start of this project, highlighting not only the need for home therapy tools but also the importance of employing design methods to navigate the complexity of designing for vulnerable groups, such as children with disabilities. Clark & Mcgee-Lennon (2011) identified potential issues that can arise when developing or providing home-based treatment: lack of acceptance, ethical and legal considerations, costs and resource availability, maintenance of the technology, and (technical) difficulties with the tools. When designing healthcare innovations for the home environment, it is essential to understand the implications of these

devices for that context. We lack clear frameworks or guidelines for creating playful experiences in home-based therapy that could help prevent the issues mentioned above. This chapter introduces the Smart Toy, Context, Theory, and Technology (Smart Toy-CTT) process framework, which aims to support designers and researchers in systematically translating clinical hand-therapy principles into motivating, adaptive, and context-sensitive smart toys for use in the home environment. This framework provides a structured approach to designing smart toys for therapy, organised into three levels: context, theory, and technology.

The Smart Toy-CTT framework is based on an analysis and reflection on our experiences in the Toys4Therapy project, where we developed two smart toys (Figure 7.1) for hand therapy for children with Cerebral Palsy (CP). Magic Monster - Chapter 5, and Squid Monster - (Alberts et al., 2022). Both monsters consist of a mo mobile phone with an application and a physical soft toy that serves as a phone holder. In this way, the phone becomes a toy-monster. The Squid Monster also uses an Arduino and an LED strip. The Magic Monster is a magician assistant that helps children perform magic tricks. The child holds the toy with their spastic hand and shakes it, performing dorsiflexion movements (bending the wrist). The current version has two magic tricks. During those tricks children make a coin or a ball disappear. The Squid Monster helps children practice wrist rotation and grip. In this game, a monkey tries to steal the monster's bananas, and by rotating the monster, the child helps the monster eat its bananas. Synthesising our insights from the development of these two smart toys led to a framework that can be used by developers and designers of smart toys that align with a therapy program. In the Toys4Therapy project, we focused on children with CP and, more specifically, with a spastic hand, for the development of our smart toys; however, the Smart-Toy-CTT framework presents the insights and lessons learned from this project at a higher level of abstraction so that it can be used to tackle the design of smart toys for home therapy aimed at a variety of disorders. In this chapter, we first describe the importance of play and smart toys in therapeutic settings. We then describe related work on frameworks and models that aim to integrate play into therapy, and outline the Smart Toy-CTT framework, which presents the theoretical and practical requirements for smart toys in therapy. The Smart-Toy-CTT framework was evaluated in a first workshop and improved. Finally, we discuss the limitations of the framework and directions for future research.

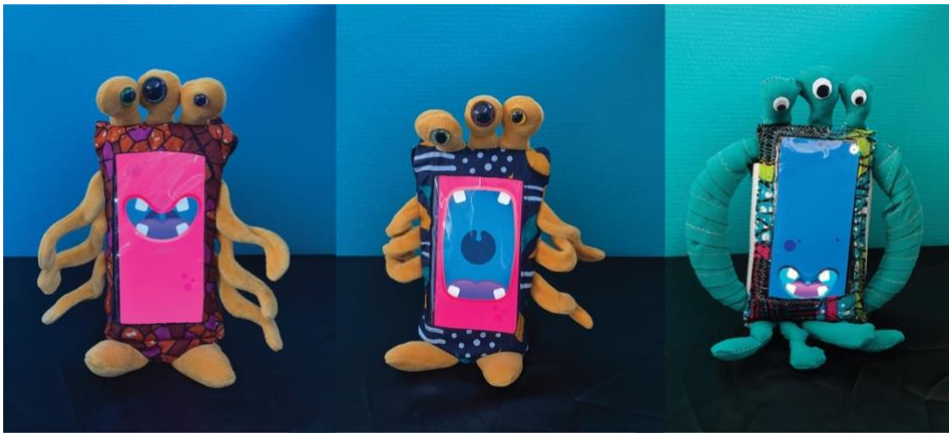

Figure 7.1 Prototypes of the Magic Monster (left - two colours variations) and the Squid Monster (right).

7.2 RELATED WORK

7.2.1 Play & Smart toys

Play is an essential part of children's development and wellbeing. Different theoretical perspectives on play exist, including how play facilitates cognitive development (Piaget, 1952), that it is important for socio-cultural development (Vygotsky, 1967), and that it is foremost an intrinsically motivating activity (Stenros et al., 2011). Play is also broadly understood as fun, motivating and meaningful, making it valuable for encouraging participation. In therapy, play is used as a means to an end (Lynch et al., 2018) to help children develop motor, cognitive, and social skills. For example, in the context of therapy for children with cerebral palsy, structured play-based therapies such as Pirate Therapy (Aarts et al., 2012) have demonstrated effectiveness in rehabilitation by making therapy sessions more enjoyable and motivating. Kudrowitz & Wallace (2009) define toys as tangible objects used for play. Toys provide the tangible means through which play takes shape, affording children opportunities for imagination, exploration, and learning (Norman, 2016; Piaget, 1952; Vygotsky, 1967).

With technological advances, smart toys have emerged as promising tools in therapeutic settings. Smart toys are interactive devices that combine physical and digital elements through sensors, artificial intelligence (AI), and play-based mechanics to create engaging experiences. Unlike traditional toys, smart toys can

track movements, dynamically adjust challenges, and provide timely feedback to users in tangible interactions. This adaptability is crucial for delivering a rewarding play experience to the participant and reinforcing correct movements and behaviours, thus maintaining motivation in home-based therapy. However, developing effective smart toys that balance therapeutic objectives with playful elements and emerging technologies remains a complex challenge.

7.2.2 Frameworks & models

Recently, three frameworks covering digital or physical play in therapy have been introduced. Although these make valuable contributions to the field, they do not offer the necessary design guidance for the design of playful tools for children's home-based therapy. For instance, in some models, integration with physical play objects is not considered, the therapy context is not embedded, and multi-stakeholder dynamics are not adequately considered. Here, we will discuss three frameworks in this field and what they (do not) offer, thereby arguing the need for a more comprehensive framework that can support the design of smart toys for therapy at home.

The PLAY Model (Antunes & Madeira, 2021) provides a structured approach to designing serious therapeutic games for children with special needs by integrating technology, game design, and therapeutic objectives. It includes the definition of games by level, as well as the sequence of actions related to therapy and the patient's needs. A platform was also developed to create game actions for specific therapies. However, its focus is on video games and it offers limited considerations for the use of the resulting therapeutic games in the home environment.

Amengual Alcover et al. (2018) propose the PROGame process framework for developing serious games for motor rehabilitation therapy. It consists of a structured, iterative design process in two dimensions. The first dimension includes a project initiation activity, an iterative flow, and a final clinical study. The second dimension encompasses three phases: interaction mechanisms to ensure the interaction aligns with patients' motor capabilities; interaction elements to encourage patients to perform therapy correctly and maintain treatment effectiveness; and, finally, the design of a serious game to motivate patients to perform the treatment regularly. This process framework focuses on developing serious games for adults. Therefore, there is limited attention to the specific

motivational needs of children (ex., intrinsic motivation through fun and enjoyment), children's lifeworld and the role of parents, siblings and peers.

The D-SALTT user-centred design framework proposed by Balzan et al. (2021) focuses on speech therapy for children. This framework emphasises a user-centred design approach and clinician-child interaction to assist play designers during the task clarification stage, enabling them to understand user requirements better. It is unclear whether the framework is helpful in therapeutic contexts beyond speech and language therapy, and it lacks explicit integration of motivational and behavioural theories and contextual factors.

Table 7.1 summarises these frameworks. Existing approaches lack comprehensive guidance for smart toys that combine digital and physical components, provide real-time feedback, are embedded in the home environment, and are grounded in motivation, play, and behavioural theories relevant to children. In the next section, we will demonstrate how the Smart Toy - CTT framework encompasses all the factors important for the design and development of smart toys for children's therapy at home.

Table 7.1: Strengths and limitations of the analysed frameworks

Framework	Structure and Key elements	Strengths	Limitations
PLAY Model (Antunes & Madeira, 2021)	- Integrated structure (Domain, Game, Technology) - Structured sequence of actions aligned to therapy levels - Emphasis on video-game based therapeutic interventions	- Systematic integration of game mechanics and therapy objectives - Clear guidelines for digital therapeutic game design	- No explicit physical interaction guidance - Limited guidance for home therapy and multi-stakeholder involvement
PROGame (Amengual Alcover et al., 2018)	- Two-dimensional iterative process: 1. Project initiation, iterative development, clinical study 2. Interaction mechanisms, interaction elements, game design - Structured, systematic	- Clear iterative design for motor rehabilitation games - Detailed attention to clinical effectiveness	- Adult-focused - Lacks child-specific motivation and playful contexts

	design for motor rehabilitation therapy		
D-SALTT (Balzan et al., 2021)	- User-centred design framework - Clinician-child interactions emphasized - Task clarification and requirement gathering explicitly addressed	- Strong user-centred and practical design approach - Facilitates detailed understanding of clinician and child needs	- Unclear adaptability to other therapeutic contexts - Lacks theoretical integration

7.3 THE SMART TOY - CTT FRAMEWORK

To overcome the limitations of current frameworks and to guide designers and developers of smart toys for therapy at home we leverage the lessons learned in the iterative design research process of two case studies. We considered various factors in the design process and applied design research methods to deepen our understanding, using these insights as starting points for our framework, which we further developed in co-creation with designers. Reflecting on the case studies made us realise that our design decisions were based on bringing together knowledge from three distinct domains:

1. Technical opportunities
2. Clinical/contextual knowledge
3. Theoretical foundations

This led to the initial conception of a framework with three layers: Technology, Context and Theory. We tested the initial framework in a workshop, where we also introduced initial an canvas to guide the design team through the different layers, and found that it needed more clarity on the order of addressing the layers and the accompanying canvas. The following sections describe the development of the initial framework and the related canvas (section 7.3.1). In section 7.4, we describe the evaluation session and resulting improvements.

7.3.1 Framework development process

Designing smart toys for children with CP revealed complexities across stakeholders (children, therapists, caretakers) and disciplinary domains (health, design, and technology). After reviewing the literature on CP and therapy for children, we used design research tools and methods to align the design of our smart toys with children's play preferences, therapeutic goals, and the home environment. Table 7.2 summarises the design tools and methods used in our Toys4Therapy project with their purpose and key insights they brought.

Table 7.2: Methods used in the Toys4Therapy project that informed each layer of the framework

Framework Layer	Method	Purpose	Key Insights That Shaped Framework
Context	Cultural Probes	Gain glimpse on daily routines and values from families in home therapy contexts without researcher presence	Home therapy happens amid family chaos, not controlled settings; therapy must fit into existing routines, not replace them
	Expert Interview	Understand cerebral palsy and the requirements of the therapy	Therapists balance many factors: child's capability, family capacity, clinical progression
	Survey	Understand the needs and values of therapists	Wide variation in therapeutic approaches; need for flexibility in toy design
Theory	Secondary research	Analyse and synthesise information about motivation, behaviour and play theories from books, journals, etc.	SDT, Flow, BCTs provide complementary explanations: WHY engage (motivation), HOW to engage (play), SUSTAIN engagement (behavior change)
	Observation	Understand therapeutic interactions and behaviour change dynamics	Therapists intuitively apply Flow (adjusting difficulty), SDT (offering choices), BCTs (feedback); formalization helps embed in toy design

	Playful Interaction Analysis	Identify which playful experiences emerged during play sessions	Children most engaged when interactions involved surprise responses, progressive challenge, and tangible feedback, informing sensor and actuator design
Technology	Co-Creation Sessions	Explore themes, interaction with technology, and feedback mechanisms with children	Children rapidly understand sensor-based interactions; prefer physical over screen-only; surprising feedback delights and motivates
	Form & Material Studies	Explore material affordances for interaction, tactile and sensory engagement, safety, and accessibility	Soft materials better for CP (grip challenges); embedded sensors must not create rigid points; texture important for sensory engagement
	Technology assessment	Evaluate different devices, sensors and actuators	The technology used should support the tangibility and playful interaction of the toy
	Moderated Usability testing	Evaluate the functionality of our prototypes and validity of the AI model	AI needed more training data; feedback timing critical; durability issues in enthusiastic play
Cross-Layer	Stakeholder Mapping	Map key stakeholders, relationships, and roles	Parents gatekeepers for home use; therapists need oversight; children need agency; balancing these requires explicit framework
	Participatory Design Workshops	Engage stakeholders in joint creation of concepts	When stakeholders collaborate, integration happens naturally; framework could formalize this process
	Scenario-Based Design	Envision future use across settings and stakeholder interactions	Same toy used differently by different families; need for adaptability across contexts

7.3.2 Framework Structure: Three Interconnected Layers

The framework systematically integrates three critical layers: Context, Theory, and Technology, structured as a circular diagram with three interconnected concentric layers (Figure 7.2), with the playful smart toy at its centre. The design process moves from outside in: understanding context, grounding in theory, translating to technology. Layers inform each other, ensuring coherent integration. The Context layer roots design in real-world conditions. The Theory layer provides foundations for engagement and motivation. The Technology layer enables practical implementation through available and innovative technology (sensors, data, and algorithms). Each layer complements and interacts with the others: context shapes theoretical considerations, theory informs technological implementation, and technology operationalises context-sensitive, theory-informed therapeutic interventions. At the core lies the smart toy: the tangible outcome translating contextual insights, theoretical foundations, and technological capabilities into a practical therapeutic tool. Play is intrinsically valuable for children's wellbeing. Centring the playful smart toy symbolises that every design decision revolves around enhancing playfulness. A variety of design methods and tools can be used to understand and work with each layer. In the following section, we will discuss each of these layers and their components, reflecting on the various methods we used in our case study of designing smart toys for children with CP to explore each layer.

Context

The outer layer of the Smart Toy - CTT framework considers the context of at-home therapy for children. It includes five elements: patient, family, therapy, goals, and skills. We examine the entire context of children who need therapy by identifying each child’s therapeutic needs, capabilities, preferences, and personal goals; understanding the specific therapeutic exercises, objectives, and clinical guidelines; and integrating the therapy into the child’s daily life. This leads us to identify the personal and therapeutic goals and align them with the specific skills that the therapy targets, including exercises, therapist guidance, frequency, and other relevant factors. Finally, family dynamics, home environment, home setting constraints, and the role of caregivers are also considered, as they influence the success of therapy at home.

Theory

The second layer integrates theoretical frameworks guiding the therapeutic design. We focus on three key theoretical areas: motivation, play and behaviour. Motivational theories and models, such as Self-Determination Theory (SDT) (Ryan & Deci, 2000) and the Synthesis of Child, Occupational Performance, and Environment in Time Model (SCOPE-IT) (Poulsen & Ziviani, 2004) ensure that the therapy is intrinsically engaging, which allows children to maintain interest and adherence. SDT highlights autonomy, competence, and relatedness as core psychological needs that underpin intrinsic motivation and wellbeing. The SCOPE-IT model applies and expands these principles within the specific therapeutic, occupational, and developmental context, adding practical guidance and addressing environmental and temporal dimensions. Play is an intrinsically motivated experience that allows children to learn. Playful experiences are inherently rewarding and enjoyable, fostering ongoing participation.

Play theories, such as Flow (Csikszentmihalyi, 1990), suggest that optimal engagement occurs when the activity presents a balance between challenge and skill, meaning it is challenging enough to maintain engagement and not so challenging as to cause frustration. To incorporate Flow theory into our framework implies designing toys that dynamically adapt levels to the children's skills, ensuring optimal engagement and avoiding boredom or frustration. The Lenses of Play (Bekker et al., 2014) introduces the concept of designing for playful interaction and provides a structured method for analysing and designing playful experiences through four lenses: open-ended play, forms of play, playful interaction, and stages of play. Finally, behavioural theories provide a base for understanding the factors that influence behaviour change and offer strategies to promote positive health outcomes. We apply behavioural change techniques (BCTs) in our framework (Michie et al., 2013) to sustain engagement and promote habit formation, helping children transition from short-term to sustained long-term engagement in therapy. Techniques such as feedback and feedforward help guide children in adopting beneficial therapeutic behaviours. Combining motivation, play, and behavioural theories creates a holistic approach that ensures therapy is enjoyable, meaningful, and practical.

Technology

The third layer comprises practical technological components to implement theory-driven, context-sensitive therapeutic smart toys. Technology offers a wide

range of possibilities, including sensors that capture real-time data on children's interactions with the smart toy, enabling precise tracking, and actuators that provide immediate feedback and feedforward. Data collection facilitates progress monitoring, analysis and therapy personalisation tailored to each child's skills and goals. The incorporation of AI in adaptive algorithms ensures responsiveness, dynamically adjusted difficulty, and detection of the targeted therapy goal, such as dorsiflexion movement (bending the hand upwards at the wrist). The physicality of the smart toy also needs to consider the materials used to ensure comfort, safety, and usability, and to support tangible interaction, while remaining in line with children's fantasies and the story we want to tell. The framework integrates these components to provide therapy objectives that align with user engagement and technological capabilities.

The chosen technology should support not only the toy's functionality but also its dynamics, interactions, and aesthetics. When designing toys for therapy, we are ultimately designing an experience for the child—one that must be engaging, motivating, and enjoyable. In the case of the Magic Monster, children perform a playful "magic trick" by shaking the toy up and down. From a context perspective, this interaction addresses the therapeutic need to practise a repetitive hand movement (dorsiflexion) while accommodating each child's abilities and range of motion. This connects to the theory layer, where the toy draws on principles of play and motivation, such as feedback, feedforward, autonomy, and relatedness, to sustain engagement and support motor learning. Consequently, in the technology layer, the interaction informed our choices: a gyroscope and accelerometer capture the toy's angle and speed of movement, while an AI classifier identifies the type of motion based on sensor data, which fuels playful feedback and guides adaptive challenges. The toy's soft, fabric-covered body invites tactile interaction and contributes to its friendly, monster-like character. Table 7.3 lists qualities relevant to the elements of this layer. Together, these elements ensure that technology facilitates the intended therapeutic play experience, demonstrating the strong link between context, theory, and technology within the framework.

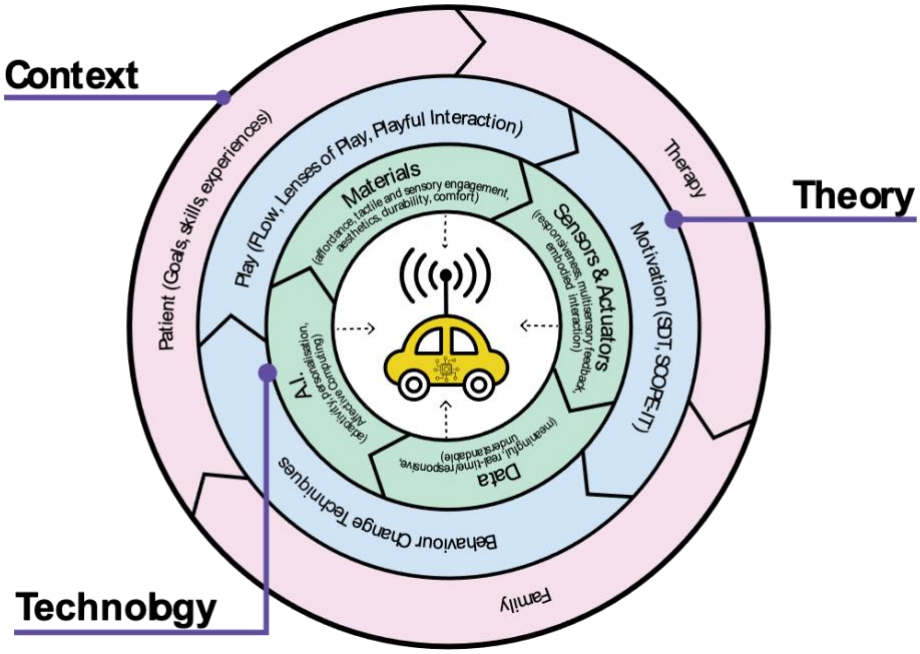

Figure 7.2 The proposed Smart Toy - CTT framework model (SDT: Self-Determination Theory, SCOPE-IT: Synthesis of Child, Occupational Performance, and Environment in Time Model, BCT: Behaviour Change Techniques, AI: Artificial Intelligence)

Table 7.3 Qualities of the elements of the Technology layer

Element	***Quality***	***Description***
Materials	Affordance	• The physical properties of a material suggest how it can be interacted with: grasped, squeezed, shaken, stretched, or thrown
	Symbolic and Narrative Potential	• Materials contribute to the ***imaginative character*** of the toy, how children interpret or project meaning onto it.
	Tactile and sensory engagement	• Materials that stimulate multiple senses (touch, texture, sound) enhance embodied play and curiosity.
	Aesthetics	• Materials can evoke feelings (warmth, familiarity, friendliness) that influence a child's emotional relationship with the toy.
	Durability	• Materials used in play must withstand repeated, dynamic, and sometimes unpredictable manipulation.
	Comfort	• The chosen material should provide a sense of physical comfort.
	Responsiveness	• The immediacy and accuracy with which sensors detect actions and actuators

Sensors & Actuators		respond determine how alive and engaging the toy feels.
	Multisensory feedback	• Actuators that stimulate multiple senses (light, sound, vibration, motion) enrich the play experience.
	Embodied Interaction	• The physical relationship between the child and the toy is mediated by how sensors detect motion and how actuators express feedback.
Data	Meaningful	• Data collection should serve a clear therapeutic or experiential purpose rather than gather information arbitrarily.
	Real-Time/responsive	• Playful interactions benefit from immediate feedback loops; real-time data allows the toy to respond dynamically to the child's actions.
	Understandable	• Data use and feedback should be comprehensible to both children and caregivers, turning abstract numbers into intuitive information.
A.I.	Adaptivity	• AI enables the toy to adjust difficulty, pace, or responses based on the child's performance and preferences.
	Personalisation	• AI tailors interactions to each child's abilities, routines, and motivational triggers.
	Affective Computing	• AI can elicit and detect emotions and adapt its tone, timing, or response to match the child's emotions and effort.

7.3.3 The Smart Toy – CTT canvas

Working across three levels revealed critical design requirements. While the Smart Toy - CTT framework covers all elements necessary to the design of smart toys for therapy, it does not, in itself, guide the design process. Therefore, we have developed a canvas as a clear and practical tool to facilitate its use (Figure 7.3). This canvas provides systematic questions that serve as a starting point for exploring the framework's layers, selecting relevant components, and deciding on design research methods to explore specific aspects further. Furthermore, this tool can directly support collaboration between different stakeholders, such as designers and clinicians. Using the canvas in a multi-stakeholder workshop can provide a shared understanding of all elements and can support the development of effective, theory-informed, and practically usable smart toys.

The canvas contains four sections: one per layer with aligned questions, plus one for ideas, sketches, and scenarios. The questions (see Table 7.4) were

designed based on insights gained during our iterative design process. We identified the critical questions we needed to answer at each layer and translated them into prompts others could use. Questions are intentionally open-ended to accommodate diverse contexts while providing enough structure to ensure systematic exploration.

Table 7.4 Canvas' questions of the Smart Toy - CTT Framework

Framework Layer	Structured Questions	Rationale
Context	What do we know about the patient/target group?	Individual capabilities and needs shape all design decisions
	What do we know of the home environment of the patient?	Physical/social environment constrains/enables design
	How are the parents or siblings involved?	Family dynamics affect implementation
	What are the patient's goal?	Personal goals drive intrinsic motivation
	Which type of therapy is needed?	Clinical requirements are non-negotiable
	Where will the toy be used?	Setting affects design requirements
Theory	Which behaviour do we want to change/promote?	Clear behavioral targets guide design
	How do we elicit intrinsic or extrinsic motivation?	Intrinsic motivation sustains engagement
	Which type of play do we want to foster?	Play type shapes interaction design
	Which playful experiences do we want the toy to have ?	Playfulness characteristics guide mechanics
	Which metaphors do we want to use?	Metaphors make interactions meaningful
Technology	Which interactions do we want?	Interaction types determine data, sensors and actuators
	Which data is needed for the interaction?	Data requirements drive sensor selection
	Which sensors offer that interaction?	Sensor capabilities/limits must match needs
	What type of materials do we want to use?	Materials affect affordance, interactions, safety and comfort

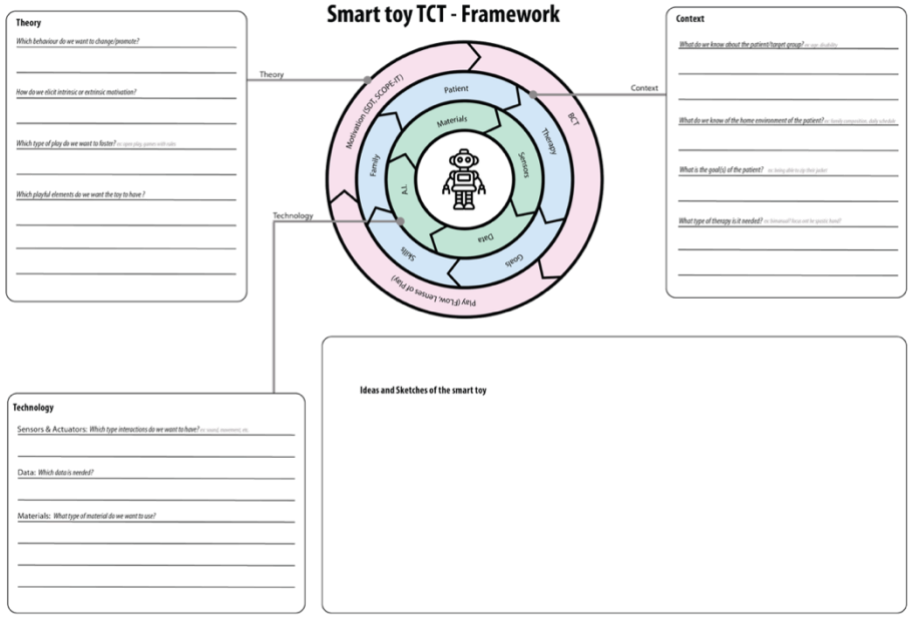

Figure 7.3 First version of the framework and canvas.

7.4 SMART TOY - CTT FRAMEWORK IN (EXPLORATIVE) ACTION

The use of the Smart toy - CTT framework and the canvas was explored during a dedicated workshop with designers and researchers who had not been involved in the framework's development. In total, eight designers and researchers participated, with backgrounds in interaction design, healthcare and software development. Participants received an introduction (to smart toys for therapy and the general framework) and explored examples of commercial smart toys (Mario Lego, GoCube, Sphero Mini, Hatchimals) (Figure 7.4) and therapeutic toys (Magic Monster, Squid Monster) (Figure 7.1). Participants worked in pairs using the canvas (A3) for 30 minutes to develop smart toy concepts for children with CP. Each pair presented concepts, followed by a group discussion on the usability, clarity, completeness and usefulness of the canvas and the framework.

The workshop's outcome was a range of diverse, innovative smart toy concepts, each grounded in therapeutic objectives and informed by the structured questions provided by the Smart Toy - CTT canvas. Participants found the canvas useful, and the overall experience of the workshop was enjoyable. The discussion revealed some challenges that participants encountered. First of all, there was insufficient time to go through all the questions on the canvas. Participants struggled with the layer order and found the theory questions too abstract until they understood the context. Abbreviations like BCT, SCOPE-IT and SDT required explanation. Participants also found it difficult to see how theories could translate to technical features and which sensors and actuators could be used. Finally, one participant noted the potential to adapt the canvas for other health interventions (e.g., social robots for elderly care), suggesting the framework structure may generalise beyond therapeutic smart toys for children.

Figure 7.4 Examples of smart toys (from left to right): Mario Lego, Hatchimals, GoCube Edge and Sphero Mini.

This practical exercise highlighted the framework and canvas' potential to guide multidisciplinary teams through a structured yet creative design process, resulting in feasible, therapeutically relevant smart toy concepts. It also provided insights on how to improve the canvas to facilitate its understanding and application. One of the changes included reordering the layers (Context, Theory, and Technology) to enhance the flow, as most participants felt they needed to understand more of the context before continuing to other layers. Another change was to add questions, modify their order, clarify some questions, and provide

example answers as inspiration. We also added brief definitions of acronyms. Further, we added visual cues in the canvas to guide users on how to start and to continue the analysis. More concrete examples of playful elements were also added. Figure 7.5 shows an improved version of the canvas and printable version of the canvas is available in Appendix B.

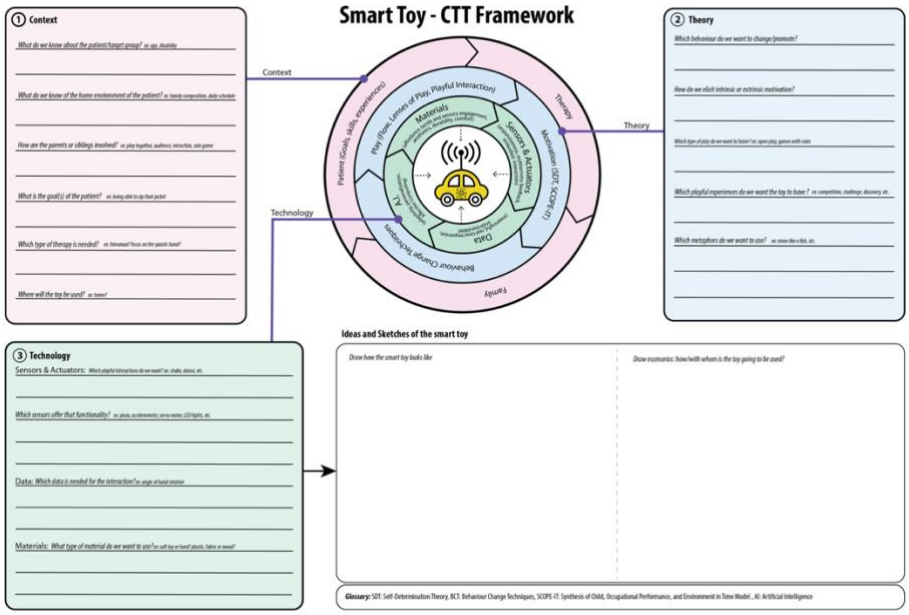

Figure 7.5 Improved version of the canvas to guide the application of the Smart Toy - CTT Framework

7.5 DISCUSSION AND FUTURE WORK

The creation of this framework is the result of having to navigate the complexity of healthcare innovation, where various stakeholders and regulatory bodies are involved, multidisciplinary teams collaborate, ethical guidelines and medical standards evolve, and cultural and social norms are in place. The insights and lessons learned through two cases of designing smart toys for therapy showed that the successful design of smart toys for therapy depends on several interconnected factors: the context of use, the integration of play (including the type of play and the

playful experience) alongside theories on motivation, and technical aspects that enhance engagement and adaptation.

In this chapter, we have presented a first short evaluation of the framework and the improvements that followed. Further and broader evaluation of the framework is necessary to assess its merits. We envision its use at the start of a project, involving a multidisciplinary team, but it could also be applied iteratively, allowing teams to return to specific layers to integrate new insights obtained during the design process. The framework can serve as a tool in research settings to structure and compare studies exploring different aspects of smart toy design, thereby linking theory and practice. In development or industry contexts, it can act as a communication and decision-making tool that helps product teams translate therapeutic and motivational theories into design requirements, align stakeholders, and ensure that regulatory and ethical considerations are addressed early in the process. In both contexts, the framework encourages reflection and collaboration across disciplines, promoting coherence between user needs, theoretical grounding, and technological innovation.

To enhance the framework's applicability, we aim to develop complementary tools. These include improved guided prompts for reflection and design decisions, a knowledge base with a centralised repository of relevant therapeutic theories, case studies, co-creation design strategies, previous smart toy examples, and best practices; and a component library with a collection of reusable technological and interactive components that can connect to therapy needs and that can be used in workshops. Similar approaches have proven valuable in related domains. For example, design toolkits such as the *IDEO Human-Centred Design Toolkit* (IDEO, 2015) and the Tiles IoT Inventor toolkit (Mora et al., 2017) provide structured methods, reflection questions, and examples of sensors and actuators. In game design, the MDA Framework (Hunicke et al., 2004) examines games from three aspects (mechanics, dynamics, and aesthetics). It offers structured, theory-informed guidance through prompts and taxonomies for analysing and designing interactive games. Repositories like the *Behaviour Change Techniques Ontology* (Marques et al., 2023) serve as a shared reference point for evidence-based practice. Our envisioned tools would follow these examples by supporting designers and healthcare practitioners in systematically collecting patient-specific information, selecting appropriate theoretical foundations for each case and integrating guidelines and recommended hardware components. Ultimately, the framework's primary intention remains to support participatory

design practices, actively involving therapists, families, and children in the design process.

Our work in the Toys4Therapy project, specifically focused on children with spastic CP prompted the need for a structured approach guiding the design of therapeutic smart toys. The Smart Toy - CTT framework emerged from our experiences, informed by literature reviews, expert interviews, surveys, co-creation sessions, and cultural probes. Despite its specific starting point, the framework's design, structured around three generalisable layers, makes it flexible and transferable across various therapeutic contexts beyond a single diagnosis. Future research could apply this framework to diverse patient populations, such as children with speech delays or those who need physiotherapy after injury, further validating and enhancing its versatility.

7.6 CONCLUSION

This chapter presents the Smart Toy-CTT framework, addressing a gap in the design of therapeutic smart toys for home-based therapy for children. The framework integrates context, theory, and technology, maintaining playfulness at its core while keeping children's wellbeing in focus. Adopting the framework opens the possibility of providing children with access to enjoyable, affordable therapy that can be integrated into everyday play.

The framework's key contributions include: explicit integration of motivation, play, and behaviour change theories with contextual realities and technical possibilities, and practical application through a canvas tool. The framework's structured approach helps multidisciplinary teams navigate competing demands, including clinical effectiveness, child engagement, family feasibility, and technical constraints. While the smart toys developed with this framework do not aim to replace the therapist, they aim to be a supportive tool to optimise therapy, particularly extending it to the home environment and making it both personalisable and adaptable.

Ultimately, this framework supports a change in home-based rehabilitation: from therapy as an obligation to therapy as a meaningful, joyful engagement. By placing playfulness at its core while maintaining therapeutic rigour, we can design smart toys that enhance not just clinical outcomes but

children's quality of life, autonomy, and development. The framework provides both a conceptual foundation and practical tools to make this vision achievable.

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Chapter 8

CONCLUSION AND DISCUSSION

Sabrine took the Magic Monster home for three weeks; she changed its name to “Schatje” and enjoyed playing with it. When it was time for the monster to go back to the clinic, she didn’t want to let it go. But she asked if it could visit her again to play new games or if there are other monsters that can come to play as well!

The story above is a literal remark from a child in the study presented in Chapter 5. This child’s reaction to the Magic Monster captures the goal of this thesis: play-centred, adaptive smart toys can make home practice something children want to return to. This chapter reflects on the Toys4Therapy research, consolidating the answers to my research questions, identifying the main contributions, and reflecting on what worked, what did not, and what comes next.

8.1 RESEARCH AIM, SCOPE AND APPROACH

This thesis aimed to explore the design of smart toys that support home-based therapy for children with cerebral palsy by integrating play into the therapeutic process. Through a Research through Design approach, I engaged with children, therapists, and caregivers to understand their needs. I focused on children with spastic hemiplegia and on home-based hand therapy because of the constraints that children face in continuing with therapy at home. Two research questions guided the work: (RQ1) *How can smart toys be designed to support motivation and adherence in home-based hand rehabilitation for children with cerebral palsy?* and (RQ2) *How can self-adaptation support motivation and adherence in smart toys for rehabilitation*?

With this thesis, I aim to invite designers, researchers, and health professionals to incorporate play and technology as components of their

therapeutic programs. This closing chapter provides an overview of my findings. It reflects on the steps taken in this research, as well as the implications for future health, by addressing how the studies presented here answer my two research questions. I will also discuss the implications of my work for research practice in society.

8.2 ANSWERING THE RESEARCH QUESTIONS

In this section, we answer the research questions introduced in Chapter 1.

8.2.1 RQ1: "How can smart toys be designed to support motivation and adherence in home-based hand rehabilitation for children with cerebral palsy?"

RQ1 addresses a complex design challenge: designing toys that bridge clinical goals with children's play needs while fitting into chaotic home routines and supporting an entire therapeutic community (child, parents, therapists). The literature indicates that the role of play in the interventions that use innovative technologies in hand therapy for children with CP is to create an enjoyable activity for children that can also help them improve their motor skills (Chapter 2). The combination of digital and physical play can make targeted movements observable and adjustable while preserving the enjoyment that supports adherence. This indicated a promising new direction: smart toys that provide feedback and adapt, encourage object manipulation with both hands, and promote hand exercises at home.

As a result of this thesis, we now know what to design and how to get there. Chapter 2 showed which technologies and playful elements have promise; Chapter 3 surfaced children's needs in hybrid play (curiosity, open-ended exploration, meaningful feedback); Chapter 4 explained which clinical elements matter at home (goal-directed bimanual practice, variation, clear feedback, low caregiver burden) and transferred clinical goals and clinic exercises into home routines. The insights from each study and research activity were translated into design principles (Chapter 5 – Table 5.3), which were applied and tested in two working smart toys (Magic Monster and Squid Monster). The same principles were packaged in the Smart Toy–CTT framework (Chapter 7), which moves from Context, Theory, Technology into Smart Toy and is operationalised through a shared canvas. This

triangulation from evidence synthesis, design case to process formalisation, elevates the contribution from a single artefact to reusable design knowledge.

The analysis of findings addressing RQ1 demonstrated that motivation arises not from technological novelty alone, but from the alignment of play, context, and therapeutic intent. Across the studies presented in this thesis, sustained engagement emerged when play experiences were meaningful to the child, adaptable to their abilities, and compatible with the everyday routines of their families. These insights highlight that motivation in therapeutic play depends on designing with children's play needs, within home constraints, and around adaptive and agency-supportive interactions rather than fixed exercises or prescriptive tools.

To consolidate these insights into actionable guidance for designers and practitioners, this thesis synthesises them into six overarching design principles for therapeutic smart toys (Section 8.3.2). These principles integrate evidence and reflections from the co-creation sessions, prototype iterations, and in-situ evaluations across Chapters 2–5. They represent the distilled design knowledge that answers RQ1 in a transferable form, providing a foundation for future design and evaluation of playful health technologies.

8.2.2 RQ2: "How can self-adaptation support motivation and adherence in smart toys for rehabilitation?"

RQ2 explicitly addresses the effects of self-adaptation on the motivation and adherence of children to home therapy. Chapter 6 answers RQ2 by providing the blueprint of signals, interpretation, and adjustment. It (1) senses movement with phone sensors, (2) classifies dorsiflexion robustly on-device, then (3) adapts difficulty by tuning per-child thresholds for range and speed through calibration and simple performance rules, keeping challenge in the optimal zone, thereby maintaining engagement and supporting adherence in everyday play. Chapter 5 answers RQ2 by designing and developing a self-adapting smart toy (Magic Monster), deploying it in homes, and presenting mixed-methods evidence to show how its self-adaptive play complexity supports motivation and (partially) adherence, as well as what else is needed for sustained use. In the in-home single-case evaluations (Chapter 5), self-adaptation increased engagement, but adherence over weeks also depended on content variety, comfort/ergonomics, and family routines. This result, consistent with observations in Chapter 4, reframes the design target: adaptivity is necessary but not sufficient; it must be paired with

variety, fit-for-home materials, and caregiver-light scaffolding. This finding aligns with the research by Jung et al. (2020) on rehabilitation games, which shows that engagement is shaped not only by therapeutic relevance but also by perceived effort and available alternatives, with children often preferring easier or more immediately rewarding activities when given a choice.

Finally, Chapter 7 also helps us to answer **RQ2** by turning "self-adaptive play complexity" into a method that can be followed**.** Chapter 7 links *why* to adapt (theory), *what* to sense (context), and *how* to implement (technology). In the **Context** layer, it analyses the needs of children, their family and therapy. In the **Theory** layer, it anchors adaptivity in SDT/flow by keeping difficulty optimally challenging to support competence and motivation and embedding behaviour-change techniques (feedback/feedforward) to sustain adherence. In the **Technology** layer, it specifies the building blocks for adaptivity (from data to sensors to AI-driven adjustment**)** so smart toys can personalise difficulty on the fly while remaining tangible and playful. The Smart Toy - CTT canvas then operationalises this with guided questions (e.g., "Which data are needed?", "Which sensors?", "What interactions/actuators?"), helping teams instantiate signals, inference and adjustment paths for a given therapy goal. Collectively, these studies crystallise what to design, how to design it, and how to coordinate stakeholders.

8.3 CONTRIBUTIONS

This thesis makes contributions across three interconnected domains: research and theory, design practice, and society. Together, these contributions move beyond simply answering the research questions to reveal how the findings connect theory to practice and create value for families and therapists.

The following subsections outline these contributions, beginning with the design constructs the bridge theory and design practice, followed by the practical tools developed through design research, and concluding with their broader societal implications.

8.3.1 From Theory to Practice

Self-Adaptive Play Complexity as Flow Theory in Practice

A central theoretical contribution of this thesis is the operationalisation of Flow theory (Csikszentmihalyi, 1990) within the design of self-adaptive smart toys for therapy. Flow has long been used to explain intrinsic motivation in play and learning. This work translates its core principles, balancing challenge and skill, providing clear goals and immediate feedback and feedforward, into an implementable design mechanism for physical play objects.

By synthesising Self-Determination Theory (Ryan & Deci, 2000) and Behaviour Change Techniques (Michie et al., 2013) within a sensor-driven interaction loop, the concept of Self-Adaptive Play Complexity provides a concrete pathway from psychological theory to functional artefacts. The technical architecture (sense, classify, calibrate, adapt) enables the toy to modulate its behaviour in real time according to the child's performance, maintaining the "just-right" challenge central to Flow.

This contribution bridges the gap between abstract motivational theory and practical design implementation. It demonstrates that adaptive feedback can sustain engagement autonomously, without the need for continuous therapist supervision. In doing so, it expands the theoretical understanding of Flow from a descriptive framework into an actionable design principle for embodied interactive systems.

Empirical validation was achieved through both controlled and in situ studies. The laboratory sessions with typically developing children (n = 22) and children with cerebral palsy (n = 8) established the feasibility of adaptive calibration using lightweight AI models. The field studies (3 weeks single case study) with five families further confirmed that when the smart toy was successfully adjusted to the child's performance, motivation, and adherence increased. Parents reported excitement, interest in use, and reduced perceptions of therapy as a chore. These findings show that maintaining a balanced challenge through automated adaptation can replicate one of the therapist's most critical roles, adjusting task difficulty, while preserving playfulness and autonomy in home settings.

This work extends motivation theory into the realm of interactive physical artefacts by demonstrating a viable mechanism for automating Flow. It positions adaptivity as a key design principle for technologies aiming to sustain engagement over time. The same principle can be transferred to other domains, such as gait or speech therapy, and to educational or cognitive adaptive toys. Collectively, these findings establish Self-Adaptive Play Complexity as a novel theoretical construct

that embodies Flow in practice and connects behavioural theory with design research.

Smart Toy - CTT Process Framework

A second major contribution of this thesis lies in the development of the Smart Toy - CTT Process Framework, a structured design method that integrates Context, Theory, and Technology into a coherent process for creating therapeutic smart toys. The framework introduces a three-layer concentric model in which the toy is placed at the centre of the design space. Its novel concentric structure, with the smart toy at the centre, ensures that playfulness drives decisions. Each surrounding layer builds upon the previous one: the context layer defines the therapeutic and domestic setting; the theory layer grounds the design in motivational and behavioural principles (e.g. Self-Determination Theory, Flow, Behaviour Change Techniques, Playful Interactions); and the technology layer translates these into interactive features and sensor-based mechanisms. This concentric structure ensures that design choices remain playful and user-centred, while still grounded in therapeutic and technical validity.

The framework addresses a key gap in current design practice. Existing frameworks do not optimally address the intersection of home-based therapy for children with play (and with physical and digital objects). They tend to privilege either clinical rigour or technological novelty, leaving the playful dimension underspecified. The Smart Toy - CTT framework makes clear connections between theoretical constructs (e.g. SDT, agency, choice mechanics) and concrete design decisions focused on play. In doing so, it enables multidisciplinary teams to collaborate effectively through a shared language and process. The framework thus transforms fragmented design efforts into a reproducible, communicable method.

This was demonstrated in a first exploration of this framework through a co-design workshop involving eight participants from diverse backgrounds, including therapy, design, and engineering. Participants reported that the structure helped them to align disciplinary perspectives and to ensure that playfulness remained at the centre of their designs. This evidence suggests that the CTT framework can facilitate productive interdisciplinary collaboration while maintaining focus on therapeutic engagement.

Beyond its immediate application, the Smart Toy - CTT Process Framework positions therapeutic smart toy design as an emerging sub-discipline within Human–Computer Interaction and design research. By articulating a clear, theory-

informed process, it lays the groundwork for reproducible research, supports design education, and offers a transferable structure for industry adoption. The framework's emphasis on context-sensitivity and play-driven design also makes it adaptable to adjacent domains such as educational games, workplace wellness, or assistive technologies for other populations. As such, it not only consolidates the methodological contribution of this thesis but also provides a foundation for future interdisciplinary work at the intersection of health, play, and technology.

The Smart Toy—CTT Canvas as a Practical Tool

Complementing this framework, this thesis introduces the **Smart Toy—CTT Canvas**, a fillable worksheet that operationalises the Smart Toy CTT framework into a hands-on design instrument. Teams use the canvas sequentially to prevent premature technological fixation and to ensure understanding of context and theoretical grounding before implementation. It also supports iterative refinement, enabling the negotiation of constraints between clinical, design, and technical perspectives. As a communication artefact, the canvas serves as a shared record of evidence-based decisions and aligns with documentation requirements in design research.

In practice, the Smart Toy - CTT Canvas functions as a tool that bridges disciplines by making abstract principles visible and negotiable. It addresses long-standing translation gaps among health professionals, engineers, and designers, enabling more coherent and collaborative development of therapeutic technologies.

8.3.2 Six Design Principles for Therapeutic Smart Toys

As a synthesis of the findings addressing RQ1, this thesis proposes six design principles for therapeutic smart toys. These principles distil the lessons learned across all design iterations, evaluations, and collaborations (Chapters 2 – 5). Together, these principles articulate how to design smart toys that remain playful while achieving therapeutic value. Each principle integrates theory, field insights, and technical considerations into concise, actionable guidance.

1. **Begin with play needs, not features.**
   How to apply: Start the design process from children's intrinsic motivations and play preferences rather than from specific therapeutic exercises or technical affordances.

Why it matters: This ensures that therapy is embedded within play rather than the reverse, maintaining intrinsic motivation and enjoyment while still meeting therapeutic objectives.

2. **Embed self-adaptive complexity.**
   How to apply: Integrate sensing and feedback mechanisms that automatically adjust the level of challenge based on the child's performance.
   Why it matters: Adaptive complexity sustains engagement over time and allows toys to replicate one of the therapist's most critical functions (calibrating task difficulty) thereby supporting independent, home-based therapy.

3. **Design for the entire play community.**
   How to apply: Consider not only the child but also parents, siblings, and therapists as part of the interaction ecosystem. Provide cues and modes of engagement that accommodate all participants.
   Why it matters: Therapy at home is embedded in family routines; addressing the full social context increases sustainability and acceptance.

4. **Make hybridity purposeful.**

   How to apply: Combine physical and digital elements in ways that clearly enhance therapeutic or playful value rather than adding novelty for its own sake.
   Why it matters: Purposeful hybridity ensures that technology amplifies the play experience, bridging digital feedback and tangible embodiment effectively.

5. **Fit home constraints.**
   How to apply: Design for domestic realities—limited space, time, attention, and technical expertise. Keep setup short, maintenance minimal, and interfaces intuitive.
   Why it matters: Feasibility and consistency in real homes determine adherence far more than technical sophistication.

6. **Anchor in agency.**
   How to apply: Offer children meaningful choices in how, when, and for how long to engage, and use positive feedback instead of corrective cues.
   Why it matters: Agency sustains intrinsic motivation and fosters ownership, transforming therapy from obligation to voluntary play. Prior work in play and interaction design has shown that autonomy and agency can be shaped through design choices and are critical for sustaining engagement in playful systems (Deterding, 2016). In therapeutic contexts in particular, autonomy-supportive design has been shown to counterbalance externally imposed activities and support more self-endorsed engagement (Aufheimer et al., 2023).

These six principles form actionable heuristics rather than abstract recommendations. They can be used as evaluation criteria during design reviews, ideation prompts in co-creation sessions, and communication tools among multidisciplinary teams. In a validation workshop, participants successfully applied the principles to generate coherent and engaging therapy concepts within 90 minutes, confirming their clarity and transferability. Collectively, they provide a design vocabulary that can be applied beyond cerebral palsy therapy to other health, educational, and wellbeing contexts.

8.3.3 Contributions to Society

Accessible and Affordable Home-Therapy Alternative

An important societal contribution of this thesis is the development of an accessible and affordable alternative to conventional clinic-based hand therapy. Across both high- and low-income settings, families encounter barriers to therapy access, including extended waiting periods in the Netherlands and limited availability of specialised rehabilitation centres in countries such as Ecuador. Commercial assistive devices are frequently cost-prohibitive and often require specialised support.

The Magic Monster offers a substantially lower-cost solution with a one-time build cost (a cuddly toy with an open-source pattern - Appendix D) and the installation of the app on the mobile phone of one of the caregivers. It can be produced locally through FabLabs, community workshops, or cooperative groups, using readily available (or repurposed) materials. This makes the approach replicable and adaptable to different healthcare infrastructures. Although financial accessibility was improved, non-cost barriers such as digital literacy and smartphone ownership remain and require context-sensitive adaptation in future deployments.

The benefits are particularly relevant for low-resource settings, rural families, and for maintaining therapy continuity during system disruptions such as pandemics.

Restoring Child Agency and Autonomy

A second societal contribution concerns the restoration of children's agency and autonomy within therapeutic contexts. As highlighted by Young (2024), enforced participation in therapy can damage parent–child relationships. Traditional home

programmes often rely on parental enforcement, creating dependency on extrinsic motivation and limiting the child's sense of control. The design of the Magic Monster directly addresses these concerns. By framing activities as *play* rather than *therapy*, and incorporating choice mechanics by allowing them to decide *when*, *which*, and *how many* exercises to perform, the toy invites participation rather than demands compliance. Invitational language and success-oriented feedback and feedforward replace commands and corrections, preserving the child's sense of competence.

During the field study, children consistently described their engagement as "playing" rather than "doing therapy". Parents reported fewer conflicts and greater enjoyment during daily routines. These findings demonstrate that playful, autonomy-supportive design can transform therapy from a controlled task into an intrinsically motivated activity.

Supporting Parents Without Increasing Burden

A third societal contribution lies in supporting parents while reducing emotional and logistical strain. Previous studies (e.g., Niyonsenga et al., 2024) identify depression, stress, time pressure, and low confidence as major obstacles to sustaining home-therapy routines. The Magic Monster mitigates these challenges by automating therapist-like functions (movement validation and adaptive calibration), allowing sessions to proceed autonomously and effectively.

Design choices such as brief sessions of 10 to 15 minutes, one-button operation, and minimal setup time of less than two minutes reduce friction and make therapy compatible with daily family life. Parents reported that although some children needed to be reminded sometimes, the toy made therapy "easier," "less worrying," and that they "actually got it done". These outcomes suggest that well-designed smart toys can enable effective home therapy without adding to caregiver workload. Some residual challenges remain, including minor technical troubleshooting and an initial learning curve.

Together, these contributions illustrate that playful therapeutic design can be socially equitable and family-centred. By enabling affordable access, restoring autonomy, and easing caregiver burden, this work moves beyond technological novelty to address the social realities of paediatric rehabilitation. These societal impacts reinforce the broader vision of this thesis: to make therapy not only effective, but also joyful, inclusive, and sustainable in everyday life.

8.4 FUTURE WORK

The work presented in this thesis serves as a starting point for future research and practical applications in the field of healthcare design. First, future work on the Magic Monster and the Squid Monster should deepen personalisation of the characters' behaviour, voices, and colours, broaden the playful experience, and include accessibility options (grips/straps, left/right variants, sensory-friendly textures), while preparing for safe, scalable deployment of the monsters. As discussed with children, parents, and therapists, it would be ideal to develop the monsters further and make them available as a downloadable app, paired with clinic-loan plush toys, or via a freely accessible pattern. Furthermore, a family of monsters can be developed, each targeting different hand exercises (e.g., wrist extension, pronation–supination). A future scenario would be that the therapist discusses the goal of the week or a set period with the child, and together they choose the most fitting monster to take home. For now, a link to the pattern to make your own Magic Monster, a link to the demo video of the magic trick, and the magic trick book can be found in the Appendix D.

Second, in this thesis, the work was focused on how to optimally design a solution that fits the daily life and clinical requirements from the point of view of children. Although other stakeholders were involved, we did not specifically design the remote support tools for therapy programs. I still would like to continue the work by evaluating the design and development of a dashboard for therapists to facilitate goal setting, progress review, parameter setting, game selection, and to provide advice to children and caregivers. Before adding such tools, we need to assess their impact on the therapist's clinical workflow. Although we have always maintained a focus on privacy awareness in this project, as connected toys scale, future research should also examine the implications of recording children's data, including ethical, privacy, and governance considerations. Particularly if a dashboard for therapists is created and children's data is available online. Themes to consider in this area are child-appropriate consent, parental controls, data minimisation, local-first architectures and data safety.

Third, the feasibility of releasing the Magic Monster and other smart toys, taking into account regulatory and manufacturing readiness, as well as cost-effective implementation. To achieve regulatory and manufacturing readiness, the smart toy should comply with CE/EN-71 (European safety standards for toys

(Grynkiewicz-Bylina, 2012)) safety pathways, durability and cleanability tests, repairability and the use of sustainable materials. For a cost-effective implementation, we need to analyse the health-economic impact and study the real-world rollout, which may include training, analysis of support burden, and app portability.

Fourth, moving to a more generalised theory for the design of smart toys for health, we should continue to further validate the Smart Toys CTT process framework with stakeholders through studies to test usability, the inter-rater reliability of the canvas, and whether the framework improves design quality/time-to-prototype. Although Chapter 7 presents the first explorations with the framework, future work should also focus on validating it in subsequent sessions with stakeholders, iterating on and further developing it.

Finally, the future of designing smart toys for health could continue with the development of a taxonomy of adaptivity for smart toys that distinguishes between calibration, rule-based, model-based, and therapist-in-the-loop levels, along with acceptance criteria for each. A sensing-and-adaptation agenda should analyse the use of other phone sensors and actuators, such as pressure/touch, lightweight vision, and other materials, including microcontrollers and conductive fabrics, aiming for robustness against noise and compensatory movements. Parallel work should test behaviour-change techniques (goal-setting artefacts, prompts, social acknowledgement). Together, these lines of work invite designers and researchers to transform promising prototypes into robust, equitable and privacy-aware therapeutic play, keeping play not as a distraction or replacement from therapy, but as its most powerful ally.

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REFLECTIONS ON THE RESEARCH JOURNEY

As mentioned in the Introduction chapter, the seed of this project was planted in my home country, Ecuador, around 2008. There, I met children with CP, their mothers and therapists through my mother's volunteer job at a children's hospital. At the time, I was a software engineer developing products for banks and the government. The idea for this project began to take shape years later when I had the opportunity to propose a research topic at the Amsterdam University of Applied Sciences (AUAS). I was working as a Creative Technologist at MediaLab Amsterdam (later Digital Society School). I had acquired knowledge and experience in the fields of design and health, and, with my background in technology, I started exploring ways to help children in hospitals using technology. That is when Toys4Therapy began.

In the initial stages of Toys4Therapy, I had numerous conversations with doctors and therapists from various hospitals in the Netherlands and Ecuador to gain a deeper understanding of the problem, define a target group, and determine the thesis's direction. Even though I had previously met people with CP, some assumptions were wrong, such as seeing it as a disease; CP is not a disease that you can be cured of, it is a neurological permanent disorder with symptoms that may worsen over time. Physical and occupational therapy aims to improve muscle tone, increase strength and flexibility, prevent muscle stiffness and maximise functional abilities to promote independence and enhance the quality of life (Rosenbaum & Leviton, 2007). Out of these conversations, I decided to focus on children between 7 and 12 years old, with spastic hemiplegia and to focus on home therapy exercises.

In this project, we adopted a Research through Design approach because motivating, playful home therapy is a situated, experiential challenge: only by crafting and fielding tangible probes with children, families and therapists we can discover what 'works', turn it into reusable principles and a process, and then take those insights forward into robust clinical evaluation. RtD helped us coordinate stakeholders around a single artefact: therapists assess therapeutic relevance, engineers instrument sensing, designers craft the play loop, and children express their needs and wishes, all *together*. Moreover, physical prototypes serve as artefacts that children, parents, and therapists can understand, manipulate, and co-create.

Although my initial plans included several co-creation sessions and more observation studies, this was not possible. It was the 13th of March 2020, while I was at a meeting in a rehabilitation centre to organise these sessions with children with CP, when someone knocked on the door to let us know that there was a press conference with the prime minister. The announcement was that the Netherlands was shutting down due to the COVID-19 pandemic. The following months were, understandably, chaotic for everyone. The planned sessions could not take place, as families did not want to participate in any activities, and therapists were too busy figuring out their next steps to continue helping their patients. We were juggling work, family, and the fear of what was happening in the world. However, in response to this situation, I adjusted my plans. I developed a cultural probe package that was mailed to several families of children with CP. I followed the eBrok certification (Basiscursus Regelgeving en Organisatie voor Klinisch Onderzoekers) required for clinical researchers at a university medical centre involved in research under the Medical Research Involving Human Subjects Act (WMO). We conducted several surveys and interviews with therapists and teachers from the university's health department and continued to develop our prototypes based on the insights gained.

In an ideal situation, children with CP could have been involved in more steps, but for various reasons, access to them was limited. Therefore, for some activities, such as the initial evaluation of the Magic Monster, only children without CP (in the same age group) were able to participate. Hence, in that study, we focused on the toy's usability, ensuring it would function without bugs when tested with children with CP. Fortunately, we were able to work with children with CP and their families in the later studies. Working with them was an insightful experience. They showed curiosity, openness and enthusiasm for my ideas and contributed with suggestions on what they would like to see in the future of home therapy with our monsters. Overall, it reminded me that children with CP are just children, with dreams and fears; they laugh, they cry, they are discovering the world, and want to enjoy it like anyone else, but also in their own way. Personally, sharing time with them was also an opportunity to view the world through their eyes and learn from someone else's reality.

Looking back on this research journey, there are things I would do differently next time, such as increasing the inclusion of children with CP, designing more interactive elements in the Magic Monster, and better planning for the final test.

Designing for vulnerable groups comes with its limitations. Due to the COVID-19 restrictions (and stressful period), only three families agreed to participate in the Cultural Probe study that we carried out. We later tested dorsiflexion recognition in eight children with CP, although the model's training was conducted with adults without CP. Our three-weeks single-case study involved only five families. While we tried to include children with CP at every stage of the research, this was unfortunately not always possible, and we often had to work with small groups.

The results of our last study showed that children had a high interest in playing with the Magic Monster; they were enthusiastic about it and formed a strong bond with it. However, they did not play with it for the time that we had expected (30 minutes per day). In other words, although motivation was high, adherence was not. Furthermore, several factors contributed to this, including personal preferences, scheduling constraints, the weather, and the need for parental support. We also found that the benefits of the smart toy's novelty fade, and there were not enough interactive features to keep users interested; the advantages of AI alone will not be enough to sustain therapy adherence.

The timing of the last study was also not ideal. In hindsight, we would have planned the study at a different time. Testing with children with disabilities requires different preparations, such as approval from the university ethics committee, a review by an accredited Medical Research Ethics Committee (MREC) or the Central Committee on Human Research (CCMO in Dutch), and approval from the scientific board of the rehabilitation centre. Although all these steps are necessary to ensure children's safety, we underestimated the time required to complete them, which led us to start the tests around summertime.

To conclude, I set out to develop knowledge in the field of smart toys for home-based therapy for children with cerebral palsy. My research focused on the Magic Monster (with the Squid Monster as a supporting case), exploring how play can transform hand-therapy at home while acknowledging that many existing tools remain clinic-first, screen-centric, and insufficiently adaptive to children’s changing abilities and family routines. From co-creation with children, observations in rehabilitation centres, and a scoping review of technologies and play elements and I proposed the Smart Toy - CTT framework, providing a practical canvas to coordinate designers, therapists, and families. Working closely with stakeholders, we developed high-fidelity prototypes and an on-device movement-recognition and calibration engine and evaluated them in lab and in-home studies.

These studies demonstrate that adaptive, play-centred toys can increase engagement and support adherence, offering a clear blueprint: from signals to inference to adjustment for future systems. Together, the principles, framework, and prototypes advance the science and practice of playful rehabilitation while keeping home therapy engaging, feasible, and privacy-aware. When reflecting on my research journey, I want to emphasise that, at its heart, this thesis is a celebration of play.

ACKNOWLEDGEMENTS

Doing a PhD has been an exciting journey with ups and downs, and I want to take this opportunity to thank those who have helped me during this process. I want to start with my PhD supervisors, Geke, Ben K. and Ben S. Geke, you have truly been an inspiration and a strong support in many moments of this journey. You gave me freedom, guidance, critical feedback, and a necessary push when needed. I truly appreciate everything you have done for me. You have taught me a lot. Thank you, Ben K., for your confidence and support, and special thanks for being the first to see the value in my PhD idea when this project started to take shape as part of a pre-PhD trajectory at the Amsterdam University of Applied Sciences (AUAS). You have been there for me from the very beginning. Thank you, Ben S., for making this research part of the STEC project and for connecting me with essential contributors such as IJsfontein and Philips. Overall, thank you for the many interesting conversations about play; those were very insightful moments, and I hope we can continue to share them.

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Being an external PhD candidate meant I had to be in many different places, but it also allowed me to meet many people and join various teams at the University of Twente (UT) and the AUAS. At UT, I had the pleasure of being part of the Interaction Design research group. Although I was not able to be there as often as I would have liked, I always felt welcome. Special thanks to Chanmi, Benedetta Armağan, Siyuan, and Tina for answering my many questions and having virtual coffees with me. If there is something I regret, it is not having the chance to meet more often in person.

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Finally, I want to thank two beautiful countries, Ecuador and the Netherlands. Ecuador is the place where I played, dreamed, and learned as I grew up, and from where I am writing these words. Although it has many issues to be solved and is chaotic in many ways, it is also rich and fantastic in many others. The Netherlands has welcomed me and allowed me to continue growing personally and professionally. I am happy and proud to call it home.

Ecuadorian sunset in Yachana

ABOUT THE AUTHOR

Tamara Verónica Pinos Cisneros was born in Quito, Ecuador, on September 25th 1981. She studied Computer and Systems Engineering at Universidad Católica del Ecuador (PUCE) and graduated in 2005. She then worked as a software developer for the Ecuadorian government and several international banks. In 2008, she, together with a friend, started Advance Consulting, a software development company.

In 2012, Tamara moved to the Netherlands to pursue an MSc degree in the Media Technology program at the Leiden Institute of Advanced Computer Science of Leiden University. She graduated in 2014 with the thesis "Synthetic Emotions Bicycle (SEB): Building a Human-Bicycle Emotional Bond Through Abstract Expression of Affect". After graduating, Tamara started working as a Creative Technologist at MediaLab Amsterdam at the Amsterdam University of Applied Sciences (AUAS). She later became the manager of the Instruments team of the Digital Society School.

In 2019, Tamara obtained a doctoral grant from the Faculty of Digital Media & Creative Industry at the AUAS. She began her doctoral research, 'Toys4Therapy', under the supervision of Geke Ludden, head of the Interaction Design group at the University of Twente, Ben Kröse, head of Digital Life (at the time) and Ben Schouten, head of Play and Civic Media (at the time) at the AUAS. Her doctoral work investigates how playful, tangible, and data-informed smart toys can make at-home therapy more motivating for children with cerebral palsy and their families by integrating design, technology and health.

Alongside research, Tamara currently teaches at Communication and Multimedia Design at AUAS, where she focuses on technology-related topics, immersive environments and hands-on tinkering, integrating makerspace tools with craft-based methods and the use of sensors to help design students connect critical reflection with practical making.

SUMMARY

Children with cerebral palsy (CP), particularly those with spastic hemiplegia, require long-term hand therapy to maintain and improve motor function. While evidence-based interventions such as Constraint-Induced Movement Therapy and Bimanual Training are effective in clinical settings, sustaining therapy at home remains challenging. Home-based therapy is often characterised by repetitive exercises, limited adaptability, and high reliance on parental enforcement, which can decrease children's motivation, agency, and long-term adherence. This thesis addresses the gap between clinically designed therapy and the lived realities of family life by investigating how playful, adaptive smart toys can support motivating and meaningful hand therapy at home.

Adopting a Research through Design (RtD) approach, this work positions smart toys as mediators between clinical goals, children's intrinsic motivation to play, and the constraints of the home environment. The research integrates insights from play theory, motivation theory, rehabilitation science, and human–computer interaction. Across six interrelated, paper-based chapters, the thesis progresses from understanding the problem space to developing and evaluating design solutions, and finally to synthesising transferable design knowledge.

Empirical studies include a scoping review of playful technology-supported hand therapies, co-creation sessions with children, analyses of clinic-to-home therapy translation, and the design and longitudinal field evaluation of the *Magic Monster*: a smart therapeutic toy that transforms prescribed hand movements into playful interaction. Central to this design is the concept of self-adaptive play complexity, enabled through sensing and machine-learning techniques that identify the correct hand movement to dynamically adjust challenge to the child's abilities.

The thesis culminates in the Smart Toy–CTT (Context–Therapy–Technology) Framework, which synthesises findings into a structured process to guide the design of smart toys for home-based therapy. This thesis reflects on the research journey, answers the two research questions concerning motivation and self-adaptation, and articulates contributions to design research, clinical practice, and interdisciplinary collaboration. Overall, this thesis argues that embedding therapy within playful, adaptive artefacts, designed with sensitivity to family contexts, offers a viable and scalable pathway for supporting children with CP in their everyday therapeutic routines.

LIST OF PUBLICATIONS

Published

Pinos Cisneros, T., Escobar Vega, F., Kröse, B., Schouten, B., & Ludden, G. (2021). Co-creating hybrid toys as an approach to understand children's needs in play experience. In *Young Children's Rights in a Digital World: Play, Design and Practice* (pp. 219-236). Cham: Springer International Publishing.

Pinos Cisneros, T., Kröse, B., Schouten, B., & Ludden, G. (2020). Hand rehabilitation for children with Cerebral Palsy: from clinical settings to home environment. In *Proceedings of the 6th International Conference on Design4Health* (Vol. 3, pp. 65-72).

Pinos Cisneros, T. V., Brons, A., Kröse, B., Schouten, B., & Ludden, G. (2023). Playfulness and New Technologies in Hand Therapy for Children With Cerebral Palsy: Scoping Review. *JMIR Serious Games*, *11*(1), e44904.

Schoorl, K., **Pinos Cisneros, T.**, Salah, A. A., & Schouten, B. (2024). Wrist movement classification for adaptive mobile phone based rehabilitation of children with motor skill impairments. *arXiv e-prints*, arXiv-2401.

Alberts, M., De Ridder, E. A., Lodewijks, J. A., **Pinos Cisneros, T. V.**, Schoorl, K., Salah, A. A., and Schouten, B. A. (2022). Designing a smartphone exergame for children with cerebral palsy in the home environment. In Extended Abstracts of the 2022 Annual Symposium on Computer-Human Interaction in Play, pages 183–188.

Under review

Pinos Cisneros, T., Kröse, B., Schouten, B., Nederhand, M., Ali Salah, A. Schoorl, K. Hepping, A.M. & Ludden, G. (2025). Design and evaluation of a smart toy for home therapy for children with cerebral palsy.

Pinos Cisneros, T., Kröse, B., Schouten, B., & Ludden, G. (2025). Smart Toy - CTT: A Process Framework for Developing Smart Toys for Home Therapy.

APPENDICES

Appendix A – Chapter 2

Appendix B – Chapter 5

Appendix C – Chapter 7

Appendix D – Magic Monster

Appendix A – Chapter 2

Appendix A.1 PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews) checklist.

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
TITLE			
Title	1	Identify the report as a scoping review.	1
ABSTRACT			
Structured summary	2	Provide a structured summary that includes (as applicable): background, objectives, eligibility criteria, sources of evidence, charting methods, results, and conclusions that relate to the review questions and objectives.	1
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known. Explain why the review questions/objectives lend themselves to a scoping review approach.	2-5
Objectives	4	Provide an explicit statement of the questions and objectives being addressed with reference to their key elements (e.g., population or participants, concepts, and context) or other relevant key elements used to conceptualize the review questions and/or objectives.	3-4
METHODS			
Protocol and registration	5	Indicate whether a review protocol exists; state if and where it can be accessed (e.g., a Web address); and if available, provide registration information, including the registration number.	https://osf.io/hbzud
Eligibility criteria	6	Specify characteristics of the sources of evidence used as eligibility criteria (e.g., years considered, language, and publication status), and provide a rationale.	4
Information sources*	7	Describe all information sources in the search (e.g., databases with dates of coverage and contact with authors to identify additional sources), as well as the date the most recent search was executed.	5-6
Search	8	Present the full electronic search strategy for at least 1 database, including any limits used, such that it could be repeated.	26

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
Selection of sources of evidence†	9	State the process for selecting sources of evidence (i.e., screening and eligibility) included in the scoping review.	4
Data charting process‡	10	Describe the methods of charting data from the included sources of evidence (e.g., calibrated forms or forms that have been tested by the team before their use, and whether data charting was done independently or in duplicate) and any processes for obtaining and confirming data from investigators.	5
Data items	11	List and define all variables for which data were sought and any assumptions and simplifications made.	5
Critical appraisal of individual sources of evidence§	12	If done, provide a rationale for conducting a critical appraisal of included sources of evidence; describe the methods used and how this information was used in any data synthesis (if appropriate).	N/A
Synthesis of results	13	Describe the methods of handling and summarizing the data that were charted.	5
RESULTS			
Selection of sources of evidence	14	Give numbers of sources of evidence screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally using a flow diagram.	5-6
Characteristics of sources of evidence	15	For each source of evidence, present characteristics for which data were charted and provide the citations.	6-20
Critical appraisal within sources of evidence	16	If done, present data on critical appraisal of included sources of evidence (see item 12).	N/A
Results of individual sources of evidence	17	For each included source of evidence, present the relevant data that were charted that relate to the review questions and objectives.	6-13
Synthesis of results	18	Summarise and/or present the charting results as they relate to the review questions and objectives.	13-20
DISCUSSION			
Summary of evidence	19	Summarise the main results (including an overview of concepts, themes, and types of evidence available), link to the review questions and objectives, and consider the relevance to key groups.	20-22
Limitations	20	Discuss the limitations of the scoping review process.	22

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
Conclusions	21	Provide a general interpretation of the results with respect to the review questions and objectives, as well as potential implications and/or next steps.	23
FUNDING			
Funding	22	Describe sources of funding for the included sources of evidence, as well as sources of funding for the scoping review. Describe the role of the funders of the scoping review.	23

Appendix A.2 – Search query

Scopus

(TITLE-ABS-KEY ("cerebral palsy" OR "cerebral paresis" OR "cerebral palsies") AND TITLE-ABS-KEY (play* OR game OR gamification OR toy) AND TITLE-ABS-KEY (child*) AND TITLE-ABS-KEY (therapy OR rehabilitation OR treatment) AND TITLE-ABS-KEY (hand OR "upper limbs")) AND (LIMIT-TO (PUBYEAR,2022) OR LIMIT-TO (PUBYEAR,2021) OR LIMIT-TO (PUBYEAR,2020) OR LIMIT-TO (PUBYEAR,2019) OR LIMIT-TO (PUBYEAR,2018) OR LIMIT-TO (PUBYEAR,2017) OR LIMIT-TO (PUBYEAR,2016) OR LIMIT-TO (PUBYEAR,2015) OR LIMIT-TO (PUBYEAR,2014) OR LIMIT-TO (PUBYEAR,2013) OR LIMIT-TO (PUBYEAR,2012) OR LIMIT-TO (PUBYEAR,2011) OR LIMIT-TO (PUBYEAR,2010) OR LIMIT-TO (PUBYEAR,2009))

Web of Science

TS=(cerebral palsy) AND TS= (play* OR game OR gamification OR toy) AND TS=(therapy OR rehabilitation OR treatment) AND TS=(child*) AND TS= (hand OR "upper limbs")

YEARS: (2022 OR 2021 OR 2020 2019 OR 2014 OR 2009 OR 2018 OR 2013 OR 2017 OR 2012 OR 2016 OR 2011 OR 2015 OR 2010)

CINAHL

(”cerebral+palsy”+OR+”cerebral+paresis”+OR+”cerebral+palsies”+)+AND+(+play*+OR+game+OR+gamification+OR+toy+)+AND+child*+AND+(+therapy+OR+rehabilitation+OR+treatment+)+AND+(+hand+OR+”upper+limbs”+)&DT1=200901-202212

Appendix A.3

Types of hardware and studies.

Type of hardware	Name	Amount
Computers n=32	PC	(n=26) (Chen et al., 2021) (De Oliveira et al., 2016)(Elsaeh et al., 2017) (Garcia-Hernandez et al., 2021)(Gieser et al., 2015)(Hernández et al., 2018)(Hung et al., 2018)(Kottink et al., 2017)(Leal et al., 2020) (MacIntosh et al., 2020)(MacIntosh et al., 2022) (Nai et al., 2019) (Pruna et al., 2017)(Stansfield et al., 2015)(Tarakci et al., 2020)(Yildirim et al., 2021) (Choi et al., 2021)(Cifuentes-Zapien et al., 2011)(Crisco, Schwartz, Wilcox, Brideau, et al., 2015) (Fu et al., 2020)(Parmar et al., 2021)(Preston et al., 2016)(Psychouli et al., 2017)(Sabry et al., 2020) (Van Loon et al., 2011)(Weightman et al., 2011)
	Laptop	(n=4) (Hernandez et al., 2021)(Minh et al., 2021)(Mittag et al., 2020)(Peper et al., 2013)
	Tablet	(n=2) (Mirich et al., 2021)(Stroppini et al., 2022)
Controllers n=11	Custom levers	(n=3) (Hernandez et al., 2021)(Peper et al., 2013)(Van Loon et al., 2011)
	Geomagic Touch	(n=1) (Pruna et al., 2017)
	Joystick	(n=2) (Amonkar et al., 2022)(Weightman et al., 2011)
	Motion Therapy mouse	(n=1) (Parmar et al., 2021)
	Novint Falcon	(n=3) (Elsaeh et al., 2017) (Hernández et al., 2018)(Hernandez et al., 2021)
	Wii Nunchuk	(n=1) (Gregory et al., 2012)
Game consoles n=11	Nintendo Wii	(n=6) (Acar et al., 2016)(Avcil et al., 2021)(Chiu et al., 2014)(El-Shamy & El-Banna, 2020)(Kassee et al., 2017)(Winkels et al., 2013)
	Play Station	(n=4) (Golomb et al., 2009)(Golomb et al., 2010)(Goyal et al., 2022)(Li et al., 2009)
	XBox	(n=1) (Zoccolillo et al., 2015)
Motion Sensing n=14	EyeToy	(n=1) (Li et al., 2009)
	HTC Vive trackers	(n=1) (Nai et al., 2019)
	IREX	(n=1) (Guberek et al., 2009)
	Kinect	(n=6) (Chen et al., 2021) (Garcia-Hernandez et al., 2021) (Hung et al., 2018)(Kottink et al., 2017)(Leal et al., 2020)(Zoccolillo et al., 2015)

	Leap Motion	(n=5) (Avcil et al., 2021)(De Oliveira et al., 2016) (Gieser et al., 2015)(Tarakci et al., 2020)(Yildirim et al., 2021)
Robotics *n=2*	Robotic Arm	(n=2) (Cifuentes-Zapien et al., 2011)(Preston et al., 2016)
Smart Tangibles *n=18*	Interactive Story box	(n=1) (Wu et al., 2022)
	Lego Mindstorms NXT	(n=1) (Hsieh et al., 2020)
	Multitouch display	(n=2) (Leal et al., 2020)(Dunne et al., 2010)
	Pleo!	(n=1) (Gregory et al., 2012)
	PhysiTable	(n=1) (Mandil et al., 2015)
	Ride-on-toy	(n=1) (Amonkar et al., 2022)
	Smart blocks	(n=1) (Bian et al., 2020)
	Smart toys	(n=8) (van Delden et al., 2012)(Crisco, Schwartz, Wilcox, Brideau, et al., 2015) (Crisco, Schwartz, Wilcox, Costa, et al., 2015) (Minh et al., 2021) (Psychouli et al., 2017)
	TagTiles	(n=1) (van Delden et al., 2012)
	Tangible objects	(n=1) (Dunne et al., 2010)
VR headsets *n=2*	Oculus Rift	(n=2) (Bortone et al., 2020; Pruna et al., 2017)
Wearables *n=19*	5DT sensing gloves	(n=2) (Golomb et al., 2009) (Golomb et al., 2010)
	Accelerometer	(n=1) (Dunne et al., 2010)
	Arm and elbow remote	(n=2) (Crisco, Schwartz, Wilcox, Brideau, et al., 2015)(Crisco, Schwartz, Wilcox, Costa, et al., 2015)
	Arm sensors	(n=4) (Bortone et al., 2020) (Fu et al., 2020) (Mittag et al., 2020) (Psychouli et al., 2017)
	Electrical stimulation electrodes	(n=1) (Fu et al., 2020)
	Data glove	(n=1) (Sabry et al., 2020)
	Mindwave	(n=1) (De Oliveira et al., 2016)
	Music glove	(n=1) (Stroppini et al., 2022)
	Myo armband	(n=2) (MacIntosh et al., 2020)(MacIntosh et al., 2022)
	Neofect Smart Kids	(n=2) (Choi et al., 2021) (Mirich et al., 2021)
	Polhemus Liberty	(n=1) (Stansfield et al., 2015)

Appendix A.4

Studies that use a combination of different types of hardware.

Combined Technologies	Study
Arm sensors and Laptop	(Mittag et al., 2020)
Arm sensors and Oculus Rift	(Bortone et al., 2020)
Arm Sensors, electrical stimulation electrodes, and PC	(Fu et al., 2020)
Custom lever and Laptop	(Peper et al., 2013)
Custom levers and PC	(Van Loon et al., 2011)
Custom levers, Laptop and Novint Falcon	(Hernandez et al., 2021)
Data glove and PC	(Sabry et al., 2020)
Geomagic Touch, Oculus Rift and PC	(Pruna et al., 2017)
HTC Vive trackers and PC	(Nai et al., 2019)
Joystick and PC	(Weightman et al., 2011)
Kinect and PC	(Chen et al., 2021) (Garcia-Hernandez et al., 2021) (Hung et al., 2018)(Kottink et al., 2017)
Kinect, Multitouch display and PC	(Leal et al., 2020)
Leap Motion and Nintendo Wii	(Avcil et al., 2021)
Leap Motion and PC	(Gieser et al., 2015)(Tarakci et al., 2020)(Yildirim et al., 2021)
Leap Motion, Mindwave and PC	(De Oliveira et al., 2016)
Motion (therapy) mouse	(Parmar et al., 2021)
Music glove and Tablet	(Stroppini et al., 2022)
Myo armband and PC	(MacIntosh et al., 2020)(MacIntosh et al., 2022)
Neofect Smart Kids and PC	(Choi et al., 2021)
Neofect Smart Kids and Tablet	(Mirich et al., 2021)
Novint Falcon and PC	(Elsaeh et al., 2017; Hernández et al., 2018)
Play Station and EyeToy	(Li et al., 2009)
Play Station and 5DT sensing gloves	(Golomb et al., 2009, 2010)
Polhemus Liberty and PC	(Stansfield et al., 2015)
Ride-on-Toy and Joystic	(Amonkar et al., 2022)
Robotic Arm and PC	(Cifuentes-Zapien et al., 2011) (Preston et al., 2016)
Smart Toy and Arm, elbow remote	(Crisco, Schwartz, Wilcox, Costa, et al., 2015)
Smart Toys and Arm, elbow remote and PC	(Crisco, Schwartz, Wilcox, Brideau, et al., 2015)
Smart toys and Laptop	(Minh et al., 2021)
Smart Toys, arm sensors and PC	(Psychouli et al., 2017)
TagTiles and SmartToys	(van Delden et al., 2012)
Tangible objects, accelerometer, and Multitouch Display	(Dunne et al., 2010)
Wii Nunchuk and Pleo	(Gregory et al., 2012)
Xbox and Kinect	(Zoccolillo et al., 2015)

Appendix B – Chapter 5

B.1 Expert Interview 1 - Questions

1. How did the idea of the Pirate Group start?
2. Has there been major changes in the program from its start in 2010 until now?
3. At the end of the Pirate Group and Handig2Handig some tools are delivered to the parents, like videos and ideas for home exercises and written transfer, what are these?
4. Could I have access to a "Pirate book"?
5. What are the main differences between Pirate Group and Handig2Handig?
6. What is the general recommendation for home therapy for children with CP?
7. What is the current situation for Home therapy?
8. What are the issues with home therapy? (is there motivation to execute it?, lack of time?)
9. What would be the ideal scenario of therapy at home?
10. What type of exercises do children need to do at home?
11. How are home exercises executed after these programs?
12. Is there a measurement or follow-up to control the execution of the exercises at home?
13. What is the role of the parents, caretakers in the home therapy?
14. What is the role of the siblings and friends in the home therapy?
15. What is the "home assignment" in the Handig2Handig group?
16. Are there any upcoming events or therapies planned?
17. Does home therapy include modified Constraint Induced Movement? or should it include modified Constraint Induced Movement?
18. Does home therapy include Bimanual training? or should bimanual training (BiT) be included in home therapy?
19. What are the elements of the Pirate and Handig2Handig groups that could be translated into the home environment? a. BiT b. Play c. Motor learning d. Role of the parents e. Goal setting f. Feedback g. Opportunity of repetition h. Other?
20. What are other programs for hand rehabilitation for children with CP?
21. Which type of toys or tools are used during home therapy?

B.2. Child Interview 1 - Questions

1. Did you like to do the tricks?
2. Did you find the tricks easy or difficult?

3. What do you think of the monster's appearance, how would you change the monster? (drawing)
4. Did you learn anything from it?
5. Would you download the app yourself and how often would you play with it (1x per day, 1x per week etc.)
6. Did you have trouble controlling the Magic Monster while playing (e.g. difficult shaking)?
7. Do you find the monster large or small enough to hold while playing?
8. If you could add something to the Magic Monster yourself, what would it be? It can be something for both the app and the Monster.
9. If you would remove something from the Magic Monster yourself, what would it be? It can be something for both the app and the Monster.
10. Can you create a story for the Magic Monster? Where does it come from?

B.3. Expert Interview 2 - Questions

1. Will it be feasible for children with spastic hand to: - Hold the phone? - Do the magic trick?
2. Are the hand movements relevant? - Pinch grasp - Lateral rotation (shaking) - Dorsiflexion
3. We are working on a calibration functionality and using AI to adapt the shaking, would it make sense to increase the level (complexity)?
4. How would you see the use of automation or self-adaptation could be used in the toy to maintain engagement and prolong the use of the toy?
5. We are looking for new ideas of other interactions that we could add to the toy. - Is tapping the screen a movement that can be beneficial? - Pinch and grab a fish to feed the monster - Dancing with the monster
6. Most interactions are about holding the monster with one hand and doing an action with another hand, can you think of another interaction that can be done with both hands?
7. Navigating with the monster will require a rotation of wrists, will this be a useful movement?
8. Do you foresee any risks in this prototype? Which ones?
9. Other comments or remarks on the direction of the prototype

B.4. Child Interview 2 - Questions

1. Do you like the monster?
2. Is the monster funny?
3. Is the monster easy to hold?
4. Is it difficult to shake the monster?
5. What do you want the monster to do?

B.5. Therapist Interview - Questions

1. Is the calibration correct?
2. Can the child do the movement?
3. Is the movement beneficial for the child?
4. How easy did it look to grab the toy?

Appendix C – Chapter 7

C.1 Possible methods that can be used for each layer of the framework

Framework Layer	Method	Purpose
Context	Cultural Probes	Elicit daily routines and values from families in home therapy contexts
	Diary Studies	Capture lived experience over time through self-reporting
	(user) Journey Mapping	Visualise the therapy experience and identify key moments
	Photo Elicitation	Use photos to reflect on home environment and therapy engagement
Theory	Experience Prototyping	Test how theory-informed elements (e.g. Flow) influence interaction
	Design Fiction	Explore future scenarios that provoke reflection on behaviour or motivation
	Critical Artefact Interviews	Use artefacts to trigger deeper insights about values and needs
	Observation	Understand therapeutic interactions and behaviour change dynamics
Technology	Wizard of Oz Prototyping	Simulate smart toy features to test feedback/adaptation mechanisms
	Bodystorming	Physically act out interactions to refine physical form and interaction
	Technology Probes	Deploy tech prototypes to gather inspiration and real-world feedback
	Form & Material Studies	Explore material affordances for interaction, safety and accessibility
	Co-Creation Sessions	Explore themes and feedback mechanisms with children
Cross-Layer	Stakeholder Mapping	Map key stakeholders, relationships, and roles
	Participatory Design Workshops	Engage stakeholders in joint creation of concepts
	Scenario-Based Design	Envision future use across settings and stakeholder interactions

C.2 Smart Toy – CTT Process Framework Canvas

Downloadable version can be found here:

Smart Toy - CTT Framework

① Context

What do we know about the patient/target group? ex: age, disability

What do we know of the home environment of the patient? ex: family composition, daily schedule

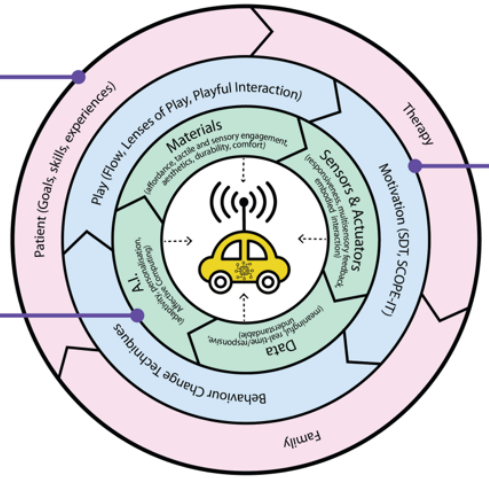
How are the parents or siblings involved? ex: play together, audience, intruction, solo game

What is the goal(s) of the patient? ex: being able to zip their jacket

Which type of therapy is needed? ex: bimanual? focus on the spastic hand?

Where will the toy be used? ex: home?

Context



Theory

② Theory

Which behaviour do we want to change/promote?

How do we elicit intrinsic or extrinsic motivation?

Which type of play do we want to foster? ex: open play, games with rules

Which playful experiences do we want the toy to have ? ex: competition, challenge, discovery, etc.

Which metaphors do we want to use? ex: move like a fish, etc.

Technology

③ Technology

Sensors & Actuators: *Which playful interactions do we want?* ex: shake, dance, etc.

Which sensors offer that functionality? ex: piezo, accelerometer, servo motor, LED lights, etc.

Data: *Which data is needed for the interaction?* ex: angle of hand rotation

Materials: *What type of material do we want to use?* ex: soft toy or hard? plastic, fabric or wood?

Ideas and Sketches of the smart toy

Draw how the smart toy looks like

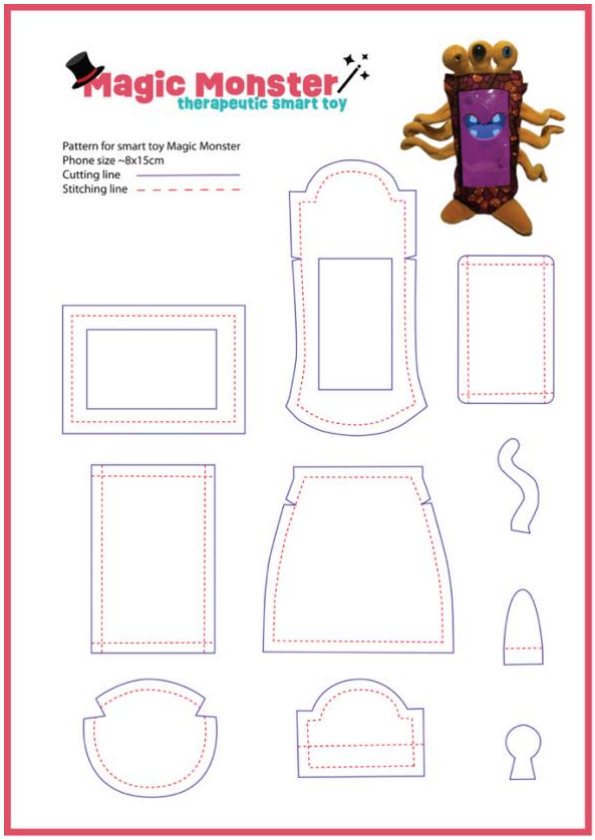
Draw escenarios: how/with whom is the toy going to be used?

Glossary: SDT: Self-Determination Theory, BCT: Behaviour Change Techniques, SCOPE-IT: Synthesis of Child, Occupational Performance, and Environment in Time Model , AI: Artificial Intelligence

Appendix D – Magic Monster

D.1 Pattern to make your own Magic Monster

The pattern to make your own Magic Monster can be downloaded from:



D.2 Demo video of the magic trick

D.3 The Magic Monster trick book (in Dutch) by IJsfontein

HET
MAGIC MONSTER
trukenboek

MUNT TRUC

Met deze truc leer je hoe een echte munt in de mond van het monster kan toveren. En hoe je de munt daarna weer tevoorschijn kan laten komen.

Voor de truc heb je twee munten nodig.

Oefen eerst hoe je een munt in je hand kan wegtoveren. Daarna kan je samen met het monster de truc gaan doen!

Wat heb je nodig

2 munten van 50 cent

HAND TECHNIEK

Voor de munt truc is het belangrijk dat je een munt in je hand kan wegtoveren. Met deze stappen leer je hoe dat moet. Oefen deze dus goed voordat je aan de truc begint!

Je kan de oefening ook eerst doen zonder munt. Als je de beweging onder de knie hebt kan je met de munt erbij oefenen.

STAP 1

Houdt de munt tussen je duim en wijsvinger. Laat hem zien aan het publiek.

STAP 2

Nu moet de munt verplaatsen zodat hij tussen je wijs en middelvinger komt. Dat doe je door de munt te draaien. En hem over te pakken met je middelvinger.

STAP 3

Klem nu de munt vast tussen je wijs en middelvinger, en zorg dat de munt uitsteekt aan de kant van je handpalm.

STAP 4

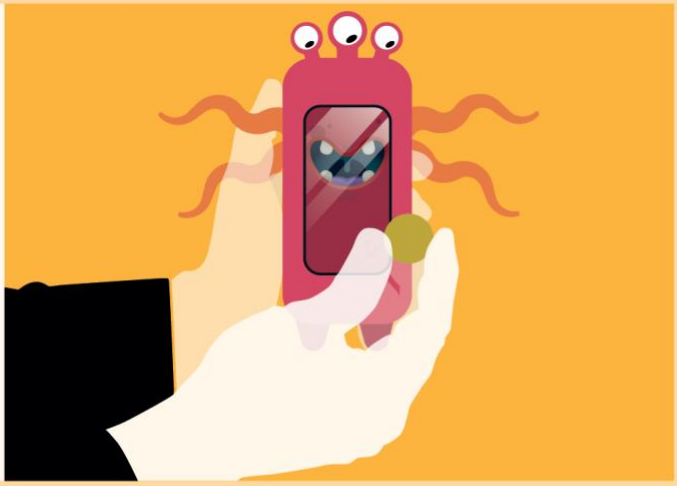
Laat je publiek de rug van je hand zien. De munt lijkt verdwenen!

STAP 1

Pak het monster in 1 hand.
Stop in die hand ook een munt. Die klem je vast tegen het monster. Je publiek denkt nu dat je alleen het monster vast houdt en kan de munt niet zien.

STAP 2

Laat je publiek nu de tweede munt zien.



STAP 3

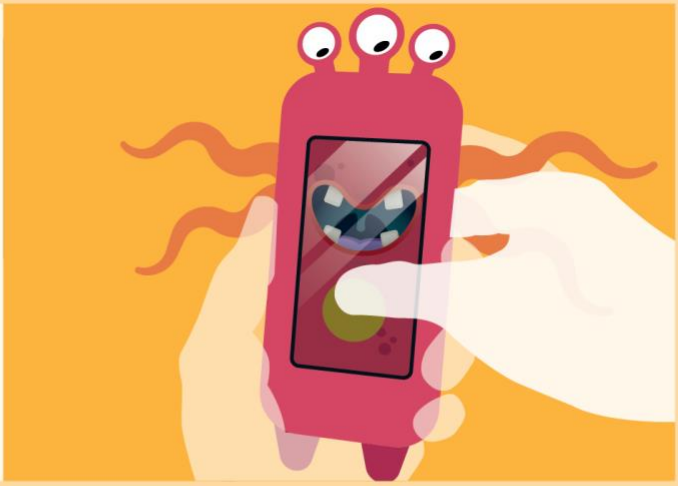
Doe alsof je de munt in de mond van het monster stopt. Maar eigenlijk verstop je hem tussen je wijs en middelvinger zoals je bij de handtechniek geleerd hebt. Met de toppen van je vingers raak je het scherm aan. Je ziet nu de munt verschijnen.

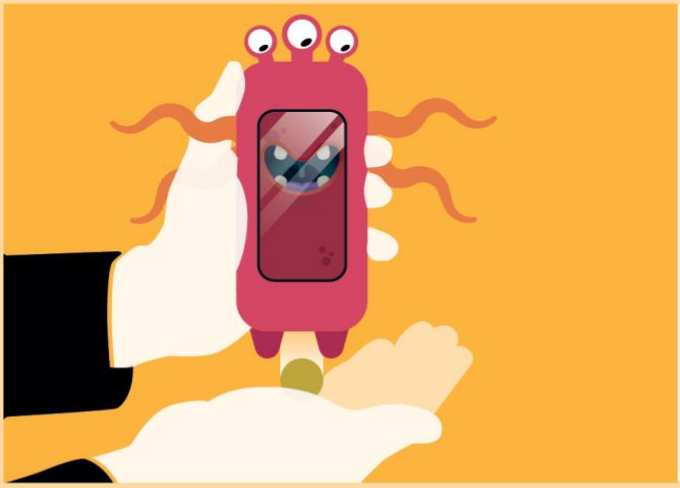
STAP 4

Laat je publiek het monster goed zien. Beweeg hem naar links en rechts om de munt te laten bewegen. Verstop in de tussentijd stiekem de munt die je nog tussen je vingers hebt. Bijvoorbeeld in je broekzak.

STAP 5

Laat nu met je vingertoppen de munt in de mond van het monster bewegen.





STAP 6

Klaar? Schud het monster dan eens goed van boven naar beneden. Laat tegelijkertijd de munt die je nog vast hebt vallen en vang die op met je andere hand. Zo lijkt het net alsof hij uit het monster komt!

TADAAA

SPONSBAL TRUK

Met deze truc leer je hoe een echte sponsbal in de mond van het monster kan toveren. En hoe je de sponsbal daarna weer tevoorschijn kan laten komen.

Voor de truc heb je twee sponsballen nodig.

Oefen eerst hoe je een sponsbal in je hand kan wegtoveren.
Daarna kan je samen met het monster de truc gaan doen!

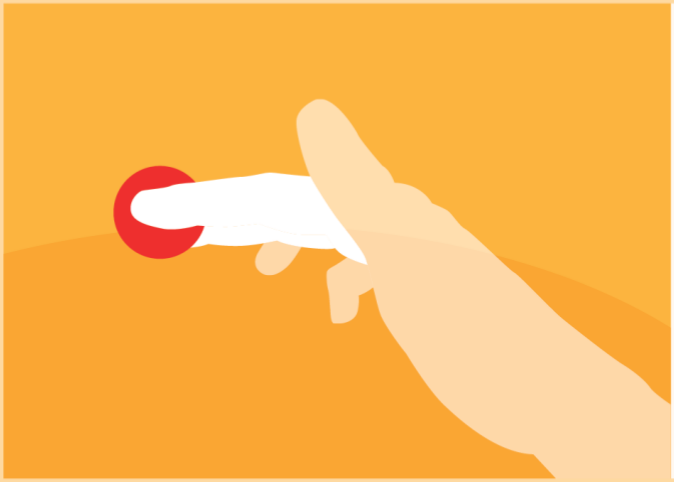
WAT HEB JE NODIG

2 Sponsballen

HAND TECHNIEK

Voor de sponsbal truc is het belangrijk dat je een sponsbal in je hand kan wegtoveren. Met deze stappen leer je hoe dat moet. Oefen deze dus goed voordat je aan de truc begint!

Je kan de oefening ook eerst doen zonder munt. Als je de beweging onder de knie hebt kan je met de sponsbal erbij oefenen.



STAP 1

klem het balletje zachtjes tussen de toppen van je wijs en middelvinger

STAP 2

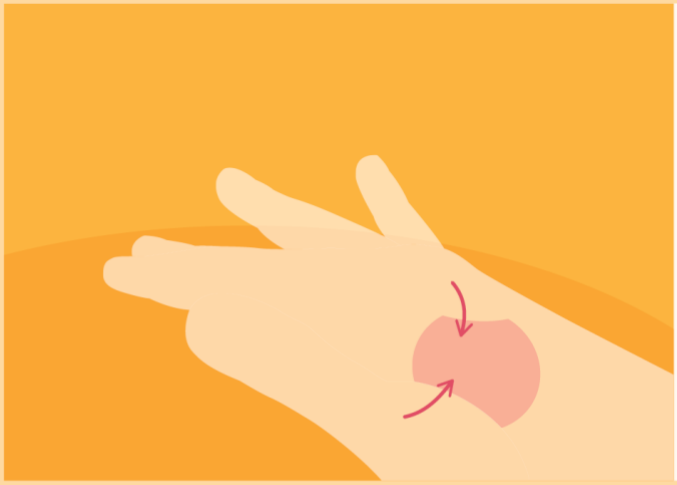
Vouw je vingers naar binnen, naar de palm van je hand.

STAP 3

Knijp de bal vast tussen je duim en wijsvinger, door je duim ertegen aan te klemmen.

STAP 4

De bal is platgeknepen tussen je duim en wijsvinger. Aan de voorkant steekt hij uit, maar aan de achterkant van je hand zie je hem niet.



STAP 5

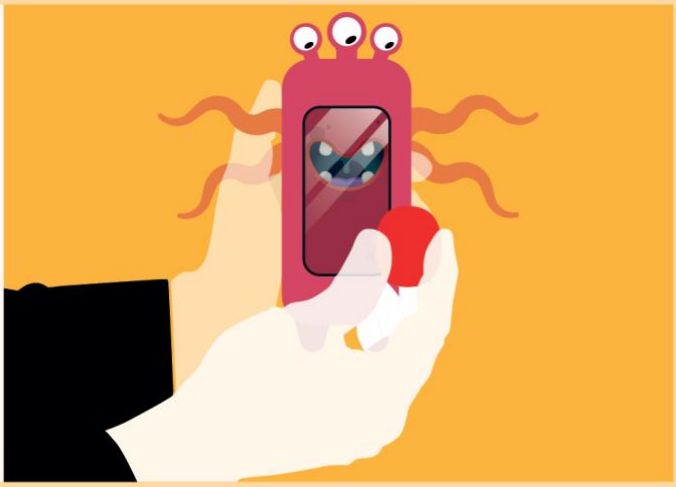
Dan strek je je al je vingers. Het lijkt alsof de bal is verdwenen!

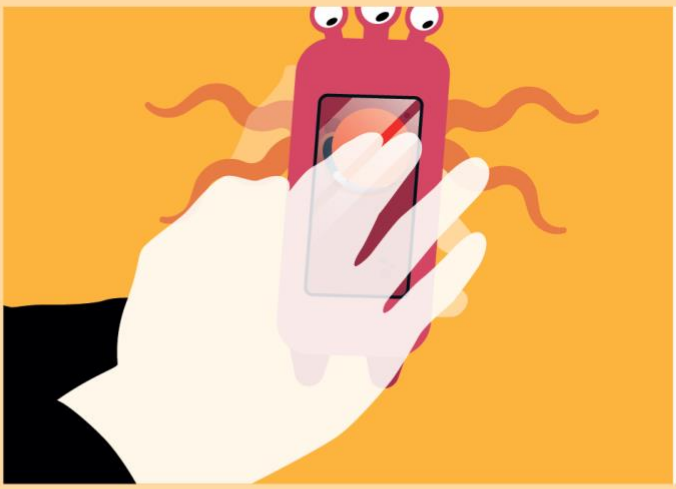
STAP 1

Pak het monster in 1 hand.
Stop in die hand ook een Sponsbal. Die klem je vast tegen het monster. Je publiek denkt nu dat je alleen het monster vast houdt en kan de sponsbal niet zien.

STAP 2

Laat je publiek nu de tweede sponsbal zien.





STAP 3

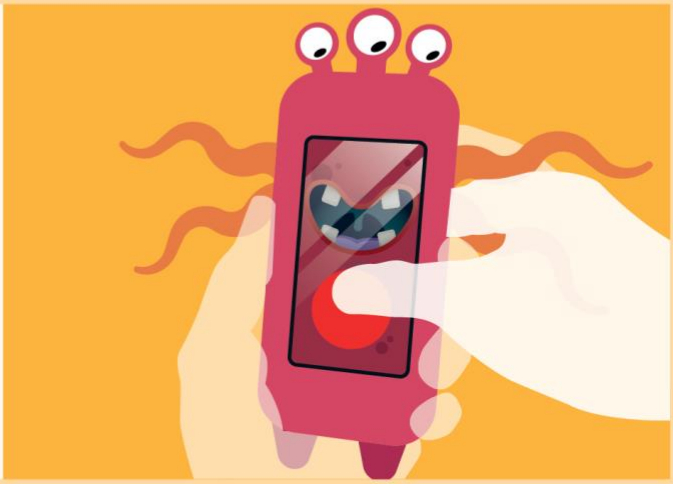
Doe alsof je de sponsbal in de mond van het monster stopt. Maar eigenlijk verstop je hem in je handpalm zoals je bij de handtechniek geleerd hebt.
Met de toppen van je vingers raak je het scherm aan. Je ziet nu de sponsbal verschijnen.

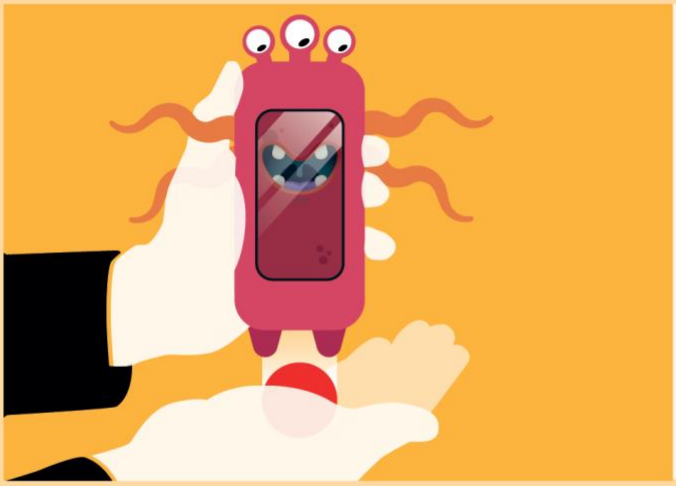
STAP 4

Laat je publiek het monster goed zien. Beweeg hem naar links en rechts om de sponsbal te laten bewegen. Verstop in de tussentijd stiekem de sponsbal die je nog tussen je vingers hebt. Bijvoorbeeld in je broekzak.

STAP 5

Laat nu met je vingertoppen de sponsbal in de mond van het monster bewegen.





STAP 6

Klaar? Schud het monster dan eens goed van boven naar beneden. Laat tegelijkertijd de sponsbal die je nog vast hebt vallen en vang die op met je andere hand. Zo lijkt het net alsof hij uit het monster komt!

UITDAGINGEN

Tijdens het doen van de trucs kun je uitgedaagd worden. Je kunt deze uitdaging doen door op het doosje te klikken. Doe je niks, dan krijg je geen uitdaging en kun je gewoon de truc doen.

SCHUD HARDER

Schud vanaf nu tijdens het doen van trucs harder en met meer beweging van je hand.

SCHUD ZACHTER

Schud vanaf nu tijdens het doen van de trucs zachter en met minder beweging van je hand.

SCHUD SNELLER
Schud vanaf nu tijdens het doen van trucs sneller met je hand.

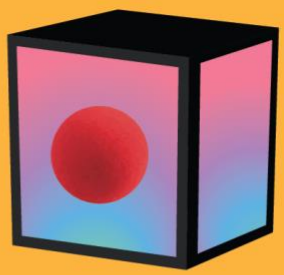
SCHUD LANGZAMER
Schud vanaf nu tijdens het doen van trucs langzamer met je hand.

NIEUWE TRUC

Als je goed je best doet dan kun je een nieuwe truc vrijspelen. Je kunt deze kiezen door het monster te schudden als het monster zijn mond open heeft.

NIEUWE TRUC

Klik op de doos om de nieuwe truc vrij te spelen.



TRUC WISSELEN

Doe alsof je de sponsbal in de mond van het monster stopt. Maar eigenlijk verstop je hem in je handpalm zoals je bij de handtechniek geleerd hebt.
Met de toppen van je vingers raak je het scherm aan. Je ziet nu de sponsbal verschijnen.