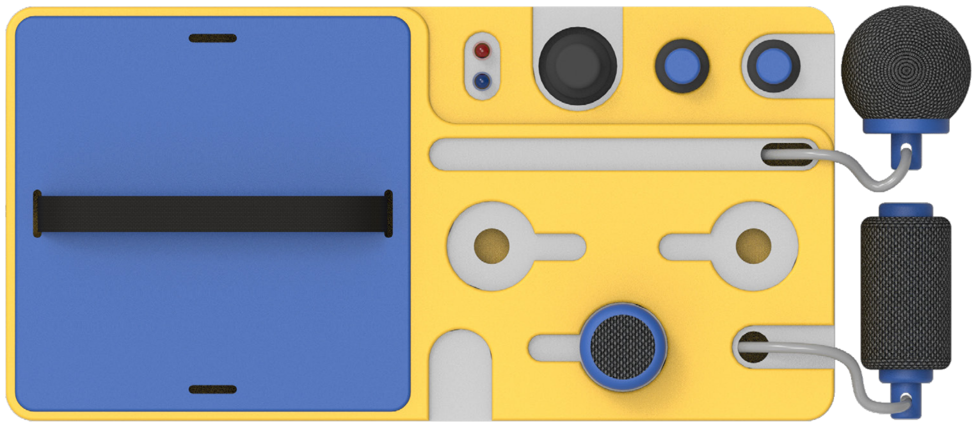
Master of Design · Interaction Design · Project 3

Designing Activity Based Exergames for Motor Skill Enhancement

For Children with Cerebral Palsy from Age 6 to 10



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Declaration

I hereby declare that the project entitled "Designing -Based Exergames for Motor Skill Enhancement : For Children with Cerebral Palsy from Age 6 to 10" submitted to IDC School of Design, Indian Institute of Technology, Bombay, is a record of an original work done by me, Karan Tanna, under the guidance of Prof. Swati Pal. I also declare that the written document represents my ideas in my own words and where others ideas or words have been included, I have adequately cited and referenced the original sources.

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Approval Sheet

The project titled "Designing Activity Based Exergames for Motor Skill Enhancement : For Children with Cerebral Palsy from Age 6 to 10" by Karan Tanna, is approved for partial fulfillment of the requirement for the degree of Master of Design' in Interaction Design.

Guide

Internal Examiner

Chairperson

External Examiner

Acknowledgements

I extend my gratitude to everyone involved in my project for their invaluable help, guidance, and support. A special expression of thanks goes to my supervisor Prof. Swati Pal, whose mentorship, patience and support was instrumental in the success of this endeavor.

I would like to thank all the doctors, therapists and the organizations in Ahmedabad and Mumbai, which helped me to understand the space and allowed me to interact with stakeholders. My heartfelt appreciation extends to all my classmates, study participants, and the institutes that supported me throughout this project.

Finally, I want to express my deepest gratitude to my parents for their unwavering belief and unfaltering support, even during the most challenging times.

Contents

Abstract

Cerebral palsy (CP) significantly impacts motor and cognitive skills in children, reducing their quality of life. Traditional therapies often lack engagement and effectiveness, hindering rehabilitation progress. This project aims to address these issues by developing task-based exergames specifically for children with CP. Through extensive research, we identified the limitations of current treatments and the need for innovative solutions. We created web-based games and 'Pico'—a plug-and-play device named for "pixel" (pi) and "companion" (co)—which controls four exergames through actions based on traditional physiotherapy exercises. These games, customizable to individual needs, were tested with children with CP under supervision and were evaluated by experts. By integrating gamification into therapy sessions, we aim to make rehabilitation more enjoyable, motivating, and effective, ultimately enhancing the well-being and outcomes of children with CP.

Introduction

Rehabilitation for children with Cerebral Palsy (CP) often involves repetitive and monotonous exercises that hinder motivation and progress. Traditional therapies, though essential, frequently fail to engage young patients, leading to decreased participation and suboptimal outcomes. This project aims to address these issues by leveraging modern technology to create engaging, task-based exergames for children with CP.

Our approach combines extensive primary and secondary research to identify limitations in CP rehabilitation. By developing web-based games and a plug-and-play device named 'Pico'—short for "pixel" (pi) and "companion" (co)—we transform traditional physiotherapy exercises into enjoyable, interactive experiences. These games are tailored to individual needs and tested under expert supervision to meet therapeutic goals while being fun and motivating for children.

This report details the evolution of our design process, from research and ideation to prototyping and iterative testing, culminating in a final prototype evaluated by users and experts. We aim to enhance the rehabilitation experience for children with CP, fostering better engagement, motivation, and therapeutic outcomes.

Motivation

The motivation for this project stems from my personal experience with partial paralysis and dystonia due to Meningomyelocele, a condition similar to Cerebral Palsy. As a child, I underwent extensive physical, speech, and occupational therapy, finding the process monotonous and progress minimal despite years of effort. This affected my confidence and caused frustration for both me and my parents. While tools and resources have improved, therapy still relies heavily on traditional exercises. I am driven to leverage modern technologies to create engaging interventions for children with Cerebral Palsy, making their rehabilitation journey more enjoyable and effective.

1. Preliminary Research

1.1 Understanding Cerebral Palsy

Cerebral palsy (CP) encompasses a set of enduring, non-progressive conditions that impair movement, posture, and motor function. These disorders arise from disruptions or damage to the developing brain, occurring during pregnancy, childbirth, or shortly after birth (Paneth et al., 2022). Specific causes include genetic factors, maternal infections, fetal stroke, premature birth, and birth complications such as oxygen deprivation (Oskoui et al., 2013).

We investigated a wide range of resources and consulted with various experts to develop a thorough understanding of cerebral palsy and its rehabilitation in children.

Types of Cerebral Palsy :

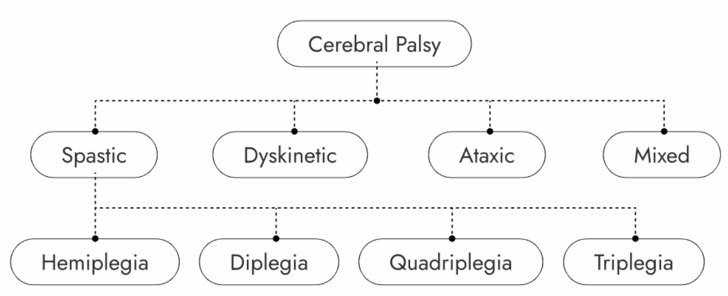


Fig1: Types of Cerebral Palsy

Spastic CP: The most common type, characterized by increased muscle tone and stiff, jerky movements. It can affect different areas of the body (diplegia, hemiplegia, quadriplegia, etc..) which happens due to the lesion in the motor area in the cerebral cortex.

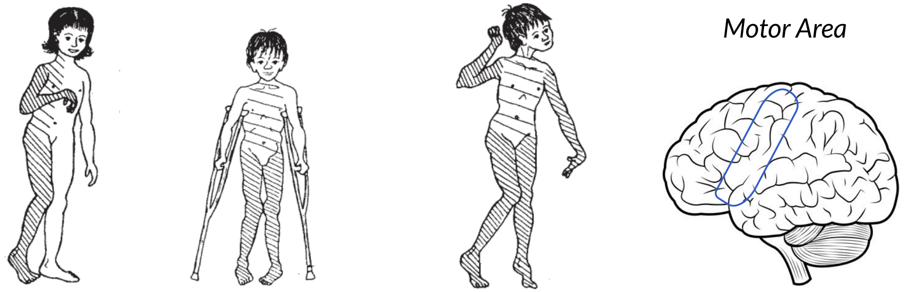


Fig 2 : Types of Spastic Cerebral Palsy (L to R: Hemiplegia, Diplegia, Quadriplegia)

Dyskinetic CP / Athetosis : Involuntary, uncontrolled body movements and fluctuating muscle tone. Includes athetoid, choreoathetoid and dystonic types occurs due to the lesion in the basal ganglia of midbrain.

Fig 3 : Dyskinetic CP or Athetosis

Ataxic CP: Struggle with balance, depth perception and coordinating movements with jerky movements & unstable walking due to the lesion in the cerebellum.

Fig 4 : Ataxic CP

Mixed CP: exhibiting symptoms of more than one type.

Muscle Tone and Cerebral Palsy

Muscle tone abnormalities are a defining feature of cerebral palsy, characterized by hypertonia (spasticity, rigidity) or hypotonia (low muscle tone).

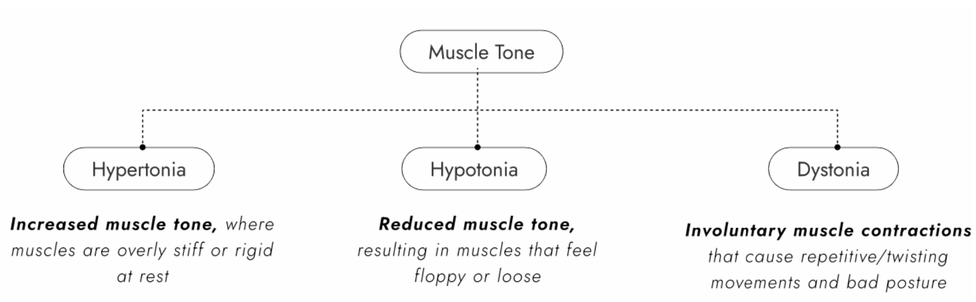


Fig 5 : Types of Muscle Tones

Right muscle tone is pivotal for motor skills and balance, but deviations can lead to stiffness or instability. Left untreated, these deviations can cause complications like contractures and chronic pain. Managing muscle tone through various interventions is essential for promoting motor development, functionality, and overall well-being.

Effects of Cerebral Palsy

The effects and severity of CP can differ significantly between individuals, influenced by the type of CP and the specific brain regions affected. The effects often include:

Motor Impairments :

- Muscle weakness, spasticity, or tightness
- Lack of muscle coordination and control
- Difficulty with gross and fine motor skills
- Issues with gait, balance, and mobility

Cognitive/Learning Impairments :

- Intellectual disabilities
- Speech and language delays
- Visual-spatial difficulties
- Memory and attention deficits

1.2 Identification of Cerebral Palsy

Identifying cerebral palsy (CP) in children necessitates a comprehensive understanding of their developmental process and the standard sequence of milestones. While these milestones can vary slightly among children, they typically follow a consistent pattern from birth to 20 months, which are crucial formative years.

Age Range	Typical Age	Milestone	Description
N/A	Birth	Physiologic flexion	Natural bending or flexing of limbs and joints present at birth.
		Turns head to side in prone	Ability to turn the head sideways while lying on the stomach.
1–2 mo	1mo	Attempts to lift head in midline	Efforts to raise the head while positioned in the center.
N/A	Birth	Automatic stepping	Reflexive movement resembling walking when held upright.
1–4 mo	2mo	Fencer's posture	Position where one arm and leg extend while the opposite arm and leg flex, resembling a fencer's stance.
N/A		Astasia	Inability to stand due to lack of coordination.
		Abasia	Inability to walk due to lack of coordination.
2–4 mo	3mo	Rolling supine to side-lying nonsegmentally	Rolling from the back to the side in a smooth motion without using distinct body segments.
2–3 mo		Beginning midline head control	Initial ability to hold the head in the midline position.
3–5 mo	4mo	Prone on elbows, head to 90 degrees, chin tuck	Lying on the stomach, propped up on elbows with the head raised to 90 degrees and chin tucked.
		Hands to midline	Bringing hands toward the center of the body.
4–6 mo	5mo	Unilateral reaching prone on elbows	Reaching with one hand while lying on the stomach propped up on elbows.
		Prone on extended arms	Lying on the stomach with arms extended forward.
		Pivot prone posture	Ability to pivot while lying on the stomach.
		Beginning intra-axial rotation	Initial internal rotation of the body around its axis.
		Rolling prone to supine, segmentally	Rolling from the stomach to the back in a segmented manner.
		Head lifting in supine	Lifting the head while lying on the back.
		Supine, hands to knees and feet	Bringing hands toward knees and feet while lying on the back.
		Supine, hands to feet	Bringing hands toward feet while lying on the back.
		Supine, feet to mouth	Bringing feet toward the mouth while lying on the back.
5–6 mo		Propped sitting	Sitting with support, not fully independent.
5–7 mo		Supine bridging	Lifting the pelvis while lying on the back.
	6mo	Rolling supine to prone, segmentally	Rolling from the back to the stomach in a segmented manner.
		Ring sitting, unsupported with full trunk extension and high guard	Sitting upright without support with trunk extended and guarded.
		Transferring objects hand to hand	Moving objects from one hand to the other.
7–9 mo	8mo	Independent sitting with secondary curves	Sitting without support with natural spinal curves.
		Beginning quadruped	Starting to crawl on hands and knees.
		Beginning pull to standing	Initiating the action of pulling up to a standing position.
9–11 mo	10 mo	Creeping	Crawling using hands and knees, but abdomen is off the ground.
10–12 mo		Plantigrade posture	Walking with the entire sole of the foot on the ground.
		Plantigrade creeping	Crawling with the entire sole of the foot on the ground.
9–12 mo		Pulls to standing and lowers self	Pulling up to standing position and then lowering back down.
9–11 mo		Cruising	Walking while holding onto furniture or support.
10–13 mo	12 mo	Pulls to standing through half-kneeling	Pulling up to standing position from a half-kneeling position.
10–15 mo		Walking independently	Walking without support.
14–18 mo	15 mo	Creeping up stairs*	Crawling up stairs.
16–20 mo	18 mo	Walking up stairs with help or handrail*	Ascending stairs with assistance from a handrail or caregiver.

Fig 5 : Stages of Child Development (Based on Paediatric Physical Therapy)

During this period, children progress through key motor, cognitive, and social milestones. Delays or irregularities in achieving these milestones, such as difficulties with sitting, crawling, or walking, may signal CP. Early detection and intervention are essential for managing CP and improving the child's quality of life. Regular monitoring and assessment by healthcare professionals are vital for identifying CP and implementing effective therapeutic strategies.

The impacts of cerebral palsy (CP) endure throughout life, yet its effects vary across different life stages, Some of these stages include:

Early Childhood (Birth - 5 years)

- *Delayed development of motor milestones like sitting, crawling, walking.*
- *Early intervention is critical for preventing secondary complications.*

School Age (5-12 Years)

- *Challenges with tasks like self-care, writing, and active participation.*

- *Potential learning disabilities impacting academics.*
- *Social hurdles stemming from physical or cognitive limitations.*

Adolescence/Adulthood

- *Continued difficulties with mobility, self-reliance, and personal care.*
- *Higher risks of pain, fatigue, obesity and other secondary conditions.*
- *Psychosocial issues like low self-esteem, social isolation.*
- *Transition to employment, independent living can be challenging.*

1.3 Classification Systems in CP

Classification systems in cerebral palsy (CP) serve to categorize and describe the severity and characteristics of the condition. These classification systems help in treatment planning, tracking progress over time, and facilitating communication among healthcare professionals and caregivers.

The Gross Motor Function Classification System

Gross motor skills involve using large muscle groups for activities like walking, jumping, and throwing. They're crucial for movement and physical coordination. GMFCS is a tool used to assess the gross motor function of children with cerebral palsy. There are 5 levels of GMFCS.

Level I: Children can perform gross motor skills like walking and running without limitations.

Level II: They have limitations in walking long distances and may need assistance with some activities.

Level III: Children require hand-held mobility devices to walk and may need assistance with transfers and mobility.

Level IV: They have limited self-mobility and may use powered devices.

Level V: Children rely on assistive technology and need full assistance.

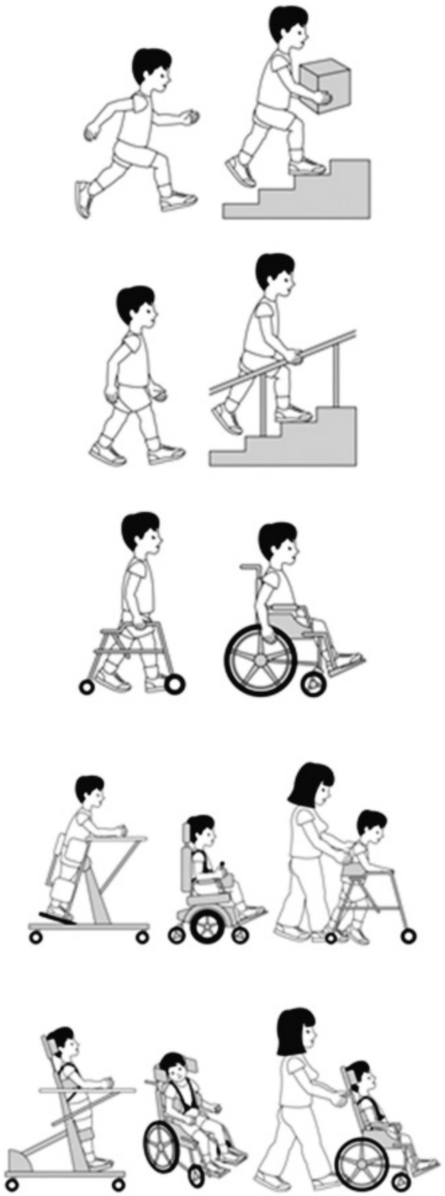


Fig 6 : GMFCS Levels I to V (Top to Bottom)

The Manual Ability Classification System

Manual ability refers to the coordination and dexterity needed for tasks involving the hands, like writing, drawing, and using tools. The Manual Ability Classification System (MACS) assesses the manual abilities of children with cerebral palsy, classified in five levels as :

Level I: Children handle objects easily and effectively.

Level II: They handle most objects but with some difficulty.

Level III: Children handle objects with difficulty and require adaptations.

Level IV: They can handle a limited selection of objects with difficulty.

Level V: Children have minimal ability to handle objects independently.

Both GMFCS and MACS are crucial in guiding treatment planning and intervention strategies for children with cerebral palsy.

Communication Function Classification System

Communication Function encompasses skills such as speaking, listening, understanding language, using non-verbal communication cues as needed. Classification System (CFCS) classifies the communication abilities of individuals with cerebral palsy in five levels.

Level I: Individuals effectively use all forms of communication, including speech, writing, and alternative communication methods.

Level I: Individuals effectively use all forms of communication, including speech, writing, and alternative communication methods.

Level II: They have limited effectiveness with communication but can convey messages with familiar communication partners.

Level III: Individuals can communicate effectively with familiar partners but struggle in unfamiliar situations or with unfamiliar partners.

Level IV: They have inconsistent communication skills and may rely heavily on familiar partners or communication aids.

Level V: Individuals have severe limitations in communication and rely entirely on gestures, vocalizations, or augmentative and alternative communication methods.

CFCS is a valuable tool for improving communication outcomes and enhancing the quality of life for individuals with cerebral palsy.

On conducting preliminary research, we gained insight into Cerebral Palsy and felt inspired to delve deeper. Seeking to expand our understanding, we engaged in discussions with a therapist. Subsequently, we delved into literature to further comprehend the needs and experiences of individuals affected by cerebral palsy and to learn from the existing body of work in this domain.

2. Literature Study

2.1 Review of Interventions for CP

Novak et al. (2013) created a chart from their systematic review examining the evidence on interventions for managing children with cerebral palsy, aiding in comparative clinical decision-making for similar outcomes. They used bubble charts to map interventions, with circle sizes reflecting the amount of published evidence.

Circle size was determined by thhe number of published papers on the topic and the total score for the level of evidence, calculated by reverse coding the Oxford Levels of Evidence (expert opinion = 1, randomized controlled trial [RCT] = 5)

The circle's position on the Y-axis corresponds to the GRADE System Rating, and its color matches the Evidence Alert System (Fig. 7).

The research studied around 64 discrete CP interventions and out of which evidence supports 15 green light interventions ie. 24% are proven to be effective. All effective interventions worked at only one level of the ICF Framework.

Observationally, exercises that were activity based according to ICF, showed a high success rate compared to others.

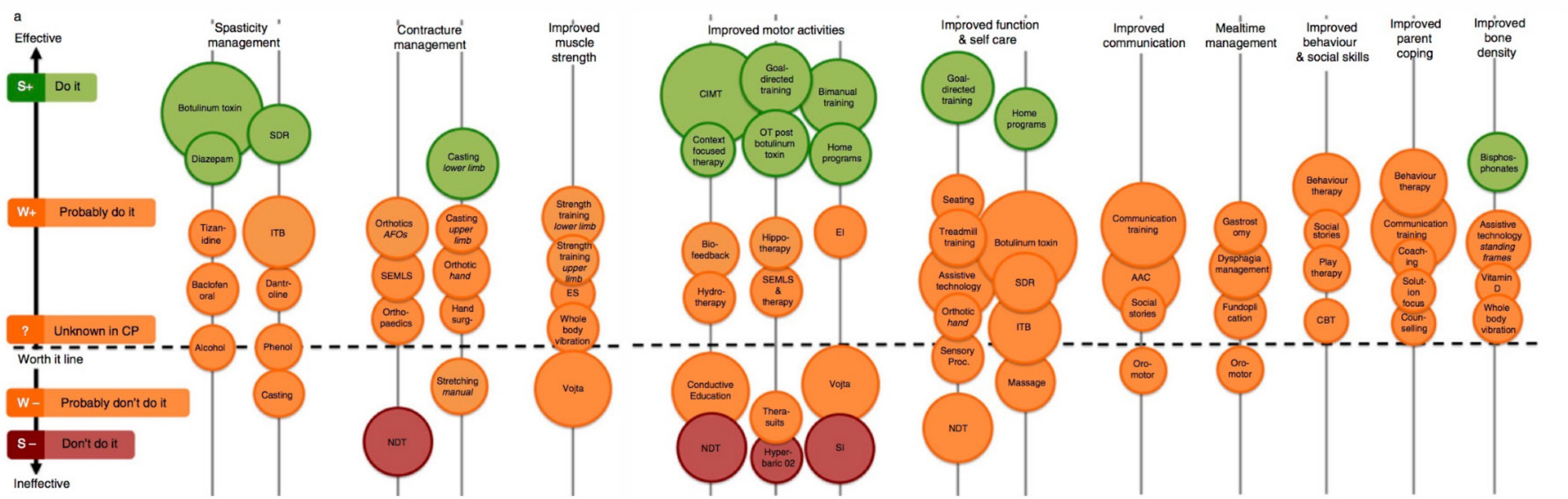


Fig 7 : Physiotherapy Treatment Approaches for Individuals with Cerebral Palsy, 2013

2.2 ICF Framework

The International Classification of Functioning, Disability, and Health (ICF) is a framework developed by the World Health Organization (WHO) to provide a comprehensive understanding of health and disability. It aims to capture all aspects of health conditions, including their impact on functioning and disability, as well as the broader context in which individuals live. It has two main components.

Functioning and Disability

This component focuses on the interaction between health conditions and contextual factors. It includes:

1. **Body Functions and Structures:** Refers to the physiological and anatomical aspects of the body.
2. **Activities and Participation:** Encompasses the execution of tasks and involvement in life situations.
3. **Environmental Factors:** Include physical, social, and attitudinal factors in the external environment.
4. **Personal Factors:** Represent individual characteristics that are not part of a health condition but may influence functioning.

Contextual Factors

These factors influence an individual's functioning and disability and include environmental and personal factors.

Rosenbaum's Interpretation of ICF

As reinterpreted by Rosenbaum et al. for childhood disability, 'Five Fs' is a simplified version of the ICF framework. It focuses on five key domains essential for children's well-being:

Fitness: Refers to physical health and well-being.

Function: Involves the ability to perform tasks and activities.

Family: Highlights the importance of familial support and relationships.

Fun: Emphasizes the significance of enjoyment and engagement in activities.

Friendships: Recognizes the importance of social connections and relationships with peers.

The Five F model provides a user-friendly and practical approach to understanding and addressing the needs of children with disabilities, particularly in clinical and intervention settings.

2.3 Modern Therapy Techniques

Over time, various therapies have emerged for children with Cerebral Palsy, often combining techniques for enhanced efficacy. Advancements in technology and medicine have introduced modern exercises into many methods like Sensory Integration Therapy, Bimanual Training, VR Therapy and Task-Oriented Therapy.

Sensory Integration Therapy : Sensory Integration Therapy (SIT) seeks to enhance sensory processing and integration in individuals facing sensory challenges. By engaging in structured activities, it assists in organizing sensory input and improving functional abilities and behavior.

Fig 8 : SIT Approach

Bimanual Training : It aims to enhance coordination and functional skills by promoting the coordinated use of both hands. Typically applied to children with cerebral palsy or similar neurological conditions, it aims to improve bilateral motor control and increase independence in daily tasks.

Fig 9 : Bimanual Training

Task-Oriented Therapy (SMART) : SMART therapy prioritizes functional tasks that are specific, measurable, attainable, relevant, and time-bound, tailored to the individual's daily life. Through task-specific exercises, patients enhance motor function, coordination, and overall physical abilities in a goal-oriented approach.

Fig 10: SMART Therapy

Virtual Reality (VR) Therapy : involves using immersive virtual environments to engage patients in therapeutic exercises and activities. It can help improve motor skills, balance, coordination, and cognitive function by providing interactive and motivating rehabilitation experiences.

Fig 11 : VR Therapy

Conductive Exercise (CE) : This approach employs specialized tools and methods to aid movement and muscle function in people with neurological issues like stroke or spinal cord injury. Its aim is to retrain motor control and foster neural adaptability via repetitive, task-centered exercises.

Fig 12: Conductive Exercise

- Other approaches like aquatic therapy utilizes water's buoyancy and resistance to enhance mobility and strength in individuals with physical conditions.
- Mirror therapy employs visual illusions of mirrored movements to improve motor function and reduce pain in patients with neurological disorders.
- Constraint-Induced Movement Therapy (CIMT) restricts the unaffected limb to intensively train the affected limb, aiding motor recovery in hemiparesis or hemiplegia.
- Electrical stimulation therapy applies currents to muscles or nerves to reduce spasticity and enhance muscle function in conditions like stroke.
- Robotics-assisted therapy employs robotic devices for targeted exercises, aiding rehabilitation in individuals with impaired motor function.

2.4 Exergames and Its Relavance

Exergames, merging physical activity with interactive gaming, offer a promising therapeutic avenue for children with cerebral palsy. These dynamic gaming systems can convert repetitive exercises into engaging experiences, potentially enhancing adherence to therapy for this population. Through incorporating gamification elements like goal-setting and feedback loops, exergames may amplify participation and improve therapy outcomes.

Our exploration delved into numerous papers and projects on exergame interventions. Themes included assessing exergames' effectiveness on gait performance, quantifying gamification impact, exploring motivation's role, examining action-based exergames' effects on children with cerebral palsy, gauging exergames' impact on muscle strength, observing adaptation in this population, among others.

1. Action based game for Cerebral Palsy : Liberi

The Liberi project adopted a collaborative approach, involving 10 participants with CP, a pediatrician, computer scientists, a physiotherapist, and a mechanical engineer, along with input from game designers and experts in exercise psychology and kinesiology.

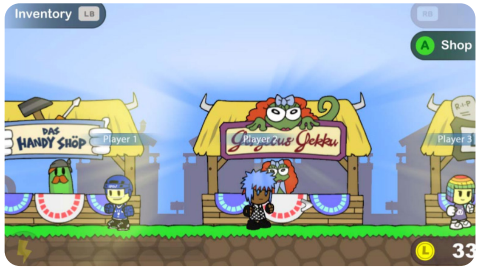


Fig 13 : Child playing Liberi, Liberi game

Over 12 months, seven sessions were held to understand the children's abilities and preferences, leading to the creation of three main minigames: Dozo Quest, Bobo Ranch, and Gekku Race. Five youth participated in an 8-week home trial, followed by custom questionnaires and interviews to assess effectiveness and experiences.

The study suggested improvements such as simplifying level design, reducing error consequences, and using clear visual cues, resulting in engaging and enjoyable minigames. This highlights the potential to develop fast-paced games for children with Cerebral Palsy, contrary to traditional therapy's focus on slow-paced exercises.

2. Interactive Carpet for Children with CP

This project introduces a novel method for remote physiotherapy in children with CP: an interactive carpet enhancing balance and stability during standing and walking. Inspired by dancing carpets, the initial prototype features a 4x4 graphite film sensor array, offering piano-like audio feedback.

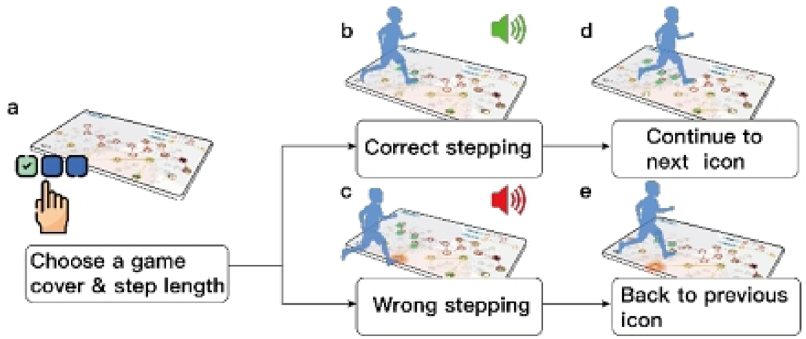


Fig 14: Gameplay of interactive carpet

Subsequent versions improved safety and functionality, leading to a third-generation design focusing on gait training and body coordination. This design includes interchangeable covers with printed characters, LED blocks for guidance, and adjustable step lengths. While children at GMFCS levels 2-4 actively engaged with the carpet, its suitability for those with severe motor impairments was questioned.

Therapists suggested design adjustments and incorporating animal voices or instructions for cognitive training. In conclusion, the interactive carpet shows promise for remote physiotherapy, offering adjustable gait training with audio and visual feedback.

3. VR Based Training for Spastic Diplegic CP

This study explores using virtual reality games instead of regular therapy for teenagers with cerebral palsy (CP). It focuses on a 15-year-old girl with CP, discussing her medical history and the challenges she faces with balance and movement.

Fig 15 : Spastic Diplegic playing VR Game

Despite these challenges, she manages daily tasks without sensory or emotional problems. They assessed the effectiveness of virtual reality games by observing her movements before and after playing. She engaged in "Fruit Ninja" on PlayStation VR for 30-minute sessions with breaks. After 18 sessions, they noticed better movement and balance.

In conclusion, the study suggests that using fun virtual reality games could help teenagers with CP move better. The study had a small sample size, and they need more games that won't make people feel sick.

2.5 Insights from Literature

- Exergames, with their interactive and enjoyable nature, have been linked to improved self-perception and confidence among participants (Flynn et al., 2014).
- Visualizing progress in measurable terms enhances patient understanding, motivation, and active engagement in rehabilitation (McCallum et al., 2012).
- Tailoring exercises to individual preferences, needs, and progress levels leads to more effective outcomes.
- Gamification's novelty and experiential aspect help combat monotony, promoting sustained participation over extended periods.
- Simplifying level geometry and flow reduces the need for precise actions and decision-making, making gameplay more accessible.
- Reducing the consequences of errors and limiting available actions simplifies gameplay and control schemes.
- Removing the need for precise positioning and aiming lessens the demands on manual ability and visual-motor integration.
- Making the game state visible reduces the cognitive load on players, easing gameplay comprehension (Liberi).
- Balancing for effort accounts for differences in players' gross motor skills, ensuring equitable gameplay (Liberi).

3. Primary Research

Building on literature and secondary resources, we sought field insights to deepen our understanding of the subject and stakeholders' perspectives. We began approaching various clinics for this.

The clinic and experts' information was obtained through referrals from friends, family, and some acquaintances via Instagram stories. We reached out to therapists and pediatric professionals through these contacts, who provided insights into the study's purpose and nature. Approximately 10 professionals were contacted, with three agreeing to assist further. Contact methods included video calls, phone calls, and in-person meetings, given that the professionals were based in Mumbai and Ahmedabad.

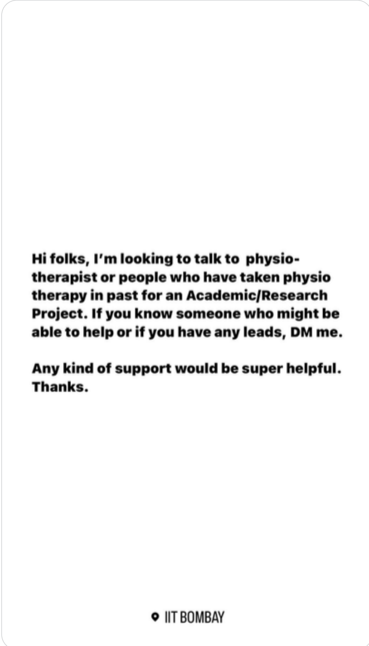


Fig 16: Getting leads via Internet

3.1 Overview

The process involved conducting interviews with experts, onsite observations, and contextual inquiries, as depicted in the diagram.

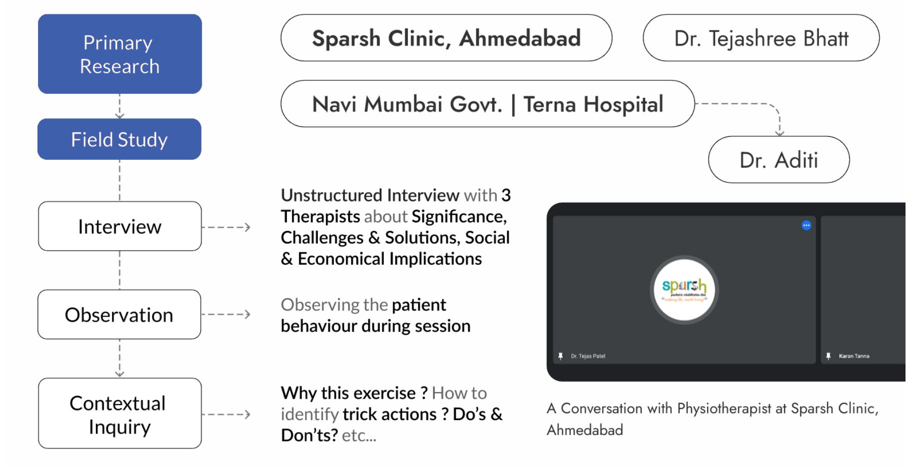


Fig 17 : Primary Study with 2 experts and one parent from 2 locations

**** The video and photography of patients were not permitted by the professionals.*

Sparsh Clinic, Ahmedabad : They are experts in pediatric therapy and have a range of therapy techniques. I once had therapy there as well. Dr. Tejas and his wife both run clinics together along with other therapists.

Fig 18 : Sparsh Clinic

Fig19 : Sparsh Clinic, Ahmedabad

Terna Hospital : Situated in Navi Mumbai, they have a physiotherapy department as well where therapists perform therapy along with intern doctors.

Fig 20 : Terna Hospital

Dr. Tejashree : She is one of the most renowned pediatric doctors in Ahmedabad, who is an expert in child psychology as well.

Apart from this few other people were contacted who are expert in this domain. But only two of them agreed to talk further.

3.2 Interviews

The attempt was to understand gaps, challenges, and patient behavior during therapy through interviews and observations. We were not introduced to the parents and patients during this time. Probably they thought we also came for hand therapy. During this, we got an opportunity to interact with one parent which turned into an informal interview.

We discussed challenges, concerns, the thought process of children, their aspirations, social challenges, and habits. We also inquired about whether children perform exercises at home and what challenges are associated with that.

Contextual Inquiry Questions :

» Why this exercise? How does it help?

» How common is the exercise ?

» Can it be used for other purposes? Does it need a repitation?

» Can it be fast paced?

» What does this motion do?

» What are the trick movements done by a children ?

Interview Questions :

» What is the distribution of CP patients?

» Would you walk me through the journey of a patient in a day or a day in the clinic ? What are the challenges?

» What are age group specific challenges for a therapist?

» What are gaps in existing therapy?

» Do you think gamification can help?

» Have you tried any exergames?

» What were the constraints / did it help ?

» What are the challenges for the parents?

» What are some of the most effective exercises for CP according to you? What if parents can't afford therapy ?

» How do you help patients with low income families?

» What kind of measures are taken to engage the patients?

» How do you determine what exercise will help in which condition?

» How long does it take to show results? and many more.

3.3 User Journey & Stakeholders

Patients are typically referred to the clinic by doctors or affiliated hospitals, accompanied by their formal caregivers or parents and carrying medical documents. The initial consultation enables the doctor to comprehensively assess the patient's condition, often including a review of family and medical histories to understand underlying causes and potential challenges. During the consultation, parents or caregivers complete a form, and the financial status of parents is evaluated using frameworks such as the Uday Pareek Scale for rural populations and the Kuppuswamy Scale for urban populations. If financial aid is needed, NGOs may be approached.

Once in the clinic, therapists mobilize the affected area and begin with gentle exercises. If a child becomes distressed or loses motivation, therapists try to engage them through conversation and rewards. Some exercises may be painful or challenging, leading children to use incorrect muscles, rendering the exercises ineffective. Therapists monitor for these "trick movements," adjust exercises accordingly, and provide positive reinforcement for achievements.

A typical session lasts 45 minutes to an hour, with breaks between exercises. Individual exercises typically last 10-20 minutes, with 4-6 exercises performed per session based on available time. Consistency is key, with therapists often recommending exercises to be continued at home, preferably under the supervision of a formal caregiver (FCG).

In addition to exercises, FSGs ensure patients wear splints, adhere to medication regimens, maintain correct posture, and use the affected part for daily tasks.

Components	Score	Components	Score
Caste		**Social participation**	
Schedule caste	1	None	0
Lower caste	2	Member of one organization	1
Artisan caste	3	Member of more than one organization	2
Agriculture caste	4	Office holder in such an organization	3
Prestige caste	5	Wide public leader	4
Dominant caste	6	**House**	
Occupation		No house	0
None	0	Hut	1
Labourer	1	Kutcha house	2
Caste occupation	2	Mixed house	3
Business	3	Pucca house	4
Independent profession	4	Mansion	5
Cultivation	5	**Farm power**	
Service	6	No draught animals	1
Education		1-2 draught animals	2
Illiterate	0	3-4 draught animals	4
Can read only	1	5-6 draught animals	6
Can read and write	2	**Material possessions**	
Primary	3	Bullock cart	0
Middle	4	Cycle	1
High school	5	Radio	2
Graduate	6	Chairs	3
And above	7	Mobile phone	4
Land		Television	5
No land	0	Refrigerators	6
Less than 1 acre	1	**Family type**	
1-5 acre	2	Single	1
5-10 acre	3	Joint	2
10-15 acre	4	Extended	3
15-20 acre	5	Siye up to 5	2
20 and above	6	Any other distinctive features	2

Grade	Category	Score on scale
A	Upper class	Above 43
B	Upper middle class	33-42
C	Middle class	24-32
D	Lower middle class	13-23
E	Lower class	Below 13

Education of head of family	Score
Profession or honours	7
Graduate or postgraduate	6
Intermediate or post high school diploma	5
High school certificate	4
Middle school certificate	3
Primary school certificate	2
Literate	1
Occupation of head of family	
Profession	10
Semi- profession	6
Clerical, Shop-owner	5
Skilled owner	4
Semi-skilled worker	3
Unskilled worker	2
Unemployed	1
Monthly income of family (2017)	
>41430	12
20715-41429	10
15536-20714	6
10357-15535	4
6214-10356	3
2092-6213	2
<2091	1

Socioeconomic status		Total Score
I	Upper	26-29
II	Upper Middle	16-25
III	Lower Middle	11-15
IV	Upper Lower	5-10
V	Lower	<5

Fig 21 : Uday Pareek Scale for (Rural-R) and Kuppuswamy Scale (Urban-L)

3.4 Findings from Primary Research

- Outdated and ineffective therapy techniques hinder progress due to financial and training limitations.
- Occupational therapy equipment fails to engage children long-term, leading to boredom and discomfort from repetitive actions.
- Tools lack design for orthoses, making exercises uncomfortable; orthoses lack necessary modifications.
- Children with CP often face social neglect and family acceptance struggles, highlighting the need for parent/caregiver education.
- Hypertonic muscles in CP lead to fatigue from repetitive tasks, eventually relaxing into a more flexible state.
- Children need tools for independence; for example, a sitting walker with a torso strap can aid balance (from CP Prevention Toolkit).
- Physiotherapy techniques are outdated and incremental, leading to patient and FSG dropout.
- Therapy lacks standardization across centers, complicating clinic selection for parents.
- Lack of fun in therapy methods diminishes patient motivation over time.
- Monotonous exercises prompt trick movements, risking lifelong deformations and muscle contractions.
- Social rejection affects CP children's confidence despite normal mental capabilities.
- Current therapy methods lack achievement and pain management mechanisms, leading to motivation depletion.
- Lack of awareness and frameworks for home-based programs hinders progress.

4. Defining the Project

Problem Statement

As per findings primary focus of CP treatment lies in physio therapy (PT) and occupational therapy (OT). The used techniques are out dated and children often find these sessions painful, boring, and devoid of meaning, leading to non-compliance.
Enhancing the playfulness of current therapy techniques could potentially improve engagement.

Goals

- The goal is to innovate and develop an exergame that serves dual purposes: suitable for both home use and therapy centers.
- It should be portable, affordable (priced under 2000 INR), and require minimal adult supervision.
- Customizability to meet individual user needs is essential, ensuring adaptability to varying abilities and preferences.
- Most importantly, it should offer a fun and engaging way for users to participate in exercise routines.

Scope and Limitations

- The project centers on creating and implementing activity-based exergame interventions to improve upper limb motor skills in children aged 6 to 10 with cerebral palsy, focusing on spastic or mild dyskinetic types, and mild to no mental retardation.
- Specific activities will involve fine motor skills exercises like grabbing, sliding, squeezing, and pushing.
- The goal is to develop and introduce at least one exergame intervention.
- Upon completion and final evaluation, the design will be published as an Open Source project for broader accessibility and future development.

The limitation of the project is that the solution may not work for some users, as the type of challenges may vary. Also, the sample size of the users is very limited.

5. Designing for Cerebral Palsy

5.1 Identifying Effective Approach

While designing for CP we took various things into considerations from previous study such as the approach presented by Novak, Rosenbaum's ICF framework, recommendations described in Liberi : action based games for CP, insights from interviews, existing novel approaches, toolkit for prevention of CP and much more. However, first we identified effective interventions based on literature and expert advice.

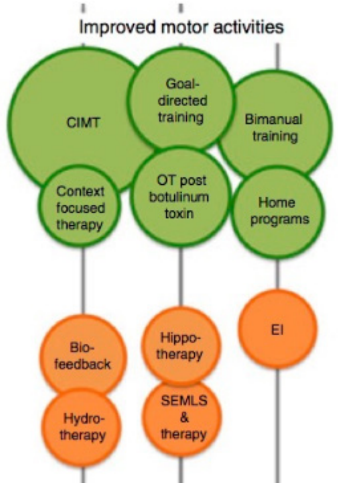


Fig 22 : Top Approaches for motor activities

We created a table by assessing existing methods and narrowing them down based on prior research. Subsequently, we sought expert review. Based on that following approaches were found to perform best.

Goal Directed Training: Involves tailored exercises and activities aimed at achieving specific functional goals in rehabilitation.

Constraint-Induced Movement Therapy (CIMT): Restrains the unaffected limb to encourage intensive training and functional improvement in the affected limb.

Bimanual Training: Focuses on improving coordination and function by encouraging the simultaneous use of both hands.

Conductive Functional Therapy (CFT): Integrates functional activities with conductive education principles to improve mobility and independence in individuals with motor disabilities.

Goal Directed Training		Bimanual Training	Constraint-Induced Movement Therapy	Context Focused Therapy
ICF (Rosebaum)	Does it Fall Under That?	Does it Fall Under That?	Does it Fall Under That?	Does it Fall Under That?
Fitness	☑	☐	☐	☐
Function	☑	☑	☑	☑
Friends	☐	☐	☐	☐
Family	☐	☑	☐	☑
Fun	☐	☐	☑	☑

Fig 23 : Classification of Top Approaches

5.2 Initial Ideas

1. Flappy Bird with Soft-ball Controller

Exergame Type : Goal Directed Training, Constraint Induced Therapy

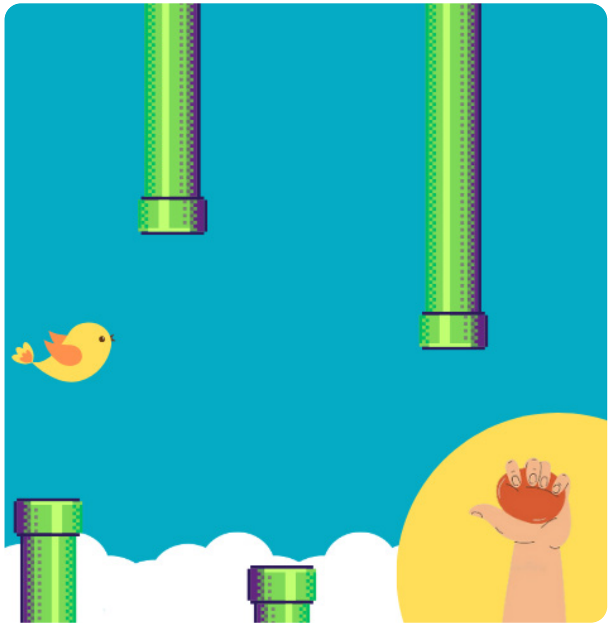


Fig 24 : Flappy Bird Controlled by Fist

Goal :
Through this strategy and game, our aim is to enhance an ineffective therapy by incorporating gamification. We seek to improve hand-eye coordination, strength, contextual learning, and foster a sense of enjoyment and achievement.

Improves : Motor skills, Hand-eye coordination, Strength

Interactions : One has to push the ball with affected hand to jump the bird and avoid obstacle on the screen. The feedback is given visually when child sees the screen.

2. Angry Birds with Rubber Strap

Exergame Type : Goal Directed Training, Constraint Induced Therapy

Fig 25 : Angrybird Controlled by Rubber Strap in an angle intensity

Goal : The goal of this game is to target strength training while also developing skills such as visualizing projectile angles, thereby enhancing cognitive abilities, among other benefits.

Improves : Motor skills, Strength

Interactions : One has to pull the strap with the affected hand in an angle to set the bird for hitting the target and once released it will projectile to hit the target.

3. Instruction based Painting Game Kit

Exergame Type : Goal Directed Training, Constraint Induced Therapy, Bimanual Training

Fig 26 : Goal Oriented Learning + Painting Kit

Goal :
Through this task we are involving use of both hands and restrictions at times. Children can pick color and tools, follow on screen instructions and paint on paper. This will improve fine motor skills, this can be used to do therapy before beginning with writing. The challenge here is logistical and adherence.

Improves : Motor skills, Hand-eye coordination, Imagination

Interactions : One has to use different part of affected and non affected hand to draw on the paper with paint, based on instructions.

4. Tangible Whack-a-mole Game

Exergame Type : Range of Motion Exercise, Sensory Integration Therapy, Strength Training

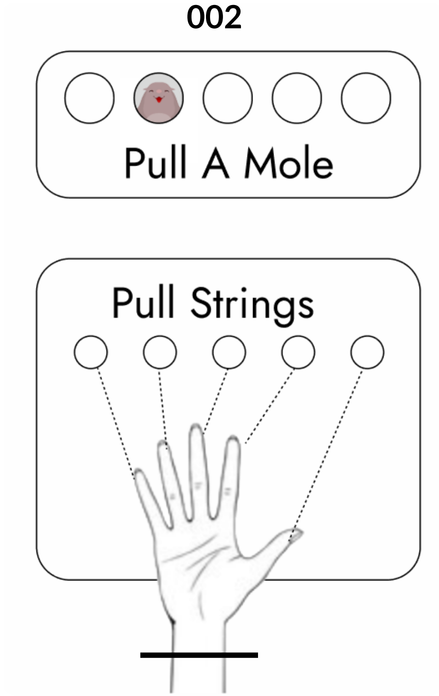


Fig 27 : Tangible Whack-a-mole Game

Goal :
The goal of this exergame is to eliminate a mole on the screen corresponding to the finger. This game can be played while wearing a splint. The screen will show mole/ moles on the screen and on the basis of that patient / player will pull the string. This will improve range of motion for the finger, and as the strings are elastic it will resist the motion as well.

Improves : Motor skills, Hand-eye coordination, Range of motion

Interactions : One has to bend inwards or open the finger corresponding to the mole on the screen.

5. Break The Bricks with Tangible Slider

Exergame Type : Strength Training, Sensory Integration Therapy

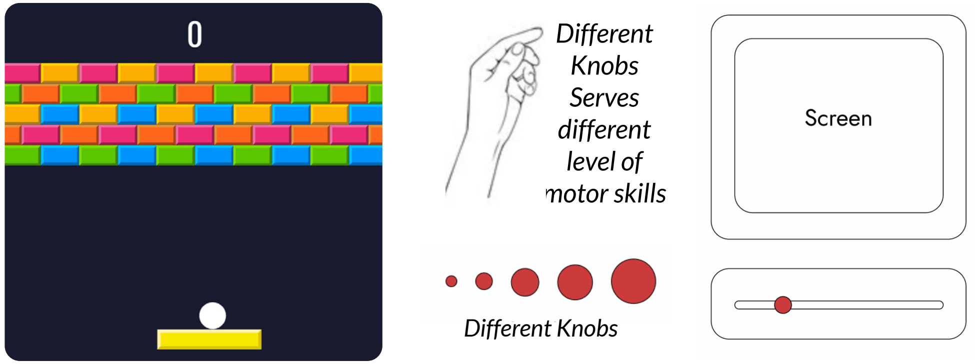


Fig 28 : Game of Pong with Tangible Slider

Goal :

In this game, players simulate gripping handles like cups or doors, sliding them according to the platform's position. The goal is to break all bricks by ensuring the ball touches each one, advancing to the next level. Different grips in the game mimic real-life scenarios, enhancing motor skills.

Improves : Motor skill, Hand-eye coordination

Interactions : One has to move knob in the given line corresponding to platform.

6. Dino Game with Pressure Pad

Exergame Type : Strength Training, Post Botox Therapy

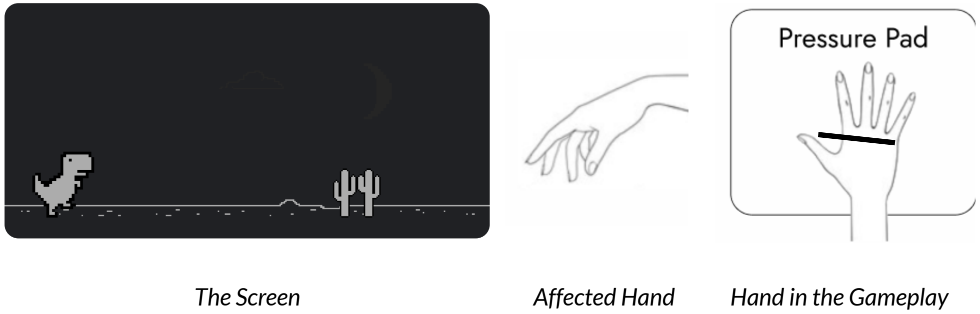


Fig 29 : Dino Game with Pressure Pad

Goal :

The patient places the affected hand on the platform and presses it to make a dinosaur on the screen jump, aiming to avoid obstacles and achieve a high streak.

This game can be effective for individuals with spastic CP and affected hand posture.

Improves : Hand-eye coordination, Posture

Interactions : One has to push the platform with palm on the platform, to jump dino to avoid obstacle.

5.3 Evaluating Ideas with Experts

The ideas were thoroughly discussed with three experts, evaluating feasibility, complexity, ease, effectiveness, likelihood of trick movements, and compatibility with splints.

Dino Game with Pressure Pad : Easy to Perform, Effective and Can be performed with a splint. The exercise can be engaging but the problem is that to be effective a patient has to press the hand for a long time.

Flappy Bird with Soft-ball Controller : Easy to Perform, Effective and Can be performed with a splint. The action is repetitive but it can be engaging for some time. The only challenge will be posture retention during the exercise, otherwise exercise won't be effective and painful.

Tangible Pull-a-mole Game : is moderately tough to perform, effective, and compatible with a splint. Challenge lies in calibrating the pace and quickly finding the correct rhythm.

Break The Bricks with Tangible Slider : Moderately challenging and effective, and can be performed with a splint. Action is slightly repetitive but it remains engaging and fun. Sliding may not address underlying issues as it primarily uses shoulder movement.

Angry Birds with Rubber Strap : The game is enjoyable, but the rubber strap component may pose challenges as it requires finding the correct angle, and calibration may be technically difficult.

Instruction based Painting Game Kit : The exercise can be slightly ineffective if instructions are not followed correctly and it's subjective. High chances of bad movement is a challenge.

Idea Evaluation (Out of 3)	1. Flappy Bird with Soft-ball Controller	2. Angry Birds with Rubber Strap	3. Instruction based Painting Game Kit	4. Tangible Pull-a-mole Game	5. Break The Bricks with Tangible Slider	6. Dino Game with Pressure Pad
Anti-trick	3	1	0	2	2	3
Effective	2	2	1	3	2	2
Play with Splint	3	2	1	3	1	2
Ease of Performing	3	2	3	3	3	3
Engaging	2	2	2	2	3	3
Feasibility	3	1	3	2	3	3
Rank (1-6)	2	5	6	3	4	1

Fig 30 : Evaluation Table

5.4 Prototyping and Testing of Ideas

The dino game, controlled by palm pressure, and the flappy bird game, controlled by squeezing a ball, emerged as promising options, receiving high rankings in expert evaluation. Despite their similar 2D gameplay, they differ in control methods—one based on finger movement and the other on palm force. The former aids in range of motion and strength, while the latter assists in posture correction. We prototyped a basic version for testing.

Prototyping : Flappy Bird with Soft Ball

The very basic Flappy Bird-like game was initially created to start with. Given the experience with Processing and p5.js, it was decided to code the game using these platforms. Arduino Nano and piezo sensors were later connected to a yellow spongy soft ball. The circuit for the same is as given below.

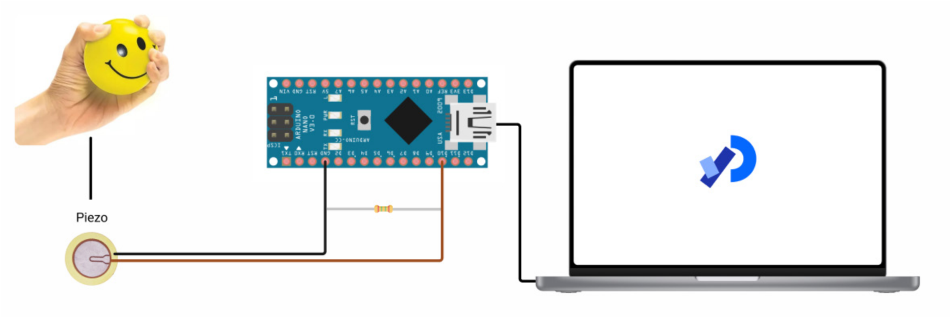


Fig 31 : Circuit Diagram of Setup

Coding and calibrating the game proved challenging, with numerous sensors, resistors, and threshold values failing to function.

Design Considersations

- Low threshold values were set for children with limited strength.
- Some children found the default ball stiffness uncomfortable, requiring precise calibration.
- Multiple lives and pauses were added to maintain gameplay.
- A pause button allowed immediate suspension, and a restart button enabled continuous gameplay.
- Highscores were recorded to track progress.
- Calibration was done on gap width and spacing between obstacles.
- Minimal visuals were used to reduce distractions.
- Vertical gaps between obstacles were set at 4 times the size of the ball/bird.

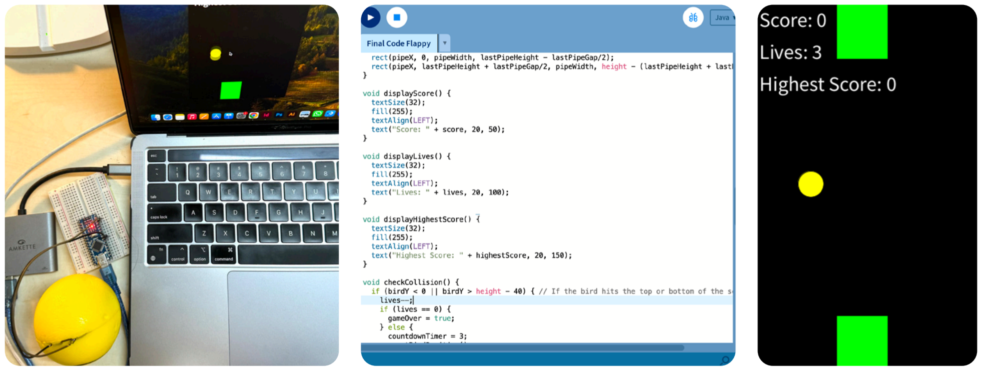


Fig 32 : Setup, Processing, Game

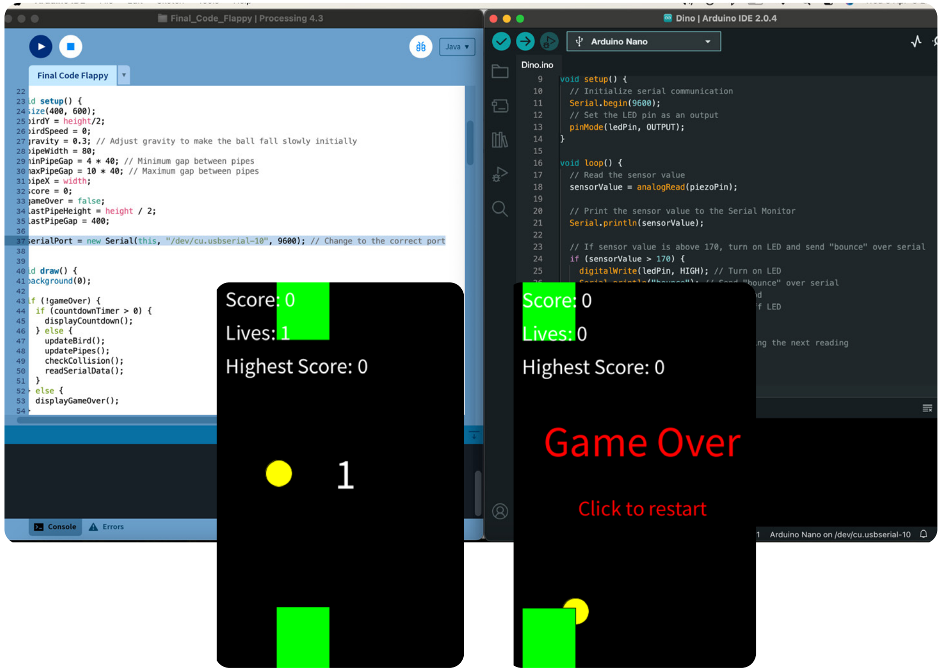


Fig 33 : Arduino Code, Processing Code, Screenshots

Prototyping : Dino with Force Pad

A basic dino game, inspired by the Chrome browser, was developed using Processing and p5.js for testing. An Arduino Nano and piezo sensors were connected to a square pad, with the circuit shown in the figure. The game was streamlined to its essential elements for testing and prototyping. The challenge involved calibrating the required force and minimizing unintentional bounces.

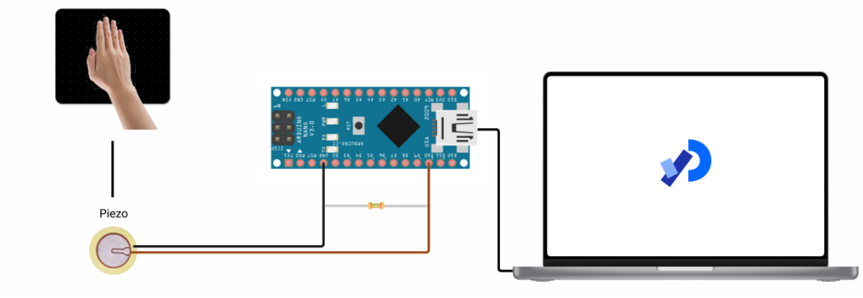


Fig 34: Circuit Diagram of Setup

Adjusted threshold values prevent errors and erratic bounces, set higher than softball due to initial force. Gameplay streamlined for continuous play with consistent obstacle spacing and slight height variations. Access all codes here.

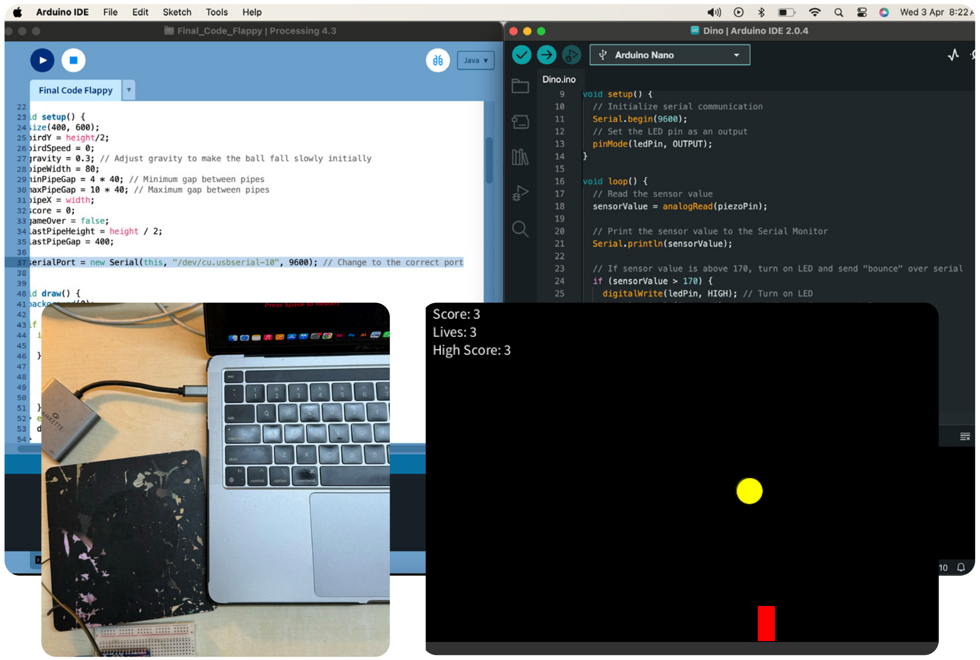


Fig 34 : Setup, Codes, Gameplay

Prototyping : Fill the Bucket with Force Pad

This exercise was inspired by observing a dino game with a force pad. It required the patient to keep their hand on the pad, secure the strap, and press the pad firmly. To facilitate this, a small game was created for testing. In this game, a bucket (bar) fills up as the force pad is pressed.

A basic version of this exercise was created using the same setup as the dino game. Screenshots of the game are provided below, and the code can be accessed here.

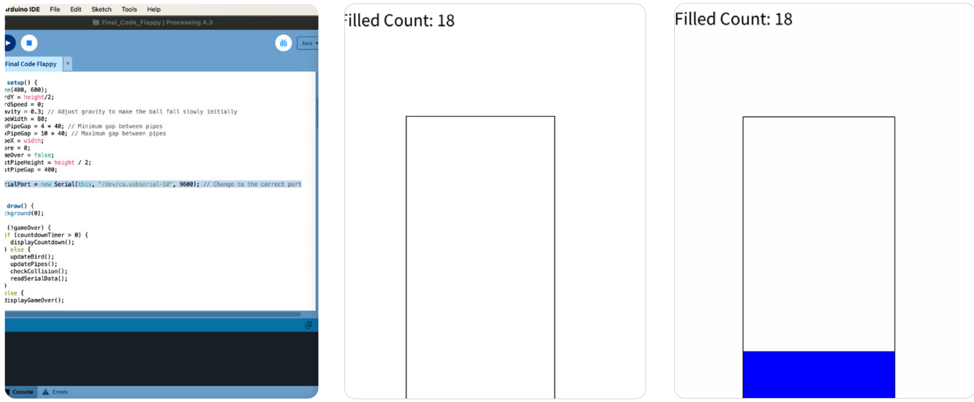


Fig 35 : Java Code, Screenshots

5.5 Insights from Inital Tests

Dino and Flappy Bird tests were supervised by a therapist with two participants on separate days. Challenges included calibrating pressure for the child. Experts ensured smooth exercise execution, albeit with longer than expected setup time. Only qualitative data was collected through observations.

- Flappy Bird experience was poor due to the bird falling off and patients struggling to squeeze the ball quickly.
- Piezo sensors were inaccurate; other options must be explored.
- Thresholds varied for both participants.
- Participants scored 3 and 2, respectively.
- In the dino game, patients performed better as the ball continued moving even without firm pad pressure.
- The threshold in the dino game was adequate and easy to play, but not aligned with the exercise goals.
- Experts suggested redesigning the dino with longer pad presses.
- Graphics and setup were basic and time-consuming; a plug-and-play standalone device was recommended.
- Sound effects were suggested if feasible to enhance the experience.
- Provide a variety of games for the same input type.
- Overall, dino games with a force pad had better performance and adherence; patients could play independently.

6. Prototyping

6.1 Iterations & Material Exploration

In the final version, exercises were refined based on feedback from tests and experts. Iterations improved user experience. The next section shows the design evolution. These were modelled in rhino and then developed further into working prototype.

First Iteration :

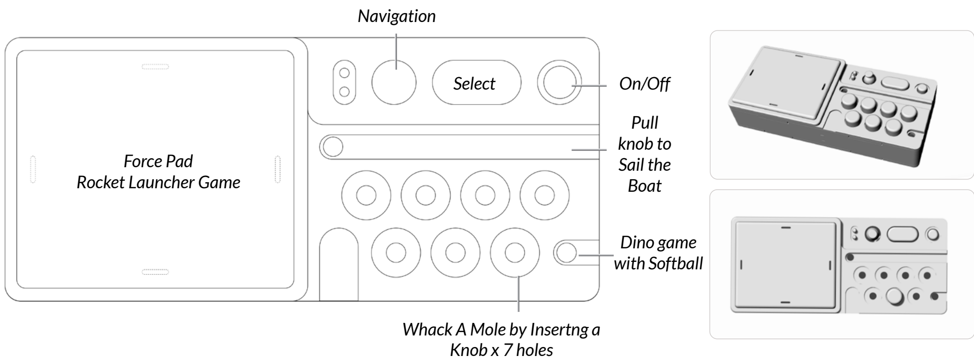


Fig 36 : First Iteration of Device

Shortcomings Changes of the Iteration :

- The device was heavy and big.
- The affordance between holes was not adequate for the users. The holes were too close.
- Fill the bucket was to be replaced with Rocket Launcher game.

Second Iteration :

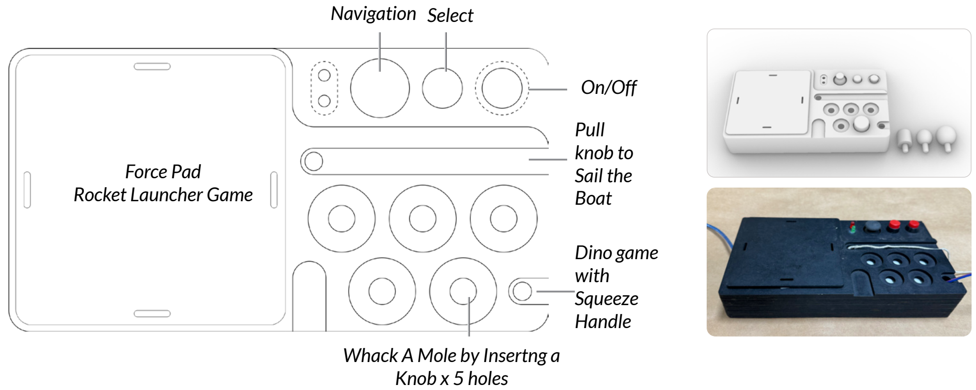


Fig 37 : Second Iteration of Device

Changes done in this Iteration :

- The board was further made compaxt.
- Number of holes were reduced to five.
- Select button was made coherrent with other buttons.

Shortcomings of the Iteration :

- The affordance between holes was not still adequate for the users. The holes were too close and confusing for kids.
- Pull thread gets stuck at the edge of the hole.

Third Iteration :

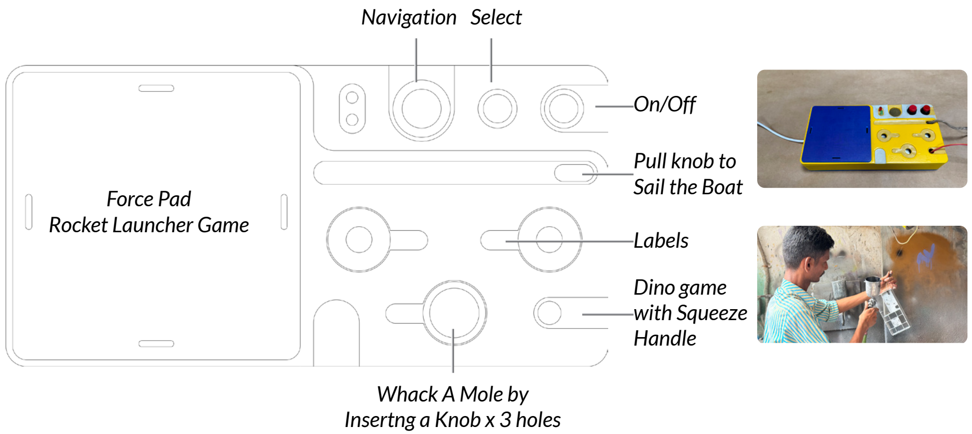


Fig 37 : Second Iteration of Device

The third and final iteration then later was used for final prototype as most things worked out in the iteration in terms of layout and sizes. The next phase we focused on look and feel of the device and Intetrface.

Material Exploration and Grips Iterations

While testing these iterations, we also explored sizes of the grips and materials for the body of device ie. PLA, acrylic and MDF and various finishes. We tried knobs of various sizes from 20mm diameter to 50mm diameter of multiple shapes ie. cylinderical and spherical, with fillets and without fillets. We compared and tested with eachother to find right minimum size and optimal size range.

Fig 38 : Iterations of Material, Finishes and Grips

6.2 Game UI Explorations

First few tests were done using basic UI made in processing, however it did not look aesthetically pleasing and was only functional. To make games more engaging I had to add graphic elements.

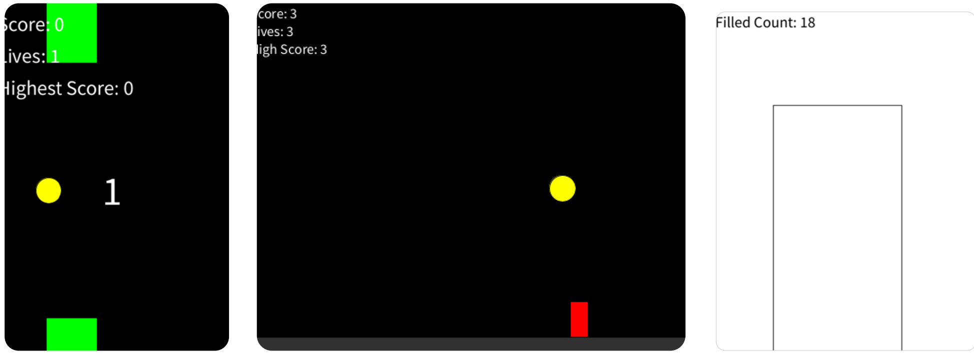


Fig 39 : Screenshots of first UI iteration

It was difficult to acquire skills in gave development with coding on processing, thus we switched to game design with figma. As figma has now variables and stats and animation one can easily design aesthetic games even though its tedious task.. Hence we explored making few games with figma such as flappy bird and dino game to begin with.

Then we experimented plugins to let our arduino communicate with figma game.

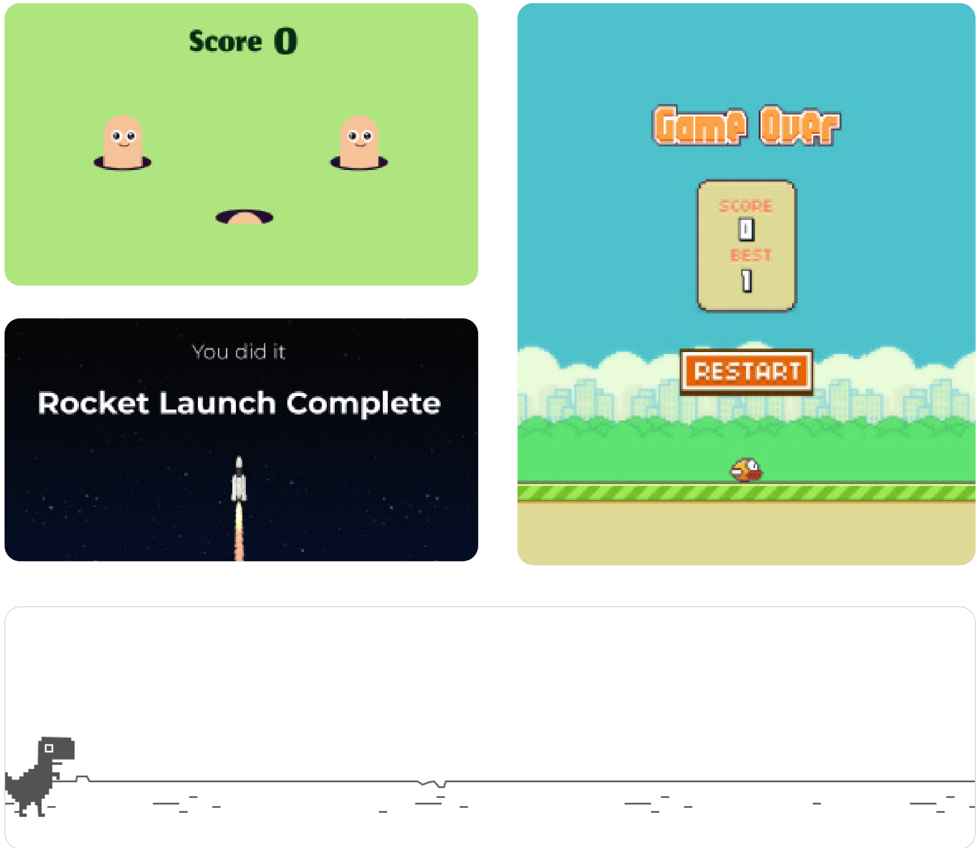


Fig 40 : Screenshots from Figma game explorations.

6.3 Insights from Testing of Iterations

While getting reviews from experts and testing with users, we discovered number of issues and insights :

- The experience and perception of kids improved with improved graphics.
- Piezo were replaced with push buttons and because of that acccuracy improved.
- Participant score increased with improved iteration and UI.
- It was suggested to improve on the device and make it children friendly.
- The pulling mechanism was weak, and was about to break several times. It was suggested to change in the final version.
- Experts suggested to optimise knob sizes as most of the users could not use the small knobs properly.
- Sound effects were suggested to enhance the experience.

6.4 Final Prototype : Pico

After numerous iterations and tests of both the physical device and game interface, we developed the final prototype named 'Pico'. The name 'Pico' combines the words "pixel" and "companion," symbolizing a friendly companion aided by pixel-based games. The name is catchy and appealing to children. We selected neutral, child-friendly colors to ensure an elegant and engaging design. The design of this involved many aspects and considerations.

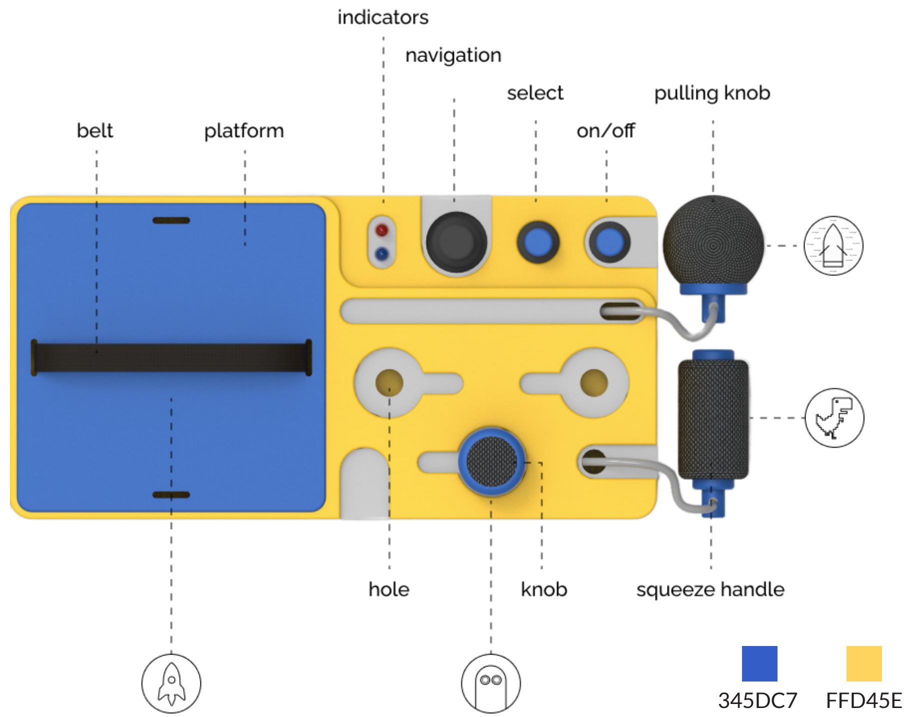
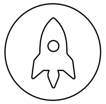
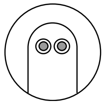


Fig 41 : Pico with labels, icon showing associated games

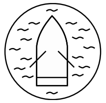
Included Games



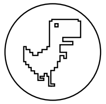
Rocket Launcher : Press the platform to fuel the rocket and release to launch.



Whack A Mole : Put the knob of your comfortable grip in the hole to kill the mole.



Row to Shore : Pull the knob of appropriate size out to row the boat to shore.



The Dino Game : Jump the dino to avoid obstacles using the grip.

Packaging and Box Contents

Fig 42 : Pico and Its Box and User Guide

Features of Pico

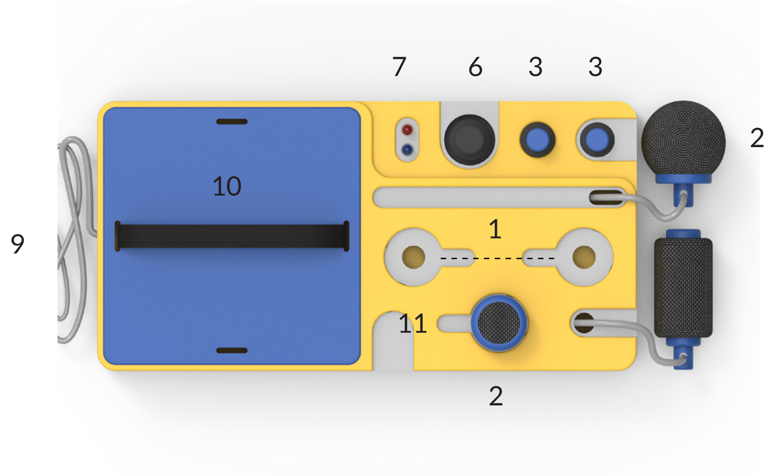


Fig 43 : Features of Pico

1. Optimal Distance Between Slots for Whack A Mole.
2. Replacable knob and grips.
3. Durable physical buttons.
4. Aesthetic layout and colour scheme.
5. Smooth finish of the surface.
6. Joystick for easy navigation.
7. LED indicators for on/off and input.
8. Adjustable game elements for calibration.
9. Plug and Play USB device.
10. Belt for better hand grip in absense of splint.
11. Space for labels.
12. Easy minimal user interface of games.

Unboxing and Setting Up Pico

Unbox pico companion device. Plug it to any pc or internet enabled USB device. Turn on pico using power button and go to www.karantanna.in/pico to play, if it doesn't redirect automatically.

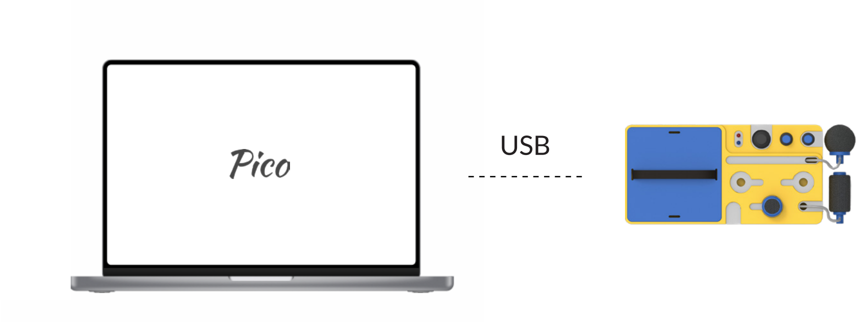


Fig 44 : Connecting Pico

Once you turn on pico and open the website, use navigation joystick and select button to choose a game. Control it using appropriate actions.

Components and Materials

We have used many electrical components to prototype the device, ie. Arduino Pro Micro, Force Sensor, LEDs, 2 Large Buttons, 3 SMD Buttons or , Flex Sensor, Joy Stick Module, Wires, Sliding Potentiometer etc. The cost of all electric components would be less than1500 INR. The total cost of the device would be less than 2000 INR.

Using Pico : A Video

This video shows how pico is used and how to navigate and play with it. It also suggests how to customise and how each game works. It also shows the process of making it. Find video link here along with all the codes involved.

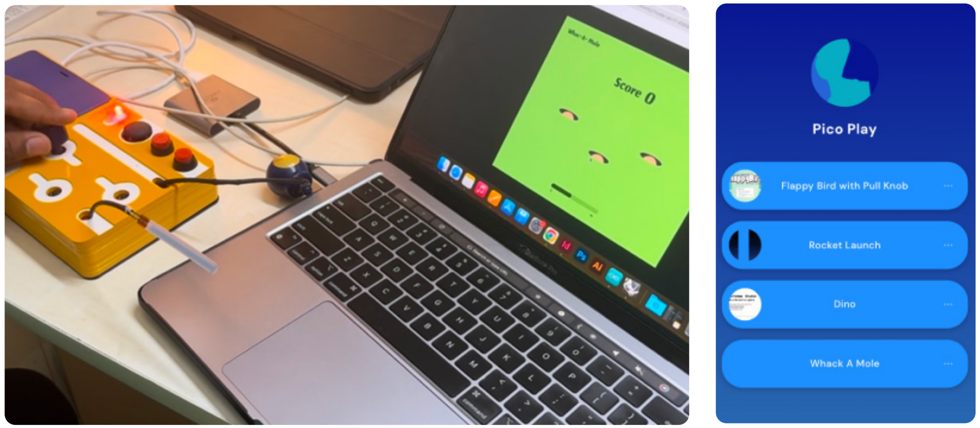


Fig 45 : Snippet of Video and Interface of Game Selection

7. Evaluation

7.1 Overview

In this case its difficult to evaluate the prototype for the efficiency, since the effect of therapy shows up after many years. Hence, it would be out of scope of the project.The expert feedback would be taken before this as well to determine if pico device is effective.

However we can test how engaging and fun they find using the device, their adherence, and comfort. We can monitor progress over time with the help of score data.

The evaluation was done in two parts. In the first phase, an expert evaluated and gave feedback on each exercise, the prototype accuracy and if it adheres to the therapy goals. Based on their consultation, we conducted further evaluation with users.

The user study was conducted with 8 users, each session lasting 12-15 min. We tested all four games under supervision. We will observe the particpants and determine level of engagement and comfort with help of parents and therapist.

7.2 Insights from Evaluation

The final version was shown to an expert. She gave a review for the final prototype. However, I was not able to test final version with kids.

- Whack a mole game could be made bit slower. It is more accurate and pleasing than previous version.
- Dino game had slight glitches. Sensitivity of the squeeze can be made more accurate.
- Pulling mechanism was better than previous versions. However, resistance could be increased.
- Different patients have different capabilities and problems, it will be difficult to test all in same way.
- The visual language was good and felt like a play toy and did not feel like that of medical tool.
- Whack a mole's holes and knobs can be reiterated to allow mistakes.
- Rocket launcher game could get boring, system status or some kind of interaction is needed.
- Overall build was better, sturdy and smoother and exercise basically follows the goal but not there yet.

8. Future Scope

Exergames can significantly enhance and elevate the therapy experience by incorporating game elements, making the process more engaging and enjoyable. We aim to further develop the prototype and conduct extensive testing with more users, particularly because progress in cases of cerebral palsy is typically slow and requires long-term commitment. Our ultimate goal is to publish this project, secure a patent for the design, and continue refining it to ensure it is robust, safe, and highly useful.

We plan to re-prototype the device using professionally designed electronics to ensure safety and reliability. Additionally, the user interface will be further enhanced and integrated into a website for easier accessibility. Extensive testing will be conducted to assess the efficacy and long-term impact of the device.

9. Discussions

The evaluation of the exergames for children with cerebral palsy highlights several strengths and areas for refinement. Experts praised the device's visual appeal and interactive elements for making therapy more engaging than traditional tools. However, adjustments are necessary to enhance therapeutic efficacy and user experience.

Key improvements include adjusting the "Whack a Mole" game speed, fine-tuning the "Dino Game" squeeze mechanism, and increasing resistance in the "Pulling Mechanism" to meet therapy goals. The rocket launcher game needs more interactive elements to prevent monotony.

Customization is crucial, with a need for settings that address diverse motor functions and cognitive abilities. Ensuring the device is effective and inclusive will encourage regular use and reduce stigma.

Looking ahead, questions arise: How can the device be more adaptable to different types of cerebral palsy? What new games or features could be added? How can it be integrated into existing therapy routines?

In conclusion, the initial feedback is promising, but further development is needed. Focusing on customization, engagement, and effectiveness will make the device a valuable tool for enhancing therapy for children with cerebral palsy. Continued testing and iteration, guided by feedback, will be essential for success.

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