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Master Thesis

Design and Implementation of a Rehabilitation Exergame for Physically Impaired Children

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Matriculation Number: 0406032
October 28, 2020

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For those who sacrificed their lives in the November 2019 Iranian protests,
For the victims of January 2020 Ukrainian Flight PS752,
And for those who have lost their lives and loved ones during 2020 Coronavirus Pandemic.

Hereby I declare that I wrote this thesis myself with the help of no more than the mentioned literature and auxiliary means.

Berlin,
October 28, 2020

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(Signature: Shamim Karimigolpayegani)

Abstract

Children with physical impairments can benefit from easily accessible and engaging motor therapeutic tools in conjunction with their regular rehabilitation programs. Interactive rehabilitation games show promise in aiding physical impairments, as they could increase active participation in therapy while being less costly and requiring less effort in comparison to therapy sessions. In this thesis, we explored the design space for rehabilitation games and followed an iterative user-centered design approach to offer a solution in the form of an exergame. We developed the designed game and conducted subjective and objective user studies to evaluate the engagement of the game. The results showed a high engagement rate, as well as a significant difference in player engagement between variations of the game, where different types of challenges, namely motoric and cognitive, were included. Furthermore, this research looks at insight into the causes of the observed difference and suggestions on future work.

Keywords: Game Engagement, Exergames, Rehabilitation Games, Physical Impairments

Zusammenfassung

Kinder mit körperlichen Beeinträchtigungen können in Verbindung mit ihren regelmäßigen Rehabilitationsprogrammen von leicht zugänglichen, motorisch-therapeutischen Geräten und Hilfsmitteln profitieren. Interaktive Rehabilitations-Videospiele sind vielversprechend bei der Unterstützung von körperlichen Beeinträchtigungen, da sie die aktive Teilnahme an der Therapie erhöhen und gleichzeitig im Vergleich zu Therapiesitzungen kostengünstiger sind und weniger Aufwand erfordern. In dieser Arbeit untersuchten wir den Designraum für Rehabilitations-Videospiele und verfolgten einen iterativen, benutzerzentrierten Designansatz, um eine Lösung in Form eines Exergames anzubieten. Wir haben das entworfene Spiel entwickelt und subjektive sowie objektive Benutzerstudien durchgeführt, um das Engagement des Spiels zu bewerten. Die Ergebnisse zeigten eine hohe Engagement-Rate sowie einen signifikanten Unterschied in Hinblick auf die Anteilnahme der Spieler zwischen Variationen des Spiels, bei denen verschiedene Arten von Herausforderungen, nämlich motorische und kognitive, berücksichtigt wurden. Darüber hinaus untersucht diese Arbeit die Ursachen der beobachteten Unterschiede sowie Vorschläge für zukünftige Arbeiten.

Schlüsselwörter: Game Engagement, Exergames, Rehabilitations-Videospiele, körperliche Beeinträchtigungen

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1 Introduction

1.1 Motivation

Cerebral palsy (CP) is a physical impairment that affects the development of movement, and it is the most common physical disability in children [Ros03]. Although cerebral palsy cannot be cured, the patient's functional abilities and quality of life can be improved through physiotherapy and rehabilitation programs. The effectiveness of therapy programs depends on various factors; one of these factors is active participation, and it can be promoted by making the training programs both more engaging and more accessible.

The development of interactive rehabilitation technologies has been an interesting research topic in recent years. Serious games and exergames are amongst the game categories that are concerned with purposes other than mere entertainment, such as training purposes. The idea behind gamifying the training programs is to increase the motivation to participate in rehabilitation tasks, prolong the rehabilitation sessions, and thereby contribute to the training goals achievement. As a result, the success of such games is tied to their engagement level.

These games can be played at home, minimizing the efforts needed for traveling to a rehabilitation center, and in some cases, reducing the time and support needed from a therapist or the parents. Home-training solutions can increase the frequency of the training sessions and, as a consequence, contribute to the program's outcome.

1.2 Objective

We believe that computer games have much to offer training programs in general and training for CP children in particular. This Master Thesis is aimed to design and develop a game to help the children with cerebral palsy in their training program. The proposed design includes physical activity as a means of interacting with the game to achieve training goals, as well as engagement elements to keep the child motivated. In this Thesis, we try to broaden the field of designing games with rehabilitation purposes by following a user-centered design approach, evaluating the results by conducting user studies and publishing the findings of the applied design and suggestions on further works.

1.3 Context

This Master Thesis is defined in the context of SHArKi project: a research project focused on multimodal, sensor-based hand and arm function training for physically impaired children. The goal of SHArKi project is to foster physiotherapy exercises in children's everyday

life through games and by providing an interactive wearable system for monitoring and provision of feedback on upper body movements. SHArKi project is funded by the Federal Ministry of Education and Research as part of the "Small patients, great needs - Medical technology solutions for child-friendly health care" funding program.

The SHArKi team supported the author of this Master Thesis in many ways such as helping in finding the focus area, sharing resources and contacts, providing guidance and feedback, and much more.

1.4 Scope

In this study, we focus on the engagement element in the design of rehabilitation games. We will deploy an iterative design approach, and implement a testable prototype to evaluate the gaming experience both subjectively and objectively.

The scope of this thesis does not allow for evaluating the effectiveness of the designed game in an actual training program, as it requires specific technical implementation to recognize physiotherapy exercises accurately, as well as a multi-session study trial.

1.5 Outline

This thesis is separated into 7 chapters.

Chapter 2: In this chapter, we summarize the fundamentals needed for designing a game with rehabilitation purposes, such as usability definition and metrics that are relevant to our use-case, main components for an optimal experience, and an in-depth review of both serious games and exergames components. Apart from the conceptual review, we will also discuss some examples of related work that has been done in each of the mentioned categories.

Chapter 3: In this chapter, we briefly discuss the study goals derived from the study objectives and framed based on the related research in the previous chapter. We also set the requirements that are specific to our solution space, target audience, and technical setup.

Chapter 4: This chapter is concerned with describing the steps that were taken during the design phase. We illustrate the design journey from context ideation, finding the right genre and core mechanics, applying the expert feedback, idea selection, and designing game variations based on our research independent variables.

Chapter 5: This chapter gives an overview of the technical side of the study, as well as highlighting the challenging aspects of the game implementation, such as setting up the remote test and re-implementation of some parts of the game.

Chapter 6: In this chapter, we discuss the hypotheses in greater detail, and describe

the evaluation methods and tools that were used for conducting the user study.

Chapter 7: In this chapter, we discuss the statistical methods, analyze the results of the user study, conclude the findings, and give suggestions for future work.

2 Fundamentals and Related Work

2.1 Quality of Experience and Children

ISO defines usability as "The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use." But Hourcade argues that the way we define "goal" is often different for children: "Children are more likely to value the quality of the experience over completing a task." [Hou15] In this section, we discuss the concepts of usability and user experience, focusing on how they apply to children.

Csikszentmihalyi, who is a widely known psychologist and is mostly famous for his concept of flow, has defined a set of specific components for an optimal experience. [Csi90] These components are mostly conceptual and therefore can be applied to different target groups such as children:

Having a challenging activity that requires skill:
According to Csikszentmihalyi, "For an activity to have the right level of difficulty, it needs to strike a balance." By applying this principle to our case, we can assume that if the game is too challenging children may become anxious or frustrated. On the other hand, if the activity is too easy, children may find it boring. We will bring this point up several times in various steps of the work as it is applicable wherever there is a decision to be made on the type or amount of challenge.

Adding novelty to the experience:
Csikszentmihalyi observed that one outcome of an optimal experience is that people are more skilled after they went through the experience. Hence, a degree of novelty is needed in order to put the children in a situation where they have to learn a new skill or become better in what they have already learnt. The greater the skill set, the more accomplished they feel after the experience.

Having a sense of control:
According to Csikszentmihalyi, even in a difficult situation, people should have a sense of control in order to avoid feeling anxious.

The merging of action and awareness:
According to Csikszentmihalyi, a loss of self-awareness is usually an indicator of high engagement. To feel immersed in an activity, among other things, is dependent on how natural the interaction is.

Having clear goals and feedback:
This has been a fundamental rule in human computer interaction and has been applied to a variety of use-cases. Deriving from Csikszentmihalyi's work, making the goal clear and

giving the appropriate amount of feedback with the correct timing is necessary for a user to have a sense of their progress and therefore to have an optimal experience.

Transformation of time:
Csikszentmihalyi observed that when people go through an optimal experience time seems to pass much faster for them. Although this concept has been widely used in usability tests, it might not be a good idea for a children's test, as they have no correct sense of time until they reach a certain age.

Depending on the development stage, we can extract design principles, usability checklist, or evaluation measures from this set of components. In this thesis, we mostly made use of these components as a design guideline.

Hourcade's book, Child-Computer Interaction [Hou15], is one of the few books dedicated to the unique and less explored characteristics of children's experience with computer systems. One of the questions he asks in his book is: how can usability goals that are defined for adults and are widely used in usability studies, be applied to children's technologies? He argues that "regarding learnability, the younger the children, the less likely they are to want to spend time learning how to use a technology. Technology for children should come with the minimum amount of instructions. The concept of multi-layer user interfaces could be used to start out with a simple user interface that increases in complexity as children explore more options. Similarly, for younger children, fewer functions and simpler user interfaces where only a few operations are possible may lead to better results."

2.2 Serious Games

One of the first formal definitions of a serious game was introduced by Zyda: "Serious game: a mental contest, played with a computer in accordance with specific rules, that uses entertainment to further government or corporate training, education, health, public policy, and strategic communication objectives." [Zyd05]
To put it simply, "games are considered serious when they strike a balance between education and entertainment." [CM08]

2.2.1 Serious Games Conceptual Framework

As suggested by given definitions, learning and engagement are the two core concepts in serious games. Similar to Csikszentmihalyi's theory for engagement, we can use a conceptual framework for the learning aspect of the game which includes learning and pedagogy theory in combination with gaming requirements: [YCGW09] This framework consists of the following components:

Capability:
"Capability refers to the cognitive, psycho-motor, and possibly effective skills which the learner is to develop as a result of playing the game." [YCGW09] In our use-case, we are interested in the first two types of skills; Firstly, "cognitive skills that include the capabilities of recall, analysis, synthesis, and evaluation." And secondly, "psycho-motor skills that include the capabilities of well-timed, fluid execution."

Instructional content:
"The instructional content is the subject matter that the learner should learn." [YCGW09] Gilbert and Gale [GG08] state that instructional contents can be classified into four types: facts, procedures, concepts, and principles.

Intended learning outcomes:
"An intended learning outcome is a particular combination of capability and subject matter." [YCGW09]

Game attributes:
"Game attributes are those aspects of a game which support learning and engagement." The attributes that are relevant to our use-case, defined by [YCGW09], include:

- Incremental learning and linearity: Intended learning outcomes are addressed one by one to support a smooth learning curve. Linearity refers to the extent which the learner can construct their own sequence of activities.

- Attention span: Short term memory load should be calibrated according to target learner.

- Interaction: The extent to which the game activities require responses and engagement from the learner.

- Practice and drill: Repeating learning activities with increasingly harder tasks for better achievement of the intended learning outcomes.

- Intermittent feedback: The extent to which every game interaction receives feedback, or whether feedback is provided less frequently.

- Rewards: Arrangements in the game to encourage the learner and to keep their motivation high.

- Situated and authentic learning: The provision of a gaming environment or world where the learner can relate their learning to their needs and interests in the outside world.

Reflection:
"Reflection is where the learner thinks about the purpose of the learning activities that have been undertaken, and should take place within the game without letting the learner step out of the game world. One example of reflection activities is corrective suggestions." [YCGW09]

Game genre and game mechanics:
This topic will be covered in more details in game design section.

2.2.2 Serious Games for Rehabilitation

Rehabilitation is defined as "a dynamic process of planned adaptive change in lifestyle in response to unplanned change imposed on the individual by disease or traumatic incident." [GB05]

"The focus in rehabilitation is not on cure but on living with as much freedom and autonomy as possible. The success of a rehabilitation program depends on various factors, amongst them are appropriate timing, choice of rehabilitation program and continued medical management." [GB05]

"One of the major problems in therapy sessions is the repetitive nature of exercises which can cause the loss of patient's motivation to participate actively. This is where the design of computer games can offer valuable contributions about how to develop more effective games for rehabilitation programs." [RMR10] "As traditional treatment approaches include exercises that are often considered repetitive and boring for patients, using computer games to augment physical and cognitive rehabilitation can offer the potential for a significant therapeutic benefit. Games require cognitive and motor activity, hence they can engage a person's attention and help with the pain management." [KSYZ95]

Several studies regarding rehabilitation serious games have been done for specific target groups and specially stroke patients. Flores et al. [FTC+08] discuss that an ideal game for stroke rehabilitation would satisfy all the requirements from these two categories: stroke rehabilitation, and elderly entertainment. They believed that "the existing gaming scenarios for rehabilitation have been designed solely by engineers, scientists, and health professionals whose purpose is to build and test the overall functionality of the developed hardware. Therefor, careful attention must be given to the way in which we design the patient-system interface to incorporate motivation for active participation." [FTC+08] Although their target group was different from ours, their approach in categorizing the criteria was inspiring.

A video game-based serious game for balance rehabilitation [BDN+07], Rehabilitation Gaming System (RGS): a VR based system for the rehabilitation of patients suffering from stroke and TBI [MSCBZ+09], and a maze-solving game for balance rehabilitation in older adults [RSC+09] are examples of games with rehabilitation purposes. These examples are different from our use-case in regard to both rehabilitation program and target group.

Rego et al. [RMR10] proposed a taxonomy for rehabilitation serious games based on a number of previously done researches. They identify the following criteria in their suggested classification:

- Application area:
  The domain application in which a game can be applied: cognitive rehabilitation and physical/motor rehabilitation. Cognition can be described as the process of thinking and awareness and includes mental faculties such as memory, attention and concentration, reasoning and problem-solving, sentience, language, volition and judgment, amongst others. These faculties are very sensitive and are prone to influences from psychiatric conditions, neurological disease, medical conditions and head injuries.

  Motor rehabilitation can include: stroke rehabilitation (upper and lower limb extrem-

ity training, spatial and perceptual-motor training), balance training, acquired brain injury, wheelchair mobility, Parkinson's disease, orthopedic rehabilitation, functional activities of daily living training, and telerehabilitation.

- Interaction technology:
  Used technology can vary from the traditional methods using a mouse or keyboard process to VR based methods using head-mounted displays and desktop monitors; haptic interfaces like data gloves; and motion tracking devices. This also depends on the targeted sensory modalities (vision, haptic, audition).

- Game interface:
  The interface can be two-dimensional (2D) or three-dimensional (3D).

- Number of players:
  Single-player or multi-player.

- Game Genre:
  The games genre can vary in relation with the technology used. This topic will be covered in more details in game design section.

- Adaptability:
  System's capability to adapt the game difficulty or challenge, dynamically and according to the patient performance in the game.

- Performance feedback:
  System's capability to transmit the results of the interaction to the patient. This can be done via multiple modalities such as aural, visual or a mixture.

- Progress monitoring:
  System's capability to allow for saving the patient's interactions over time for later analysis.

- Game portability:
  System's capability to be used at home, or a health facility.

Burke et al. [JWBMC+09] identified two principles of game design which have particular relevance to rehabilitation:

- Meaningful play:
  Meaningful play emerges from a game in the relationship between a player's actions and the system's outcome. Recognition of the effect a particular choice has can be conveyed to the player through feedback, without which that choice loses significance due to a lack of visible meaning.
  - Handling failure:
    For rehabilitation, failure can be an important issue and it should be handled much more conservatively than off-the-shelf games. The goal of a game designed for rehabilitation should initially be to encourage engagement and subsequently

to reward all engagement with success. By handling failure in a positive way, players are more likely to remain engaged.

- Initial pace:
  The game should initially be carefully paced so that the player is encouraged to play without catastrophic results.
- Using avatar:
  In many rehabilitation systems users with stroke see a virtual representation of themselves (avatar), or part of themselves (just the tracked limbs) in the simulation. In these systems, feedback is instant and continuous.
- Feedback:
  Feedback should clearly show when a user's actions result in interaction with a game element; perhaps the element lights up, changes colour, or an audible sound is played. [JWBMC+09]

"A game designer cannot possibly know in advance every player's individual level of skill. There are two ways to handle that: Using levels to structure difficulty, or dynamically adapting the game difficulty according to the player's in-game performance and abilities." [JWBMC+09]

"Games for rehabilitation offer the possibility to increase or decrease the level of difficulty to an almost infinite degree. Games designed for upper limb motor rehabilitation will require the user to point to, reach towards, touch, grasp and move game elements. The position of these game elements can be altered to make them easier or more difficult to reach in order to suit the capabilities of the player. Game elements can also be made larger (easier to touch) or smaller (harder to touch, requiring more accurate movement). Games that target bi-manual movement will require synchronisation of left- and right-hand/arm movements: perhaps one hand can be holding a game element while the other interacts with it." [JWBMC+09]

2.3 Exergames

An exergame, as the word suggests, is a combination of "exercise" and "gaming". It involves physical activity as the means of interacting with a game. Factors influencing success in an exergame involve not just the gaming experience, but also the physical requirements of the game. It is however a positive point, that the exercise itself has some characteristics of an optimal experience and can contribute to overall engagement. According to [JC99], sport settings are structured to enhance flow: "sports can offer such rewarding experiences that one does it for no other reason than to be a part of it. Although winning in sports is important, flow does not depend on the final outcome of the activity."

Similar to any other hybrid concept, updated design considerations are needed for designing exergames. One of the challenges in designing an exergame is the need to make the game attractive to players, and at the same time effective as an exercise. [SHM07] added another dimension to the original flow theory to optimize the effectiveness of exergaming

systems (Figure 2.1). "Physical fitness corresponds to the body's "skill" in being able to cope with the exercise, and exercise intensity level corresponds to "challenge" of the exercise on the body." [SHM07] The attractiveness of the exergame can be modelled by the standard flow model from [Csi90].

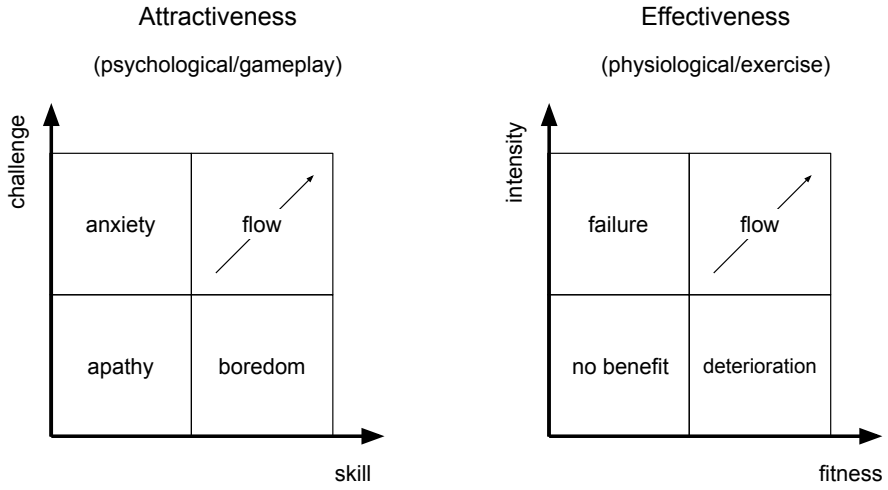

Figure 2.1: Dual Flow Theory

2.3.1 Exergame Balancing

"The basic balancing principle suggests that the difficulty level of a game can be gradually increased, because it is assumed that a player's skill level increases with playing time. Such a solution does not work properly in exergames. Although, a player's skills may increase during playing, in lengthy playing sessions the gradually increasing intensity will lead to exhaustion and failure." [KM10]

One solution as suggested by [SHM07] is to construct games with relatively simple mechanics that focus on the input device rather than the game. Another solution is to make the game adaptive to the player and adjust the difficulty level according to player's performance history. [GHW+10] applies the second solution and describes a personalized exergame that uses an adaptive engine. This personalized and adaptive environment considers both static information for example training plans, application logic or other content such as player models (authored by doctors, fitness coaches etc.), and dynamically created information during play such as vital parameters and potentially changing player behavior.

3 Study Goals and Requirements

3.1 Study Goals

The goal of this thesis is to design an engaging game that could be beneficial as part of a rehabilitation program for CP children. Based on the research on related works, we decided to set the flow theory as the foundation for our game's design and evaluation. According to flow theory, it is required to introduce the right amount of challenge to reach the flow state. Thereby, we can restate our goal as finding the optimum balance between the player's skills and game challenges.

We will evaluate the flow by measuring players' engagement both subjectively and objectively. The independent variable would be the types of challenges that we introduce in the game.

3.2 Requirements

Specifying functional requirements is the first step towards the realization of a solution. Requirements are often derived from certain goals. As the final goal of the game is to help CP children with achieving their training goals, we identified three sets of requirements that apply here. How these requirements are applied to the final result is discussed in detail in the design chapter.

3.2.1 Solution Requirements

Having the goal of fostering physiotherapy into the everyday lives of children in mind, one might think about different ways that this can be achieved. But what all of these ways have in common is allowing the child to do the prescribed exercises. As we have chosen to build our solution in the form of a game, this means that an integration of the game and the physiotherapy exercises is necessary. Having the exercises as the way to interact with the game allows for this integration, and as we have already covered in related works, the integrated solution would fit in the exergames category.

3.2.2 User Specific Requirements

The user group of our solution is, obviously, children with the cerebral palsy condition. This user group is rather unique considering two aspects; firstly, as the extent to which physical and cognitive capabilities are developed is age dependant in humans, children's physical/cognitive skills are limited compared to adults. Secondly, CP condition also

affects the development of these capabilities and therefore there are even more limitations regarding the developed skills.

We should also take into consideration that since the severity of the disease is different from one patient to another, their capabilities are also different. Hence, in an ideal world, the challenge difficulty should be adjusted to each patient on an individual basis. The scope of this thesis does not allow for providing a personalized experience for each user, but this can be considered as one of the next steps in further research.

3.2.3 Technical Requirements

If a system should be used daily and at the user's convenience, it should be easily accessible and also easy to setup. In our use case, the goal is to have the system running in a convenient environment for the child, which in most cases, is their home. The ideal case is to have the minimum required hardware to reduce the setup time as well as reducing the expenses.

4 Design

4.1 Core Concepts in Game Design

The book rules of play [SZ03] defines the game design as follows:

"Design is the process by which a designer creates a context to be encountered by a participant, from which meaning emerges."

Three core concepts can be extracted from this definition:

- The context of a game takes the form of spaces, objects, narratives, and behaviors.
- The participants of a game are the players. They inhabit, explore, and manipulate these contexts through their play.
- Meaningful play is the result of players taking actions in the course of play.

Although this division of components helps the designer to break the question of design into smaller chunks, these components are not completely separable and they have a huge impact on one another. There is usually a lot of back and forth in the design process and it can be managed by running consecutive design iterations.

We ran two design phases and each consisted of different steps depending on the stage requirements and usability priorities.

4.2 First Phase

Amongst the mentioned concepts above, the participants are the most straight forward to define. We have already talked about the user group in the requirements section, and we will elaborate more on this topic once we reach to the point where there is a context in which these requirements should be translated into design decisions.

The meaningful play seems to be the hardest to define, because its characteristics are derived from the interaction between the user and the game, and is dependant on the decisions concerning those two concepts.

For the above reasons, the game context seems to be a good starting point in our game design process.

4.2.1 Game Context

Finding the right context for a rehabilitation exergame is a complex problem and like most complex problems, there could be two approaches to handle the task: top-down versus

bottom-up. And then, there is a third option which is a mix of these two approaches. One could start by eliminating the options that will not be compatible with the requirements taking the bottom-up approach, then have a pool of all the options that are left and choose the best one by applying a top-down approach. But first, let us summarize what we already know about our desired game context.

Since we do not have any fixed object, world setting, or story in our game we can theoretically apply any given context to our game's world and that means that our possibilities are almost endless since the gaming world offers vast varieties. However, as mentioned before, some requirements should be met. These requirements are directly concluded from our use-case. After having the general requirements translated into game context requirements, it would be helpful to categorize game contexts and filter them based on their alignment with the requirements. Here comes the question of what is the best way to categorize the contexts. Games are typically categorized by their characteristics or objectives and usually, one game can fit into multiple groups or subgroups. To find a list of possible contexts for our game, we chose to group them by their genres and also their core mechanics.

Alignment with Requirements

- Applicability for exergame:
  We should determine whether a certain type of game context is suitable to be integrated with a physical exercise as a means of interaction. In other words, does it make sense and feel natural to have a hand/arm movement mapped to one action in this context.

- Suitability for CP children:
  There are several aspects that we should consider when designing a game for CP children. According to CanChild project [McM14], limitations in fine and gross motor function, eye-hand coordination, and visual-spatial reasoning (the ability to understand and remember the spatial relations among objects) associated with CP make it difficult for children with CP to play normal games effectively. Hence, we captured the game characteristics and elements affecting the physical and cognitive capacity required for the game:

  - Pace and rhythm:
    Although rhythm is one of the engaging factors in lots of fun games, it is risky to build the foundation of the game on this factor since we want to avoid any frustration associated with not being able to follow the game or not having a sense of control over it. It is also difficult to anticipate the point in the game in which the child might get tired and need to slow down or take a break. This does not mean that the child cannot enjoy the positive pressure of having to follow the rhythm of the game, but it is just to keep in mind that falling behind the rhythm should not lead to a total failure as this might be the case in some of them off the shelf computer games.

  - Failure and stress:
    A game should be challenging enough to avoid causing boredom in players, and confronting a challenge should not always lead to a win. However, unsuccessful attempts can be handled in various ways. Heavy failures can cause the belief of not being able to play, and players might give up. Hence, it is preferred to avoid contexts like survival situations which put a lot of pressure on the player and contain heavy failures as a context pillar.

  - Violence:
    Lots of games available in the market are not appropriate for children because they contain violent scenes and actions, and this has been a concern for quite a few years now. Apart from the fact that our game should not contain any sensitive contents, we also know that in some cases it is harder for CP children to control their emotions compared to healthy children. Therefore it might have an even worse impact on CP children and this is not in line with our intentions.

- Availability for home training:
  The game should be easy to set up and play. The child should be able to play the game in the home environment with little or none at all dependency on others for playing the game. This means that a single-player game is preferred over a multiplayer one since it eliminates the need for finding other players to join a playing session and makes it easier for the children to start playing whenever they feel like it.

Core Mechanic of the Game

Core mechanics of a game define the pattern of actions that are happening in the game frequently.

Based on the requirements introduced in the previous section, we cross off the concepts that are commonly used in computer games but are not suitable for our use case. With this approach, we will be able to narrow our design possibilities down to a shorter list of core concepts.

According to Challenges for Game Designers [BS08], common core mechanics are as listed in the first column of table 4.1. The next three columns are characteristic of a core mechanic that conflict with our requirements, therefore, each of the core mechanics that includes one or more of these characteristics will be crossed off from the list of possible core mechanics for our game. The rows marked with green background do not include any of those characteristics and therefore are aligned with the requirements.

As a result, the core mechanics of our game could be Prediction, Spatial Reasoning, Destruction, Building, or Collection. It is important to also mention that in computer games a game can have more than one core mechanic integrated into its world.

Core Mechanic	Multiplayer	Considered as Violent	Heavy on Failure
Territorial Acquisition	x		
Prediction			
Spatial Reasoning			
Survival			x
Destruction			
Building			
Collection			
Chasing or Evading		x	x
Trading	x		
Race	x		

Table 4.1: Core Mechanics and Their Alignment with Requirements

Game Genres

The same approach as explained in the core mechanics section is applied to the list of main genres in computer games. The first column in table 4.2 includes the list of game genres and the next columns are game characteristics that we do not want our game to be featured with, based on the requirements.

The candidates for the genre of our game, according to table 4.2, are Adventure, Role Playing, Simulation, or Sports.

4.2.2 Game Interaction

The purpose of having arm/hand movements as the way to interact with the game is to integrate physiotherapy exercises into the game. Thus, it would be necessary to extract the core movements from the exercises and design the interactions based on them. The set of core movements extracted from physiotherapy are as follows:

- Bi-manual/Uni-manual:
  - Forward-up
  - Forward
  - Sides
- Uni-manual:
  - Supination

Genre	Multiplayer	Not Applicable to Exergames	Requiring Short Reaction Time or Rhythmic	Considered as Violent	Heavy on Failure
Action			x	x	
Adventure					
Combat			x	x	x
First Person Shooter			x	x	x
Massively Multiplayer Online	x		x		
Puzzle		x			
Real-Time Strategy	x				
Role Playing					
Simulation					
Sports					

Table 4.2: Game Genres and Their Alignment with the Requirements

Some of these movements are depicted in figure 4.1.

According to our physiotherapist partner, the treatment plan starts with the movements that are focused on the arm and are easier to perform, such as keeping the arms stretched forward and pulling it back towards the body. More complicated movements such as the ones requiring fine motor development of wrists and fingers are gradually added to the treatment plan.

The same considerations should be applied to the games that are used as part of the treatment plan. The level of complexity in interactions is one of the factors affecting the overall difficulty of a game. If the interactions are basic arm movements there is a higher chance that it is a better fit for initial steps of the treatment plan. On the opposite side, if the game requires advanced motor skills in fingers it would be better if it is introduced at a later stage in the treatment plan when the arm motor skills are already developed.

In the first design phase, we keep all the interaction options on the table to have a broad range of game's difficulty to chose from in the next phase.

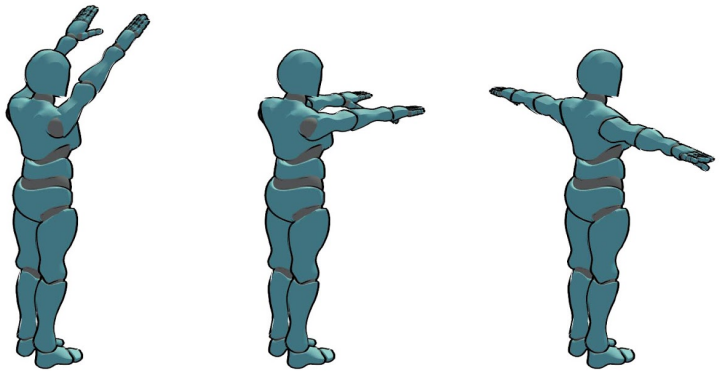

Figure 4.1: Basic bi-manual arm movements: Forward-up, Forward, Sides
models created using: justsketchme.web.app

4.2.3 Formulating Game Ideas

Up to this point, we have defined the set of possible game mechanics and game genres for our exergame, as well as the physiotherapy exercises that should be developed into interactions with the game.

In this section, we present the top three ideas that were formulated based on what we have defined so far. These ideas are the result of a brainstorming session focused on the interactions, followed by a revising session to adapt the raw ideas to one or more of the game mechanics/genres.

To have a smooth interaction with the game via hand/arm movements there should be a connection between the action in the physical world and its counterpart in the game on both actual the conceptual levels. This connection should be easily made on one's mind without trying hard to understand it or even thinking about it.

On the actual level, the physical activity should be in sync with its effect in the game world. Depending on the context this might mean for both of the actions to have the same direction, speed, timing, or other parameters. The best way to demonstrate this point is to imagine having an avatar that is supposed to be a representative object for the player. One expects the avatar's movements to be copied from the player as accurate and in sync in performance and timing as possible.

To put the conceptual connection into an example, imagine there is an apple on a table and you want to grab it. You would probably reach out your hand towards the apple to carry out your intention. Now imagine that there was a glass wall between you and the table, and therefore you could not reach out your hand to grab the apple. Instead, there was a red button beside you, and by pushing the button the apple would magically appear in your hand. This is an example of indirect interaction with the surroundings.

Now let us say that we have a simulation game. In a simulation game, interacting with the objects in the game world should feel as natural as grabbing, moving, or pointing at something in the physical world. A smooth and expected experience is one that lets the player interact with the game's world the same way they interact with the world that they know so well: the physical real world. It is therefore best to minimize indirect interactions as much as possible. It is worth mentioning that the conceptual connection might or might not be needed depending on the game parameters such as its genre.

There are of course some cases in which the intention is to use the abnormality of the interaction to create fun and surprising moments. It is not our intention, however, to introduce a set of unfamiliar interaction rules to the player since we would like to help the players with their real-life everyday tasks and laws of the real-life interaction must be applied to our game's interaction.

There could be plenty of different combinations of the interactions, core mechanics, and genres mentioned above, but we have to narrow down the options at some point. However, we tried to keep the diversity of the possibilities in the top three selected ideas. We also kept the unnecessary details of the game out and focused on describing the relevance of the idea to core features such as game interactions.

Spiderman

Spiderman is a well-known character in the world of fictional heroes. The idea of this game is to corporate the core characteristics of Spiderman superpowers into the game interactions. The player would play the role of Spiderman by performing a set of defined arm movements. The goal of each level is to collect points by following a given path. The player has to perform the right moves to be able to move between the structures in the path. Table 4.4 lists the arm movements and their corresponding actions in the game.

Genre	Role playing
Core mechanic	Collection
Camera	Follows the character
Goal	The player has to collect the points by moving between buildings. An unsuccessful move will result in falling down.

Table 4.3: Game Parameters of Spiderman

Arm movement	Outcome
Forward	Shooting spider-webs towards the structure in front
Forward-up	Shooting spider-webs towards the structure above
Sides	Jump and hop over the structures

Table 4.4: Game Interactions of Spiderman

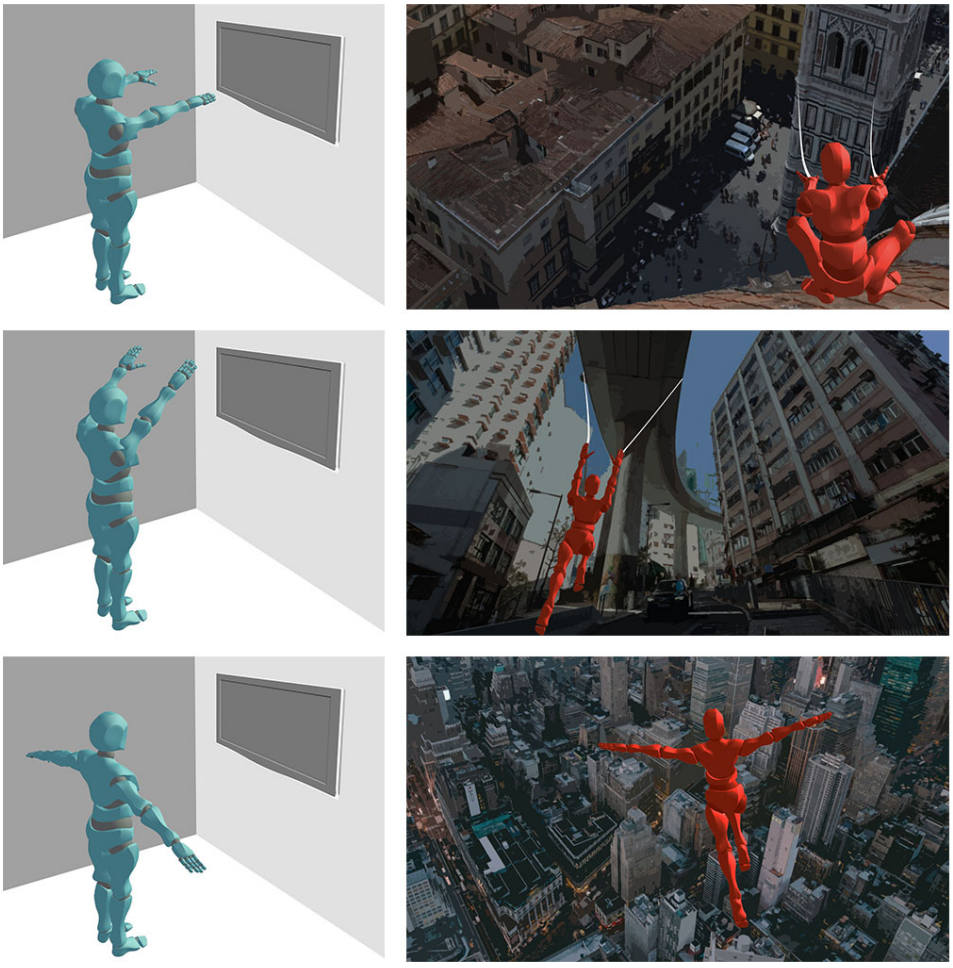

Figure 4.2: Spiderman - Visual Concept

Kayak

The idea of this game called Kayak is to navigate a boat on a river and overcome the obstacles and collect the point along the way. A repetitive movement of stretching the arms forwards and backward would simulate the paddling and result in moving the boat forward. In a more advanced version, the angle of movement would define the direction of the boat. Other arm movements such as raising and stretching to sides are used to collect the floating objects on the way.

Genre	Sport / Simulation
Core mechanic	Collection
Camera	Follows the boat
Goal	The player has to drive the boat towards the floating objects over the river and collect them while avoiding the obstacles that may appear on way.

Table 4.5: Game Parameters of Kayak

Arm movement	Outcome
Forward	Paddling
Forward-up	Collecting objects that are floating in front
Sides	Collecting objects that are floating on sides

Table 4.6: Game Interactions of Kayak

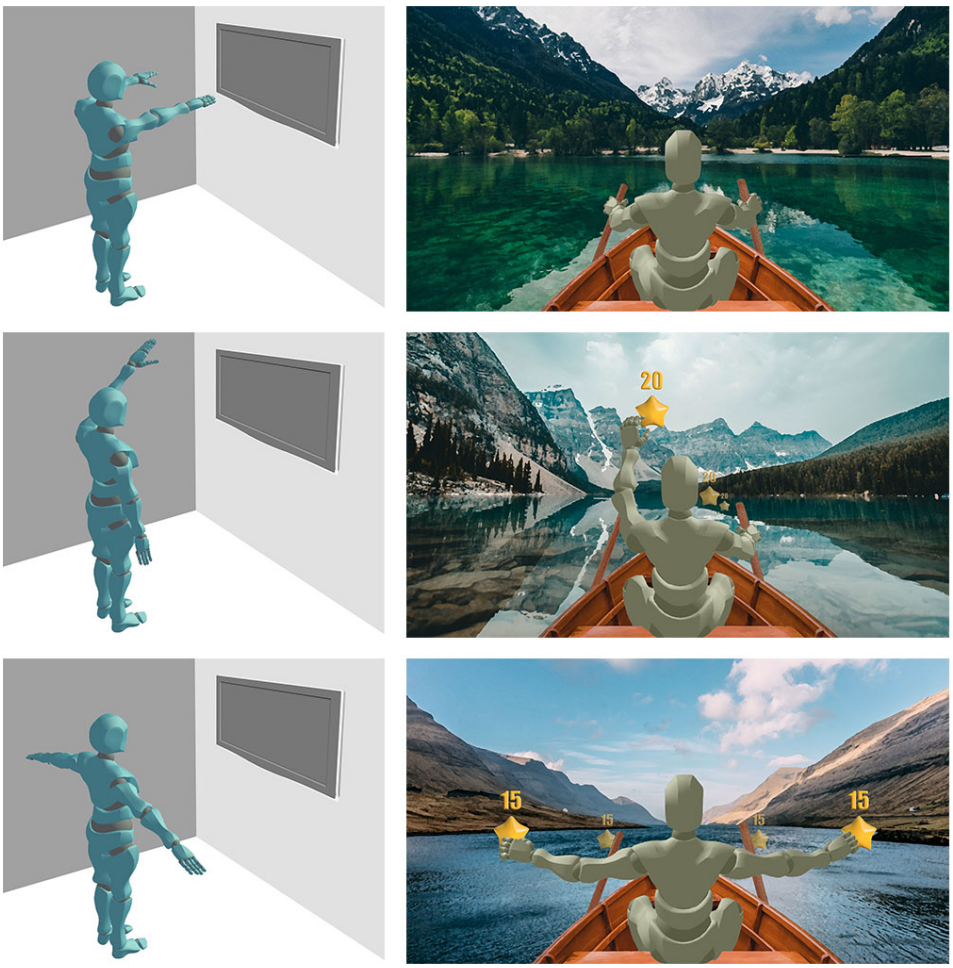

Figure 4.3: Kayak - Visual Concept

Pop

This mini-game has a comprehensible idea behind it; to pop the balloons appearing on the screen. To pop a balloon the player has to simply reach out their hands towards it. Although the idea of this game is very simple, there is plenty of variations that could be built upon it.

Genre	Simulation
Core mechanic	Destruction
Camera	Fixed position
Goal	The player has to pop (certain) balloons to gain points.

Table 4.7: Game Parameters of Pop

Arm movement	Outcome
Stretched forward	Popping the balloons located in front
Stretched forward-up	Popping the balloons located on top
Stretched to sides	popping the balloons located on sides

Table 4.8: Game Interactions of Pop

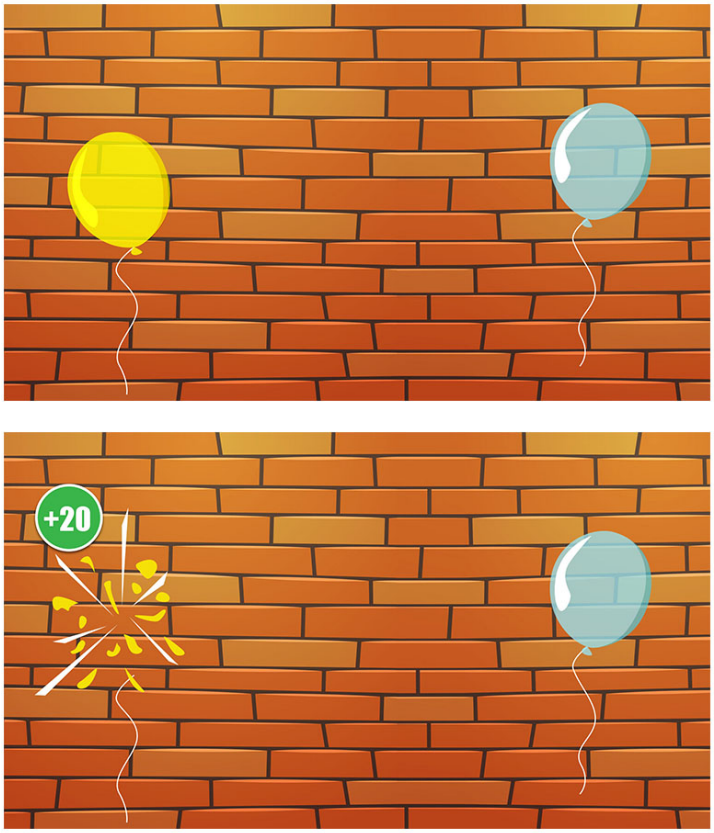

Figure 4.4: Pop - Visual Concept

Figure 4.5: Pop - Visual Concept

4.2.4 Expert Review

During the first design phase, many questions regarding the movements and their efficiency came up. To address those questions and find out about an expert's opinion on three selected game ideas, a meeting was arranged with SHArKi's physiotherapist partner. A summary of the discussed points can be found in the following lines.

General Topics

- Training Process

  We asked about the importance of the movements' features in the process of training. For example, we were interested in knowing whether the initial position is as important as the final position and if the transition from the initial position to the final position is of importance. The physiotherapist believed that all three mentioned aspects have the same level of importance. For a movement to happen, children should have a motor plan, and that is usually where they have the biggest problem. Most of them are dealing with spasticity, which is a condition in which certain muscles are continuously contracted. That means that some movements are difficult for them to perform, therefore their brain is not trained to do motor planning for the desired movement. They also tend to do the movement most easily and not in the correct way, hence they end up cheating in the transition. The final position is also naturally important because it is the final step of the movement.

- Movement Repetition

  It is difficult for the children to switch between different movements because they need a new motor plan for each one of them. Therefore, it is beneficial and a training technique to do a specific movement for let us say 10 times in a row to help the motor plan stick in their brain. Once they get it right, we can ask for a different movement that requires a new motor plan.

- Movement Difficulty

  The physiotherapist simplified the matter of movement difficulty with an example; she said it is like sports. If you start by teaching the service to a future tennis player, you are not a very good teacher. In the example of teaching tennis, you have to start with forehand, backhand, and then more complicated movements. There is a hierarchy that should be followed and it starts with the basics. The same applies to our exergame. One should start with easier movements and make the movements more difficult as the player successfully performs the previous movements. Teaching has a lot to do with making things simpler.

  It is also worth mentioning that CP children usually have problems in synchronizing their left and right sides of their bodies. The non-affected side is usually much quicker and that leads to a broken rhythm in their movements.

- Cognitive Difficulty

The physiotherapist stated that it is very difficult for CP children to concentrate if there are too many items on a page or on a screen offered to them at the same time and this is one of the biggest problems with school books. The designers try to make the book more fun by adding lots of items but that would make it harder for CP children to distinguish items from one another.

- Exhaustion

  We asked about the exhaustion a game can cause, whether physically or mentally, and if CP children will get tired faster than healthy children and if they will need a break from time to time to be able to continue the game. The physiotherapist replied: "CP children are not homogeneous." Meaning that it is not predictable how often they might need a break from the game. Some children have enormous difficulty in concentrating, and the task that is given to them has to be short

- Correlation of Physical and Mental Capabilities

  It was interesting for us to know whether a child can have a high level of physical functionality while having more severe cognitive problems and the other way around. The answer was that all the combinations are possible. Physical and mental impairments are not correlated.

Feedback on Game Ideas

We discussed the ideas one by one and the overall feedback on game ideas was positive. This section covers a summary of our discussion.

There seemed to be a remarkable difference regarding the age range and targeted gender amongst the game ideas. Our therapist consultant believed that although gender-related interest classifications are not acceptable, some parents are still raising their children according to these groupings. Therefore, Spiderman's game is most interesting for boys, and Kayak's game could be interesting for both boys and girls.

"Pop the balloons is suitable for children of 2-3 years old and above, while Spiderman game and Kayak game could be played from 4 or 5 years old." She believes that children are capable of doing more than we think, especially technology-wise. However, any interruption in cognitive development could affect the real cognitive age. "For mentally handicapped children it is very difficult to distinguish between colors."

Adjusting the difficulty of the game would also affect the age range. "If the game speeds up or gets more challenging the age range could be higher." She believes that by implementing a learning hierarchy we can prevent boredom in older children as well. Regarding the learning hierarchy, she also suggested that the Spiderman game should be very slow at the beginning, and the flying direction should not change very often. It is preferable to change the direction to the not affected side at first, and the other direction later. Also, the scene should not be too crowded and full of distractions, as we adults might enjoy it. Too many details might get irritating for these children.

We also discussed the learning outcomes and their impacts on children's daily lives. Pop the balloons game could be very useful in teaching the "cause and effect" concept to

small children. If I pop the balloon, its shape will change and a sound will be played. It is the same concept as switching the light button and turning the light on. Learning this concept is a big problem for children with brain injuries. Since this is a simple game and it is demonstrating the same concept, it could be of great help in their learning process.

Suggestions on additional movements like supination kick and other game ideas such as fishing, feeding animals, flying bird simulation, collecting flowers by bees, and dispersing flies from a cake were amongst other topics that came up during the feedback session.

4.2.5 Level of Difficulty

As we mentioned earlier, the level of difficulty of a game has a lot to do with the feeling of immersion in the game. The optimal experience happens when the challenge matches players' expertise. Different game parameters can influence the overall difficulty of a game. In this section, we discuss how the difficulty can be defined, its limits, and configuration options.

From a player's perspective, there is a screening phase when selecting a new game to play. Besides the player's interests, favorite genres, and gameplays, there are parameters such as player's age and game's target audience age that determines whether to choose a certain game or not. Selecting age-appropriate games is not only because of their content that could be harmful or irrelevant for another age group, it is also because most of the time a certain level of competence is required for the game to be entertaining for a player. If a game is too hard or too easy for a player it is likely that they will not enjoy playing as much as a player within the target group. But what makes "age" a proper parameter to rate the difficulty with? The answer is we often, and rightfully so, assume that one's skill set develops as they age. Therefore, age is used as a representative factor for the development of both motor and cognitive skills.

In our case, however, the development of skills in our target group is often delayed and the amount of the delay differs case by case. Hence, simplifying the segmentation by just age will not suffice for determining the fitting level of difficulty. This is the reason why we replace age by the following two factors: developed motor skills, and developed cognitive skills. Here we list the game parameters affecting the difficulty categorized by these two factors, and once again, we only discuss the parameters that are relevant to our use-case.

- Motoric
  - Complexity of the movements:

    As discussed in the Game Interaction section earlier, the more complex a movement is, the harder it is to master, and therefore the later it will appear as an exercise in a physical treatment plan. Similarly, the complexity of a movement that is incorporated into a game's interaction should be set according to the game's target group and their motor skills. In short, the difficulty of the game increases as the interaction movements get more complex.
  - Variation of the movements:

If there is more than one possible movement to interact with the game, the player has to pick one of them and possibly switch between them at some point in the game. Switching between movements requires a change in motor planning which means the player has to manage one extra step compared to when there is only one possible movement. In like manner, the wider the set of movements is the more complex the game becomes.

- Speed and reaction time:

  For those games that are featured with time as a parameter, being fast might refer to two things: first, game events happen at a high speed, and second, the player has to act fast and react to the game events in a shorter time duration. The faster the game events the more perception capacity required, and the shorter the time to react the more skillful the player has to be.

- Cognitive
  - Reasoning:

    Most of the games require reasoning skills to some degree. The reasoning could be the core of the game or one of the several pillars, and it could be used to solve problems with various difficulty levels. Obviously, the harder the problem is the more reasoning skills will be required. In our use-case, reasoning will not be the core of the game, but it will be used to add variety and its level has to be set according to the player's reasoning capacity.

  - Number and variation of game objects:

    Depending on a player's cognitive capacity, the maximum perceivable number of objects on the screen differs, and if the number of objects exceeds that maximum it might get distracting for the player. This is related to the concept of perception which is one of the cognitive processes that enables a person to make sense of the provided information. The variation of the game objects also affects the difficulty of the game. Each object in the game requires effort to get familiar with, learn, and memorize its necessity (if any). This means that if a game has fewer variant objects it will be easier to play compared to a game with a wide set of objects appearing on the screen.

  - Number of and variation of game objectives:

    Similar to objects, and due to the required perception, learning, and memory capacities to process an objective in a game, the overall difficulty of the game depends on the number and variation of game objectives.

Each of the 3 game ideas mentioned above can be analyzed based on these difficulty factors. In some cases, it is possible to define a range of difficulty within the context of the game idea, such as configuring the base speed of the Kayak game or the complexity of the Spiderman game scenes. In other cases, however, the difficulty of the game is bound to the idea and cannot be easily modified. For example, reasoning in the Kayak game is limited to deciding on the boat's direction in the advanced version of the game.

4.2.6 Idea Selection

At this point, the mentioned three game ideas are analyzed both from a designer and a physiotherapy expert point of view. Based on these two analyses and having the goal of research in mind, which is evaluating the engagement of the game, it is concluded that pop the balloons game is the best candidate to move forward with for a couple of reasons.

First of all, it offers the most variety in terms of game parameters and therefore could be adjusted to a wider range of difficulty from both motoric and cognitive aspects. These parameters will be considered as independent variables later on in the user study.

Secondly, according to the feedback we received in a consultation session with a physiotherapist, this game supports a wider age range and its context is not specific to one gender.

Last but not least, it can be implemented within the scope of this thesis while carrying out an acceptable visual quality compared to other options. The mere fact that the environment of this game is 2D as opposed to 3D would reduce the efforts required for the implementation.

4.3 Second Phase

In the first design phase, the context and the interactions of the game were decided on according to the defined requirements. The context and the interactions were the foundation for formulating a set of game ideas. Amongst the three game ideas that made it to the final selection round, and based on the expert's review and a few other factors regarding the research goals, a game idea called "POP!" has been elected to move forward with.

In the second phase, the focus was to clarify the details of the game mechanics in a way that it allows for exploration in the research question space. Although the hypotheses are explained in detail in the next chapters, we need to start this section with a description of the factors and the measures to justify the design decisions in the next step.

4.3.1 Research Goals, Factors, and Measure

Even though the final goal of the game is to help the children in reestablishing their physical capabilities, measuring physical improvement is not the goal of this study since it is a fact that physiotherapy helps children in their rehabilitation process. Our goal is to make sure that the game is engaging enough that the children in need of physical therapy will play it often and effectively.

Children's engagement in the game is an indicator of the game's success. According to the flow theory, an optimal and engaging experience is the result of a fine balance between the game's challenges and the player's abilities. As discussed in the previous section, motoric and cognitive challenges are the two types of challenges that our players would face. Hence, these two types of challenges are the factors that could affect the engagement which is the variable we are aiming to measure.

The game has to provide a framework in which we are allowed to measure the effect of mentioned factors on the engagement, and there are two approaches to do that. One approach is to change the value of a factor quantitatively. For example, one could change the speed of the game to find the optimal threshold for a player with a certain level of expertise and competence. The other approach is to alter the factor qualitatively. For example, the type of cognitive challenge could be color recognition, pattern recognition, or shape recognition.

Choosing the right approach depends on various factors itself: the nature of a factor that might or might not allow for quantification, the research goal, or the experiment limitations. In our case, however, the approach is chosen based on the stage in which we are. In the early stages of many design projects, the goal is to find the right path or the best area of focus in a solution space. Shaping the details and finding the fine-tuned numbers will become relevant at a later stage when the concept has already been proved. Since the essence of our research is rather exploratory, it is decided to follow a qualitative approach in defining the factors.

Based on what has been mentioned above, the effect of the type of challenge on engagement is of interest in this study. Once the design is finalized and the type of challenges are defined, we will state the hypotheses in greater detail in section 6.1.

4.3.2 Game Variations

The term "game variation" here refers to each instance of the game which offers a unique combination of values for the game factors. As mentioned earlier, these values are of the non-numerical type and categorized under motoric or cognitive.

Before going further in detail of the game variations, let us first describe the basic setup and mechanics of the game. The goal of POP! game is to pop as many balloons as you can during a game session. The means to pop a balloon can differ depending on the implementation, but essentially it requires the player to use their hands and perform a movement in a certain way and a certain area in space and with regards to the position of the balloon in which they are aiming to pop. Other rules and setups are additional and might or might not apply in a variation.

Two versions of the game and its variations were made during the second phase and the details of each one are explained in the next lines.

POP! - First Version

In the first version of the game there were 3 values for motoric challenge factor and 2 values for cognitive challenge factor and hence 6 unique combinations in total. Table 4.9 demonstrates these combinations and their corresponding variation number. Note that the motoric difficulty increases from top to bottom, and similarly the cognitive difficulty increases from left to right. Therefore, variation 1 is the easiest variation, and variation 6 is the hardest variation amongst all.

		Cognitive Challenge	
		No Cognitive Challenge	Color Recognition
Motoric Challenge	Fixed Positioned Balloons	Variation 1	Variation 4
	Moving Balloons Full Visibility	Variation 2	Variation 5
	Moving Balloons Restricted Visibility	Variation 3	Variation 6

Table 4.9: POP - First Version Variations

As discussed in the Level of Difficulty section, three parameters can be defined for the motoric challenge: the complexity of the movements, the variations of the movements, and the speed and reaction time. In the first version of the game, the 3 values that define the motoric difficulty are all related to speed and reaction time. The first value is "Fixed Positioned Balloons", which means that the balloons appear and remain on a fixed position on the screen until the player pops them. Both second and third values result in variations in which the balloons move from bottom to top in 4 vertical lanes and at

a constant speed. In moving cases, there are also 6 circles on the screen which we call "targets". The player can only pop a balloon once it is placed in a target. This means that the number of effective movements is limited to 6. There are two targets in each of the two middle vertical lanes, one on the top and one on the bottom. In each of the side vertical lanes, there is one vertically centered target as well.

Lanes concept, straight vertical moving paths, and constant speed help the player in predicting the position of the balloons and planning their moves. There are several reasons behind having the target concept too; One reason is to limit the variety of movements by reducing the number of interaction areas, which would result in less complex gameplay in general. The other reason is related to the fact that rehabilitation exercises are more effective when they are repeated. If the player could point at any place on the screen to pop a balloon, the probability of repeating a movement would be less. Having limited targets would encourage movement repetition.

The difference between the second and third values is in the visibility of the balloons. In variation 2 and 5, the balloons are visible the entire time, meaning from the moment their highest point reaches the bottom of the game screen, to either the moment their lowest point reaches the top of the game screen or the moment they get popped. The full visibility, along with bottom to top movement pattern, allows the player to have a sense of when to expect the balloon to reach the target and do the motor planning accordingly. In variations 3 and 6, where the visibility of the balloons is supposed to be restricted, the balloons are only visible when they are moving within a target. In these variations, the moving pattern is still the same as the previous ones (2 and 5), but the balloons are invisible before entering the target and after they leave the target. This means that the prediction is limited now and the player has less amount of time to react. This idea of having full or restricted visibility is directly related to how the motor planning works in the brain. Before any physical movement, a plan is made in the brain and this planning process takes time and requires skill. Those who are physically impaired are likely to have problems not just in performing a movement, but also in the motor planning itself. The shorter the amount of time motor planning takes, the faster the player can react. By having restricted visibility, we are decreasing the reaction time and aiming to practice faster motor planning.

In defining the 3 different values for the motoric challenge factor, we tried to offer distinctive gameplays and at the same time keep the changes from one variation to the next to a minimum. This was due to minimizing the learning effort and reducing the risk of having other factors affecting the experience. To make the movements consistent across the game variations, the same target positions as in moving balloon variations are used in the variations with fixed positioned balloons.

As for the cognitive challenge, we had a few options regarding the type of cognition process. Since we wanted to test the game with children as young as four years old, we decided to choose the color recognition as the cognitive challenge because it is one of the earliest cognitive processes that the children experience. Therefore, the first three variations simply require the player to pop the balloons of any color, whereas in the second three variations only the balloons of one specific color should be popped. If the player

tries to pop a balloon of the wrong color the game responds with playing an error sound.

By now we have described the similarities and the differences of the variations' mechanics, but there is yet another game attribute that we have not mentioned: The visual background of the game. The background was chosen based on the type of motoric challenge for two reasons. First, to support the idea of having full vs. restricted visibility we had to introduce a unique visual form for the two variations with moving balloons. Secondly, to facilitate the evaluation process we aimed to create a visual identity for each of the variations so that we would be able to use these visuals in the questionnaire. If the target audience for the questionnaire would have been adults, we could have used text descriptions to refer to each of the variations. But we found it easier for a child to differentiate between the variations by their visuals. Of course, having different visuals is likely to impact the look and feel of the variation and as a result, can be an additional factor in fun/engagement. However, the pros of having unique backgrounds outweighed the cons. The screenshots of the game variations after the first design pass are to be found in figures 4.6, 4.7 and 4.8.

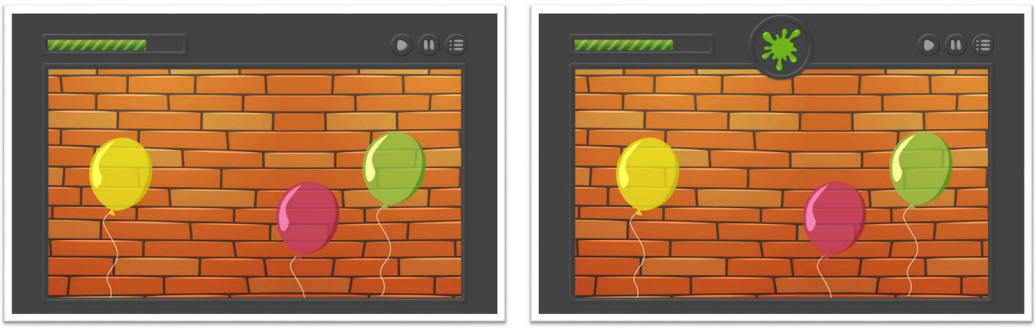

Figure 4.6: POP! - First Version - Variations 1 and 4

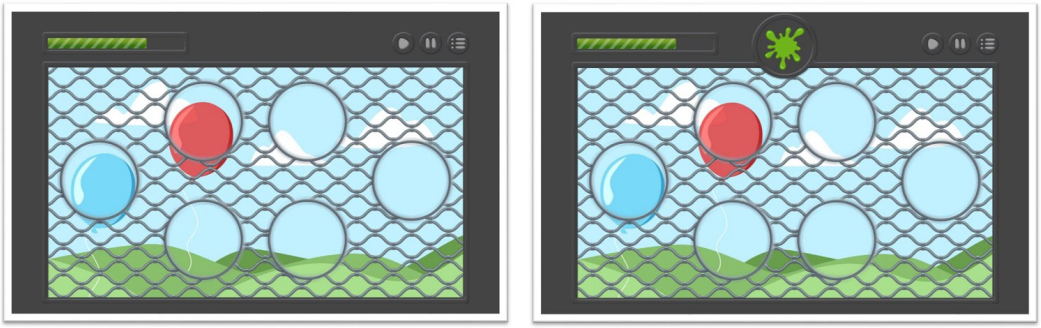

Figure 4.7: POP! - First Version - Variations 2 and 5

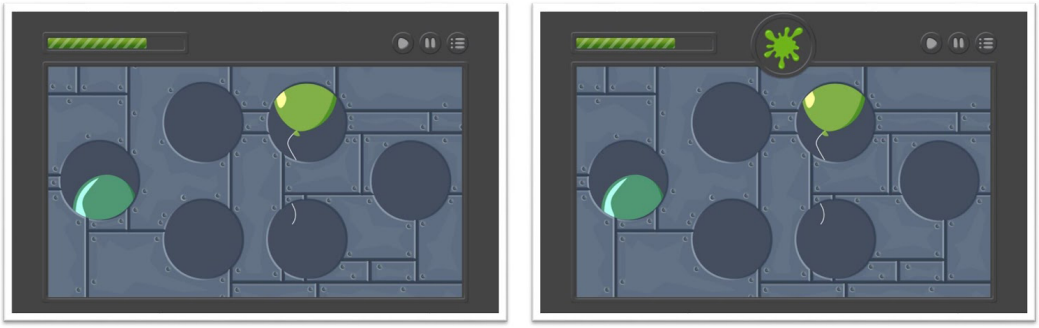

Figure 4.8: POP! - First Version - Variations 3 and 6

POP! - Second Version

After implementing the first version and testing the gaming experience internally and amongst friends, it became clear that although the player received the audio and visual feedback after successfully popping a balloon, this feedback was not enough in the learning process. Each player used the space in front of them to perform the hand/arm exercises differently. For example, some of the players only moved their arms slightly to the left or to the right to pop the balloons on the sides as they were essentially pointing at the balloons, and some others would stretch their arms sideways to do so because they were following the instructions. This behavior was also dependant on the size of the screen and the player's distance from the screen. This inconsistency was making it hard to fine-tune some of the game parameters such as the size of the interaction areas for each target.

To resolve this inconsistency in the second version, the static visual background got replaced by a live webcam video stream so that the players could see themselves interacting with the game. To make it more clear, in the second version of the game there are two layers on the game screen: the background layer is the webcam video stream that essentially serves as a mirror, and the foreground layer consists of all the game elements such as the balloons, target borders, menu icons and such. This video stream would provide constant visual feedback on how far or close the hand is to the target. It would also allow for a more immersive gaming experience as the players feel more involved in and connected to the game space.

By incorporating the webcam video stream into the game, the full/restricted visibility concept became irrelevant. Therefore in the second version of the game, the motoric challenge factor could only have two values: fixed position and moving, and as a result, there are only 4 variations in total. Table 4.10 demonstrates all the game variations in the second version. Figures 4.9 and 4.10 show how the game screen in the second version would look like.

		Cognitive Challenge	
		No Cognitive Challenge	Color Recognition
Motoric Challenge	Fixed Positioned Balloons	Variation 1	Variation 3
	Moving Balloons	Variation 2	Variation 4

Table 4.10: POP - Second Version Variations

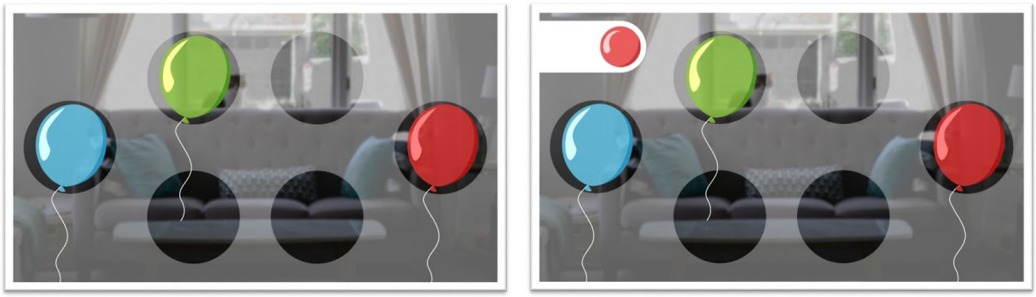

Figure 4.9: POP! - Second Version - Variations 1 and 3

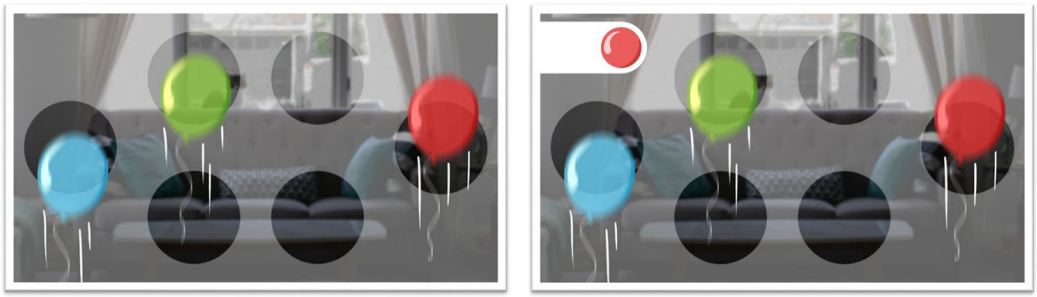

Figure 4.10: POP! - Second Version - Variations 2 and 4

5 Implementation

5.1 Overview

During this thesis, three different versions of the game were implemented. The first version was designed to make use of wristband sensors' data as the game input. However, as the development of the sensors progressed by a colleague and at the same time the game requirements became more clear, it turned out that the sensors could not fulfill the game requirements in terms of both functionality and performance.

The second version included an image recognition solution to provide the game with the player's input as the replacement for wristband sensors. This solution was considered as an alternative solution from the beginning.

Implementing a third version of the game rendered necessary on the point of conducting the user study. The second version was already operational and performing well, but new regulations were applied to user studies due to the Coronavirus pandemic and the study settings had to change. As a result, it was also required to update the game according to these new settings. The third version is to be played remotely and through an online video conferencing tool. It also makes use of a testing method called Wizard of Oz which will be explained later.

From this point forward, we refer to the second version as the main game, namely "the game", and the third version will be mentioned as "the remote version of the game".

In the next sections of this chapter, we will first discuss the technical aspects of the game including the system architecture and a brief overview of the implementation of each component. Then, we will explain how the remote version is different from the on-site version and how it is implemented.

5.2 System Architecture

The game comprises three major components. Figure 5.1 provides an abstraction of these components and the relations among them. As shown in this figure, the flow of interaction starts with the player's input which is their webcam video stream. The webcam captures the player's hand/arm movements and passes it on to the image recognition module. The image recognition module then will process the stream as a sequence of images and will recognize hand-shaped objects and track their position in each image and then forward this data in text format to the game's logic module. The game logic reacts to the data received from the image recognition module and provides visual and audio feedback to the player if necessary. If the received data triggers any kind of feedback it will be considered

as an "event". The array of the events are saved at the end of each game session as a reference for game statistics and player's performance.

In parallel with this primary flow, there is a secondary flow of data which results in having the player's webcam stream as the game background in the game's interface for the reasons discussed in the design chapter under game variations - second version.

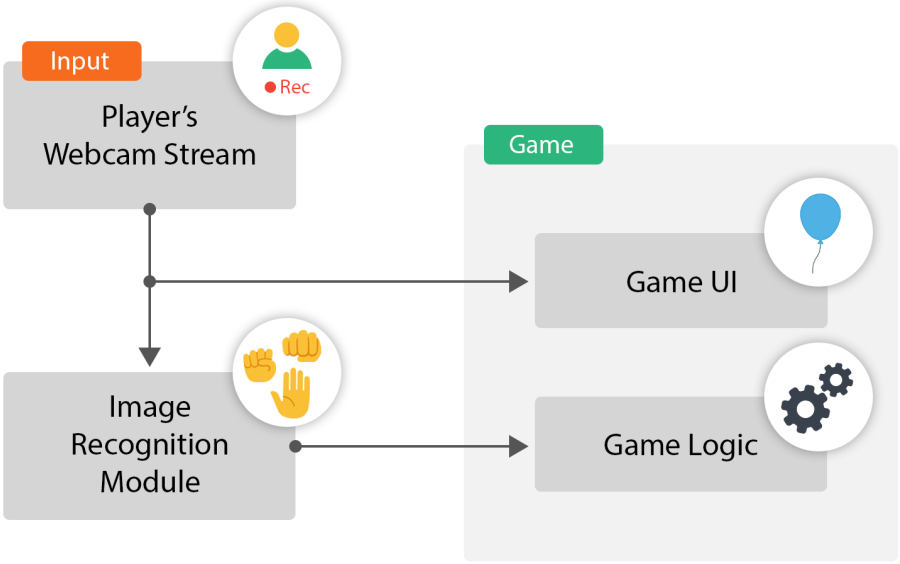

Figure 5.1: POP! Game - System Architecture

5.3 Technologies and Frameworks

Based on the abstract system architecture discussed above and to realize the functionality of each component and the communication amongst them, making use of several technologies and frameworks was unavoidable. In most cases, wiring several different frameworks harm the overall performance, yet, the final and presented setting outperformed several alternative solutions in which fewer frameworks came into play. This was because in those alternative solutions some of the frameworks were being used in ways other than their intended purpose. To give an example, we tried the Augmented Reality solutions in Unity to recognize hand/arm movements. To do so, we used two "marker" objects, one in each hand, and used the marker positions as the indicator of hand positions. In AR terms, markers are the objects that are easy to track with the help of their unique visual features such as the color and the pattern. However, the Unity AR camera and its tracking system were not performing well enough to provide a smooth interaction. It could take up to 5 seconds to recognize the marker for the first time and if the marker was moved out of the

camera frame or was tilted and lost, the player had to wait till the system recognized the marker again and started tracking. Should this solution worked out, Unity would be the only framework needed to cover all the requirements.

Figure 5.2 shows all the modules and their used frameworks involved in the making of the game. We will go into detail for each module in the next section.

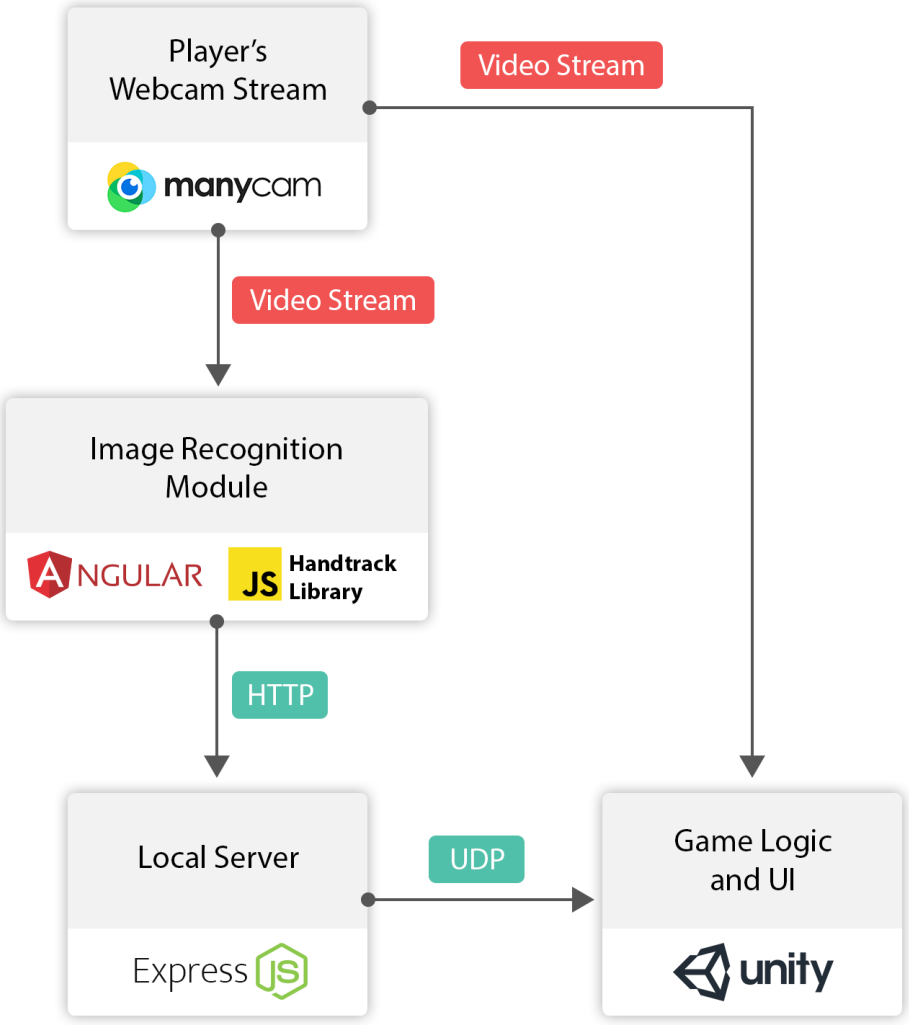

Figure 5.2: POP! Game - Technologies

5.4 Modules

5.4.1 Webcam Stream

The webcam stream is the primary source of input in the game besides a few interactions that are possible with the interface of the game through clicking, such as selecting a game variation from the menu. The webcam stream is not usually considered as a separate module since it can be directly wired to a game. But in our case, we need to transfer the webcam stream to two separate modules: the image recognition module and the game UI. Most conventional operating systems, namely Windows and Mac OS, do not allow for the webcam input to be used in two separate programs simultaneously by default. Therefore, an application called ManyCam is used as a middleware to provide the other two modules with the video stream. ManyCam lets the user define presets with custom webcam settings and the active preset can be used in several programs at the same time.

5.4.2 Image Recognition

An image recognition module is required to parse the webcam stream and recognize the hand/arm positions/movements. For this purpose, a JavaScript library called Handtrack.js is integrated into the game. This library allows for real-time hand detection using the TensorFlow Object Detection API. TensorFlow is a free and open-source machine learning and deep learning platform. Handtrack.js also uses the Egohands dataset [BLCY15] which contains 4800 images with pixel-level annotations that locate the hands. The images are captured from an egocentric view and across 48 different environments.

According to an article by the author of Handtrack library [Dib17], many of the hand tracking solutions in the computer vision domain use rule-based approaches that use the textures, color histograms, and the boundaries to extract features from an image. However, the functionality of these approaches is very much dependent on various factors such as the background and lighting conditions. Training a model with a relatively large dataset can address the challenges of poor lightning and noisy environment, but it can be more complex and expensive to run. Thanks to the lightweight libraries such as Handtrack.js that aim at a single objective, and frameworks such as TensorFlow that provide an easy to access API for model training, we can integrate a well-performing solution with a rather high confidence score into our image recognition module.

Handtrack.js is designed to be directly used in the browser and uses an HTML video element as the input. By default, the library demonstrates the results by drawing bounding boxes around the recognized objects i.e. hands. However, our use case demands a different way of generating and sending out the output. To make the output available for the game module, we wrapped the Handtrack.js library in an Angular JS Web Application that allows for transmitting data over HTTP.

Besides the HTML file containing the video element that we mentioned earlier, there is the App component file which is written in TypeScript and some of its implementation details worth mentioning. First of all, some model parameters in the Handtrack.js library are configurable. These parameters and their definition are to be found in listing 1. The

maximum number of 4 detected objects i.e. hands prevents the module from missing a newly detectable object in case there is already a false positive object like the face of the player detected. The confidence score of 0.6 might sound like a large margin for error, but in fact, it reduces the number of false negatives. In our use case, it is more crucial to minimize the missed objects than to maximize the confidence level.

```
modelParams = {
    flipHorizontal: false, // flip option for the input
    maxNumBoxes: 4, // max number of objects to detect at the same time
    iouThreshold: 0.5, // intersection over union threshold
    scoreThreshold: 0.6, // confidence threshold for predictions
    imageScaleFactor: 1 // scale option for the input
};
```

Listing 1: Handtrack.js - Model Parameters

Once the Handtrack.js library detects a hand-shaped object, the next step would be to interpret this data according to the game's interaction arrangements. To that end, the video frame is divided into 6 boxes, each of which represents one of the "targets" defined in the game (read more about the targets in the design chapter: second phase). When an object is detected in the video stream, the center of its bounding box is calculated in the form of an ordered pair which then will be used to determine whether the object's coordinates fall into one of the target boxes. If it does, a message containing this info will be sent to the game module. Figure 5.3 shows these target areas. The two-letters abbreviations are used to identify the box positions (U, D and S stand for up, down and side. L and R stand for left and right). Given that the video frame size is 960x540 pixels, the ordered pair in each box shows the coordinates of the center point of that box.

An Angular Service using the HttpClient module is injected into the app to send the HTTP requests to the local server.

5.4.3 Local Server

The reason behind having a local server is to facilitate the connection between the image recognition module which is a web app and the game itself which is implemented in Unity. Since the essence of connection in these two platforms is fundamentally different, the suitable data transmission protocol with which they are compatible also varies. A web app is well-fitted with a reliable transmission protocol such as HTTP. On the other hand, a connection-less communication model such as UDP is more proper for a gaming framework in which the speed has more importance than the rate of packet loss. We refer to this module as a server, but in fact, it is used as a server for the image recognition module and as a client for the game module.

This very light-weight module is implemented in a Node.js web application framework called Express. As shown in the listing **??** in the appendix, port 3000 is dedicated to the HTTP connection and port 2000 is used for UDP data transmission.

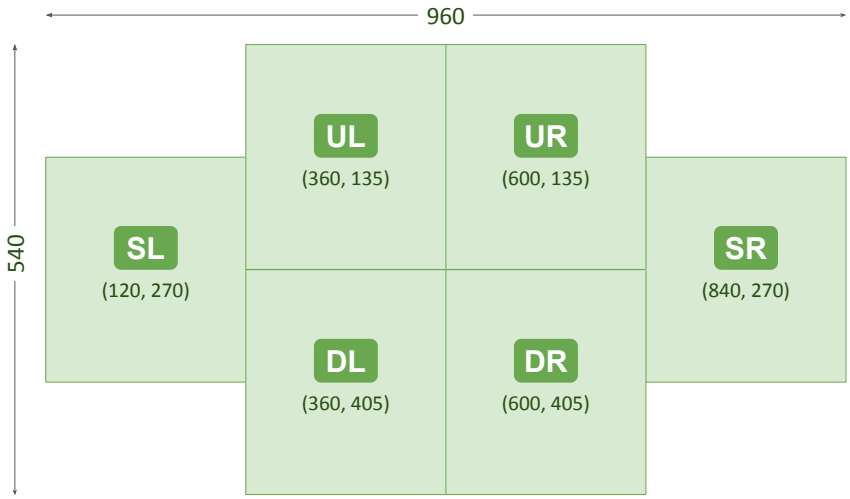

Figure 5.3: Hand Tracking - Target Areas

5.4.4 Game Logic and UI

The game module is entirely implemented in Unity but can be semantically divided into distinct sub-modules. We will briefly discuss each of them in the following sections.

UDP Receiver

Following the above discussions on transmitting the data, some details on implementing the UDP receiver in Unity is noteworthy. A UDP socket listening on port 2000 is set up to receive, enqueue, and forward the messages to the game scene. All of the game scenes have an object called "universe" which receives and reacts to the messages. This setup lets us create and use one socket throughout the game session without the need to bind and close the socket at the beginning and the end of each game scene. Listings 3 and .5 in the appendix provide more details on this matter.

Game Background

As discussed in the design chapter, the second version of the game is featured with the player's webcam stream as the background layer of the game. To make this possible, an object of the type "RawImage" is used in the game scenes, and an input of the type "WebCamTexture" is set as its texture. Quoting from Unity's documentation, webcam textures are textures onto which the live video input is rendered. WebCamTexture can take in a so-called "device" as an argument and in our case that device should be set to the "ManyCam" application. The streaming of the live video should get started at the beginning of each game scene and be stopped when it ends. More information on the implementation of the live background can be found in the listing 4 in the appendix.

Game Logic and Parameters Configuration

The logic of the game is straightforward: the balloon objects get created in real-time using pre-made prefabs, they may or may not be animated depending on the scene, and they can be popped upon the player's actions. What makes a difference in the gaming experience in such a simplistic game, are the details. By setting various game parameters we define game behaviors such as the speed of balloon movements when to generate the next balloon and the likelihood of generating a balloon of the right color. Some of these parameters are shown in the listing .7 in the appendix. The value of most of these parameters cannot be calculated accurately therefore we try different values and compare the experiences to find out which value fits best.

Game Data

Since the player's performance is of interest to our study, it is required to save the game data for further analysis. This data includes both the game's generated values and player's actions. It is obvious why we need to save the player's actions, but it is also important to have the context in which the player's inputs should be interpreted, hence the randomly generated values in the game should be saved as well. We use JSON format to save these data as a set of events at the end of each game session. An example of a game session's data can be found in listing .8 in the appendix.

5.5 Remote Version

As explained previously, major changes were applied in user research regulations due to the Coronavirus pandemic. Essentially, all the on-site user tests were to be avoided until further notice. Initially, we attempted to integrate the original version of the game with a video conferencing tool to make the remote testing possible, however, as it turned out, this was not the most practical solution considering the additional routes required for transferring the player's video stream.

The top priority in developing the remote version of the game was to provide a smooth player experience despite the hurdles of online communication. Therefore, it was decided to improve the performance in remote testing by reducing the number of modules and cutting the back and forth amongst them.

There is a method in HCI, called "the Wizard of Oz", that enables a researcher to conduct an experiment in which a certain functionality, that is perceived to be automatic by the tester, is being operated by an unseen human being. Applying this approach to our use case would result in replacing the hand tracking module with manual input from the test conductor. By doing so, we only needed to keep the Unity module and were able to improve the performance of the game.

5.5.1 Remote Test Setting

The tricky part in setting up a remote test was to receive the player's webcam stream, use it as the background of the game, and send it along with other objects of the game back to the player to complete the loop. This flow of streams became possible by using the screen-sharing feature of the Jitsi video conferencing tool and screen capture feature of ManyCam application. The game was also updated to receive inputs via keyboard keys. In this way, the test conductor could watch the players' webcam streams and operate the game based on their movements using the keyboard. 6 keys were used to represent 6 defined movements a player can perform in the game.

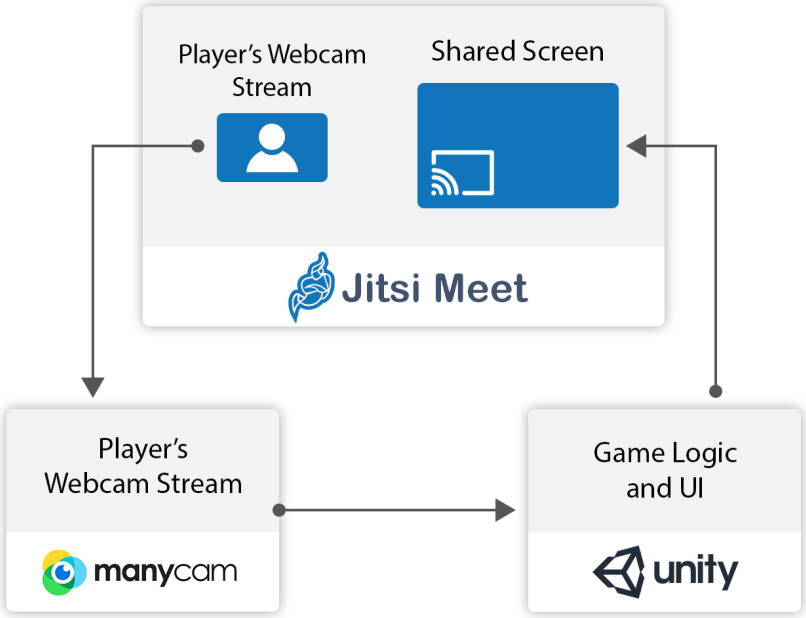

Figure 5.4: Remote Version Setup

6 Evaluation

6.1 Hypotheses

After defining the challenges in detail and designing the final game, the hypotheses that were mentioned before (section 4.3.1: Research Goals, Factors, and Measure) can be revisited once more. We have already established that the goal of this study is to find the prime type and level of challenge to create an engaging experience for the players. In order to do so, we need to find out whether and to which extent each type of challenge would affect the game engagement.

Before stating the hypotheses, it would be helpful to note the dependent and independent variables concretely:

- Dependent variable: Engagement / Engagement indicators
- Independent variable: Type of the challenge
  - Motoric challenge (limited time for reaction)
  - Cognitive challenge (color recognition)
  - Mixed challenge (motoric and cognitive)
  - None

Concerning the dependent and independent variables mentioned above, the primary hypotheses are defined as follows:

Hypothesis I: Subjective Experience - Challenge Effect

According to the flow theory, the type of challenge influences the subjective engagement of the player with the game.

Hypothesis II: Objective Experience - Challenge Effect

According to the flow theory, the type of challenge influences the objective engagement of the player with the game.

The methods to measure engagement will be different for subjective and objective experiences and we will discuss this more in the next section. We will derive a secondary hypothesis for each challenge type. In sections 7.2 and 7.3 we state the secondary hypotheses and whether they are accepted or rejected based on the data we gathered during the experiment.

6.2 Experiment Design

6.2.1 Method

An experiment was designed to measure the impact of challenge type on various engagement indicators. The goal was to design an experiment that would allow for evaluating the engagement both subjectively and objectively. We were also interested in exploring interaction patterns qualitatively and extracting research questions for further investigations.

For subjective evaluation, a questionnaire was used and the testing sessions were video recorded to be analyzed objectively after the test. Due to the characteristics of the target group related to their age, there were some limitations on the methods that we could use for evaluation. These methods are discussed in detail in the Measurement Tools section.

6.2.2 Setting and Procedure

Due to the circumstances mentioned earlier, on-site playtesting and interviews were not possible and we conducted the user research remotely and via Jitsi video conference tool. To do a remote test, a laptop or personal computer equipped with a webcam and a microphone plus a stable internet connection was required on the participants' side. As mentioned earlier, the test sessions were video recorded for further analysis.

To start the experiment, the conductor would initiate a Jitsi Meet and set a password, then send the link and the password to the participant. The conductor would begin the next step once the participant joined the meeting. The conductor would ask if the parent(s) has any questions before starting the study, and if it is okay to begin the video recording.

To start the playtest, the conductor would ask the child to sit in front of the PC/laptop in order to play the game. At this point, the conductor would set the participant's webcam stream as the game input stream so that the game shows participant's video stream in the background, behind the balloons. The conductor would also share her screen with the participant using the screen sharing feature in Jitsi Meet. At this point, the participant is able to see the game screen which has their own live picture as the background.

The conductor would ask the participant or their parent to adjust the webcam's position so that the player would be placed in the center of the screen, and their hands would reach the edges of the frame if stretched. The conductor would then start the calibration phase of the game. The calibration phase had the easiest playing mode and no limits on timing, so that the player could play freely and under no pressure until they learn how the game should be played. The conductor would then clearly explain and demonstrate how the game works, emphasizing on the hand movements and how to perform them in order to interact with the game: The goal of the game is to pop the balloons that appear on the screen by moving the arms/hands towards the balloon's position. The movements include arms stretched upward, arms stretched forward, and arms stretched to the sides.

The calibration phase could take longer depending on how well the participant was playing the game. The game is designed in a way that the player should touch the

balloons - but in an indirect way and through the game background which displays the webcam stream of the player. That means that the player should not try to touch the screen, instead, they should try to move in a way that the projection of their hands touches the balloons, similar to having an avatar in a video game. (Figure 6.1) Making this indirect connection might not be easy to understand for a child, but that also counts as an interesting finding.

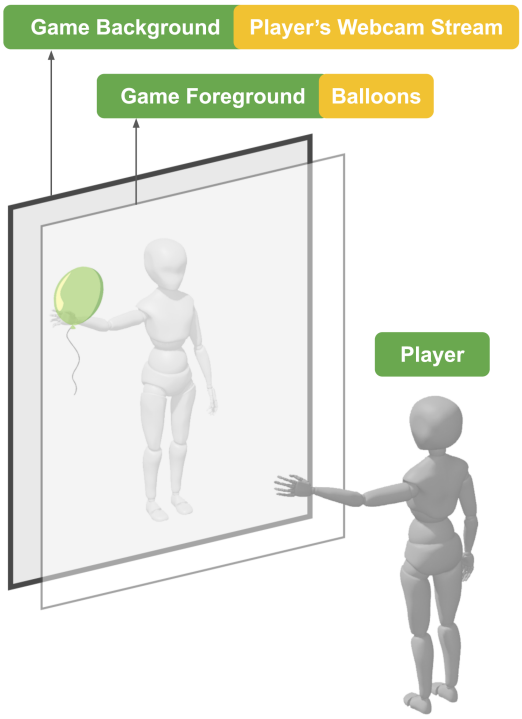

Figure 6.1: Play Setting

Once the participant felt comfortable enough to play the game, the conductor would give a short explanation on how the 1st variation of the game differs from calibration mode, and then start the 1st variation of the game once the participant is ready. After the 1st variation, the conductor asked if the participant is ready to play the next variation, and would repeat these steps for all 4 variations of the game.

Once the player finished playing all 4 variations of the game, the conductor would share the questionnaire on the screen and ask the questions one by one and note down the answers. The experiment would be complete when all the questions were answered.

6.2.3 Participants

Although the final goal of this study is to help with the training programs for children with cerebral palsy, we can test this game with healthy children since the goal of this stage

is to measure the engagement. This decision helped us in reducing the work needed for getting the ethics board approval and increasing the chances of finding more volunteer participants.

Children of a young age experience rapid physical and cognitive development and their skills level up accordingly. However, we decided to include the children of age 4 to 10 in the test to get the full picture. Due to the scale of this thesis and the limited number of participants, we could not run any age-specific research and analysis, but we kept an eye open for qualitative findings and possible patterns about participants' age.

Since the players in our target group were minors, their parents' formal consent was needed as well as the children's verbal consent. For the same reason, we had to submit a full user research proposal to the university's ethics board to get the test plan approved. The proposal and the ethics board's positive vote can be found as an index to this thesis. Before the test session, the signed consent form and the filled personal code form were received by the test conductor.

11 participants were recruited for the test, of whom 4 were girls and 7 were boys. Their age distribution is shown in figure 6.2.

The test was conducted remotely, so there was no limitation on the participants' place of residence. To eliminate the language barriers and facilitate the recruitment process due to better connections, the participants were recruited from the author's home country, Iran.

The participants were recruited through personal contacts and social media channels. A small gift card was given to the participants at the end of the test.

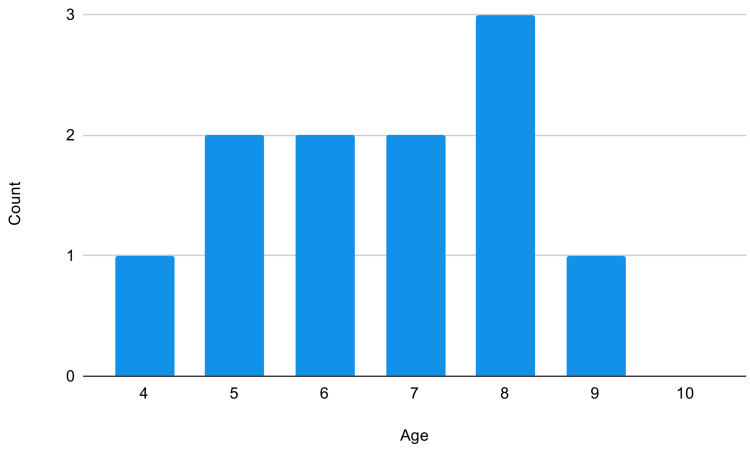

Figure 6.2: Participants' Age Distribution

6.2.4 Measurement Tools

Self-Reported Engagement

One of the challenging topics in researching with children is a subjective evaluation. To make the questions as easy to understand as possible, avoiding hypothetical and conceptual questions are crucial. On the other hand, asking concrete and exemplary questions might cause biases that are tied with concrete details. We chose to maintain the balance between the two sides of this trade-off by including visuals in framing the questions. These visuals helped us in simplifying the questions' wording and minimizing the biases caused by differences between individual imaginations. These visuals present a rather generic example and magnify the factor that is the subject of the question.

We used a method called "This or That", which is a paired-preference testing tool, in designing the questionnaire. According to [ZVADG13], This or That resulted in reliable and valid responses in preschool children aged 4 and older for measuring preferences across entertainment products. In this method, the participant chooses their preferred option among two, and their response can be interpreted as ranked data. 4 This or That questions were asked in the questionnaire to compare different game variations. We also included a question using the "Smileyometer" method to ask about participants' general opinions on the game as a whole. The questionnaire is attached as a part of the ethics proposal annex for reference.

Attention-Based Engagement

To evaluate the engagement of the player objectively, the user study sessions were video recorded to be analyzed based on involvement factors as listed in table 6.1. This list of factors was inspired by a study by Norris et. al [NWBB14] on quantifying engagement in games.

Factor	Value = 5 points	Value = 1 point
Altercentrism	Focused	Distracted
Smiling	Much smiling	No smiling
Composure	Much body movement	Minimum body movement
Posture	Leans toward	Leans away
Vocal expressiveness	Expressive	Inexpressive
Use of hands	Bi-manual	Uni-manual

Table 6.1: Attention-Based Engagement: Involvement Factors

6.2.5 Limitations

Given the age of our participants, a degree of inaccuracy was expected in subjective evaluation. Conceivably, older children seemed to be more confident in answering the questions than the younger ones. This or That method made it possible for us to compare variation pairs easily, however, having 4 questions of the kind seemed to be cognitively demanding for smaller children. We also observed a few cases in which the child tended to always choose the second given option, or choose the option that was given in the previous questions but had not been chosen. There was also one response in which we sensed a bias caused by the visual details, where the child responded with "the red ones", as it was presented in the variation screenshot.

The remote test setting was the cause of other testing limitations. Not being physically present in the test environment resulted in the conductor's limited control over environmental factors, such as how much the parents were interfering with the test. There were multiple cases in which the parents were giving verbal guidance and a few cases in which the parents were moving the children's hands to teach them or help them in playing. The conductor could have prevented such interference should they had been on-site.

7 Results and Conclusion

7.1 Statistical Methods

Due to the limited number of participants, no distributional assumption such as normal distribution could be satisfied. Therefore, non-parametric methods which do not require distributional assumptions are used to analyze the data gathered from the user research. Non-parametric methods are also widely used when data have a ranked order but no numerical interpretation, such as in the Likert scale method that we used for analyzing the video recordings, and in the "this or that" method that we used for assessing preference.

There are different non-parametric methods to be used based on how the experiment was designed. Our participants were exposed to every condition and we tested all 4 variations of the game with each of them, therefore we have related samples (as opposed to independent samples). Non-parametric methods also vary depending on the number of different treatments (K). Each of the questions in our questionnaire is a comparison between two game variations, therefore, in this case, K is equal to two, and Wilcoxon signed-rank test can be used to analyze the subjective data. To analyze the objective data, we ranked all 4 game variations for each involvement factor. This means that in this case K is equal to four and Friedman's 2-way test (all pairwise) would be a fitting choice.

In the following sections, we first state the results of the data analysis for both subjective and objective experiments, and then summarize the key findings and discuss how the results can be interpreted or explained. All the calculations in this chapter were carried out with the help of the SPSS Statistical Analysis tool.

7.2 Analysis of the Subjective Experience

A Wilcoxon signed-rank test was conducted for each of the 4 questions from the questionnaire. We ranked the data by assigning a value of "1" to the preferred game variation and a value of "0" to the remaining game variation for each paired comparison. The results of the tests are shown in table 7.1. Each row of this table shows the result of the subjective comparison between two game variations in response to this question: "which variation was more fun to play?". The second column shows which pair of variations were referred to in the corresponding question. In each pair, there is one condition that is featured in both of the variations (stated in the "fixed condition" column), and another condition that is specific to one of the variations (stated in the "treatment" column). For example, in both variations 1 and 2, the player can pop all the balloons regardless of their color, but, an additional motoric challenge exists in variation 2 which makes it different from variation 1.

The hypothesis here is that the additional challenge type (treatment condition) affects the perceived engagement, and the null hypothesis is that there is no statistically significant difference in the perceived engagement between the two variations.

As shown in the table, we only observe a significant difference in the perceived engagement between variations 3 and 4. In both of these variations, the player has to pop the balloons of a specific color, meaning that a cognitive challenge is present in both of them. In variation 3 the balloons' positions are fixed, and in variation 4 the balloons move from the bottom of the screen towards the top. Our participants enjoyed playing variation 4 more than variation 3, which in other words can be stated as:

"A game variation that is featured with a mixed challenge (cognitive and motoric) is more fun to play than a game variation that is only featured with a cognitive challenge".

Q#	Compared pair	Fixed condition	Treatment: Challenge type	P Value	Decision
Q1	V1-V2	All colors	Motoric	0.366	Retain the null hypothesis
Q2	V1-V3	Fixed balloons	Cognitive	0.763	Retain the null hypothesis
Q3	V2-V4	Moving balloons	Cognitive	0.763	Retain the null hypothesis
Q4	V3-V4	One color	Motoric	0.035	Reject the null hypothesis

Table 7.1: Questionnaire Data Analysis

The results of the Wilcoxon signed-rank test (positive and negative differences) for each of the pairs are shown in figure 7.1.

We also asked the participants to rate their overall gaming experience. The question was "how would you feel if you receive this game as a present?", and we used 5 smileys as the response options. The frequency of participants' responses is displayed in figure 7.2.

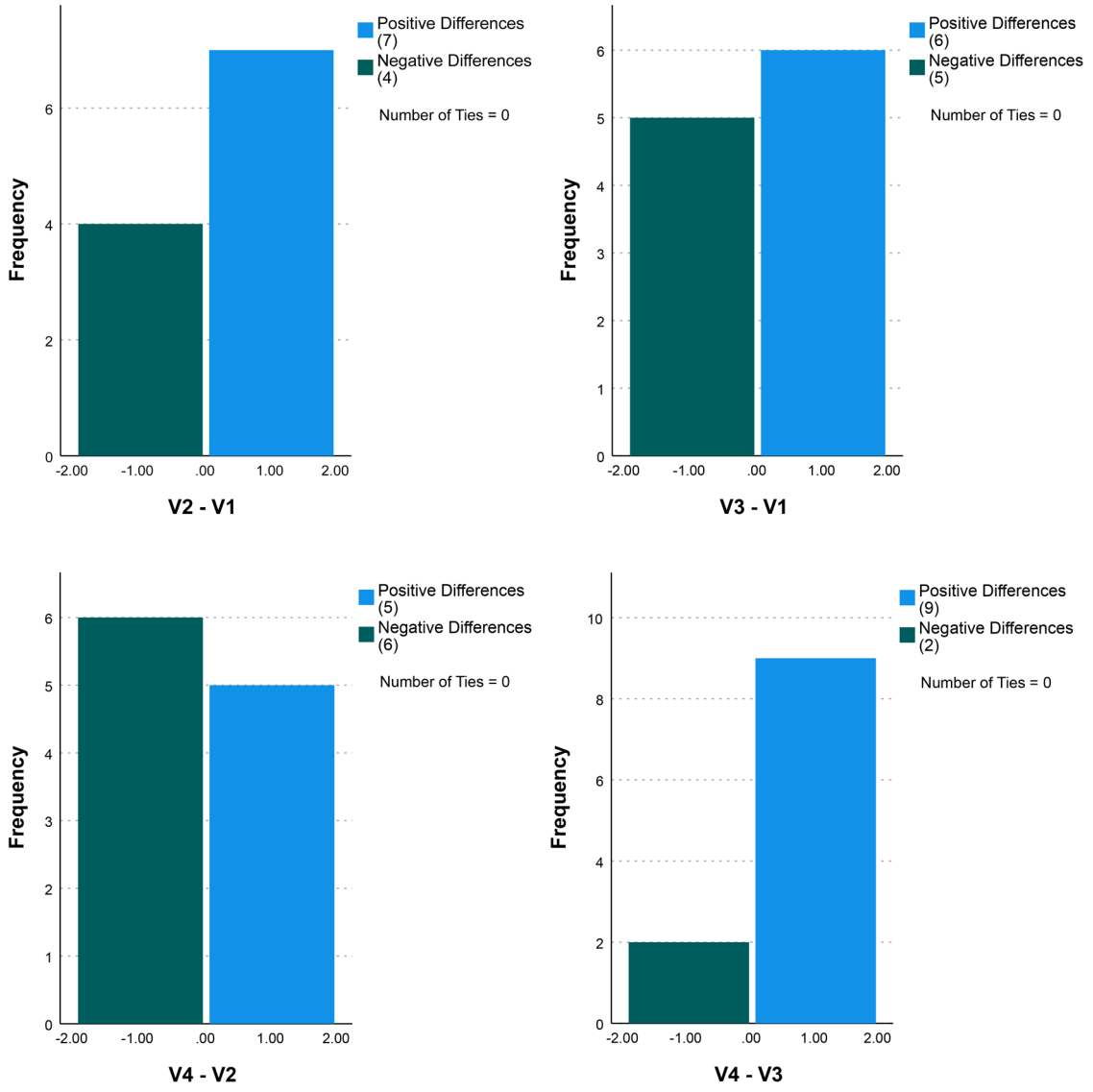

Figure 7.1: Related-Samples Wilcoxon Signed Rank Test

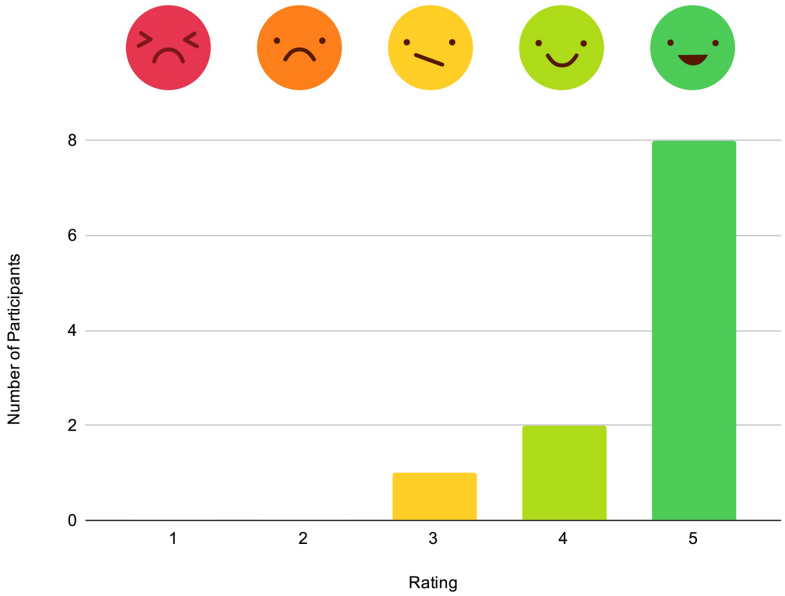

Figure 7.2: Frequency of Game Ratings

7.3 Analysis of the Objective Experience

We ranked the game variations by analyzing the video recordings and assigned a value from 1 to 5 to each game variation, for each of the participants and each of the involvement factors. A Friedman 2-way test was then conducted for each of the involvement factors between four game variations. In the case of observing a significant difference in the Friedman test, it will be followed by a pairwise test. The pairwise test will determine which pair or pairs are significantly different from each other.

The hypothesis here is that the challenge differences (treatment condition) affect the objective engagement, and the null hypothesis is that there is no statistically significant difference in the objective engagement between the four variations.

After the first round of rating the videos, and to avoid any biases caused by the order of watching the videos, we re-watched them and edited the ratings if necessary. In the following lines, we will go through the involvement factors one by one.

7.3.1 Altercentrism

All the game variations were rated for each participant based on how focused they were during playing the corresponding game variation. Focused gameplay would be rated with 5 points, and gameplay including frequent gazes would be rated with 1 point.

There were a few cases in which the gameplay was rated with fewer points than 5, and all the participants seemed to be completely focused on the game regardless of the variation and the type of the challenge. It is no surprise than the Friedman test also shows no significant difference between the variations in regards to altercentrism (P = 0.112).

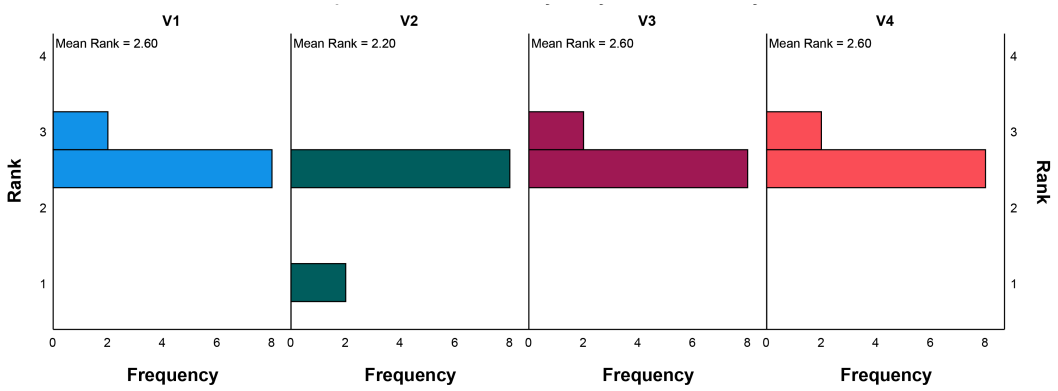

Figure 7.3: Involvement Factor: Altercentrism
Related-Samples Friedman's Two-Way Analysis of Variance by Ranks

7.3.2 Smiling

We rated the game variations according to the facial expressions of the player. A neutral face would be rated with 1 point, and a constantly smiling face would be rated with 5.

Slightly smiling faces and occasional smiles would result in 2, 3, or 4 points depending on its extent or frequency.

The result of the Friedman test shows a significant difference (P = 0.008), and the post-hoc pairwise test shows that this difference is between V2 and V3 (P = 0.019), with V2 having the higher rank.

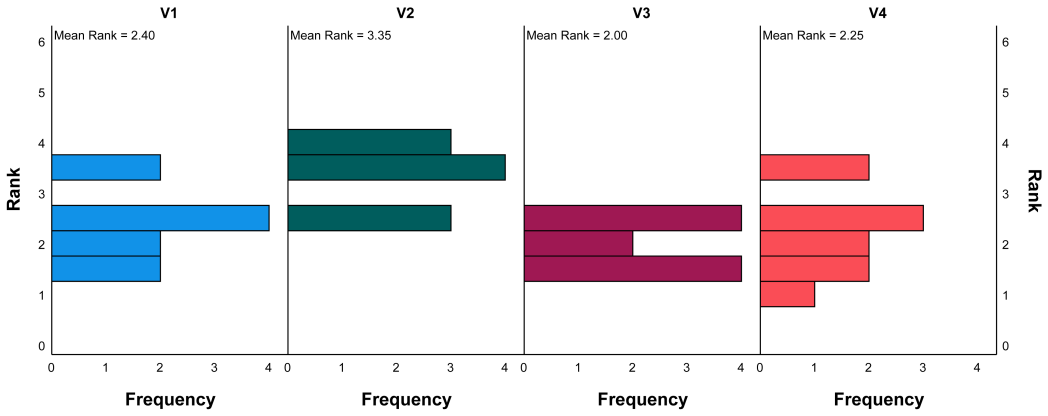

Figure 7.4: Involvement Factor: Smiling
Related-Samples Friedman's Two-Way Analysis of Variance by Ranks

7.3.3 Composure

The game variations were ranked based on the amount of player's body movements. If the body movements were just enough to play the game, it was ranked with 1 point. Any additional movement in the body, arm or hand would increase the rating: Some of the participants were moving their hands rapidly and in all directions regardless of the positions of the balloons; There were also some cases where the participants adjusted their sitting position a couple of times during playing; All of these and other similar cases were considered as additional body movements.

The Friedman test shows no difference between the game variations in regards to composure (P = 0.362).

7.3.4 Posture

Although the best way to play the game is to sit up straight to have the full agency of the hands, leaning toward the screen can be an indicator of engagement. We ranked the game variations based on participants' posture: leaning toward 5 points, sitting straight 3 points, and leaning away 1 point.

The result of the Friedman test shows a significant difference (P = 0.035), and the post-hoc pairwise test shows that this difference is between V2 and V3 (P = 0.038), with V2 having the higher rank.

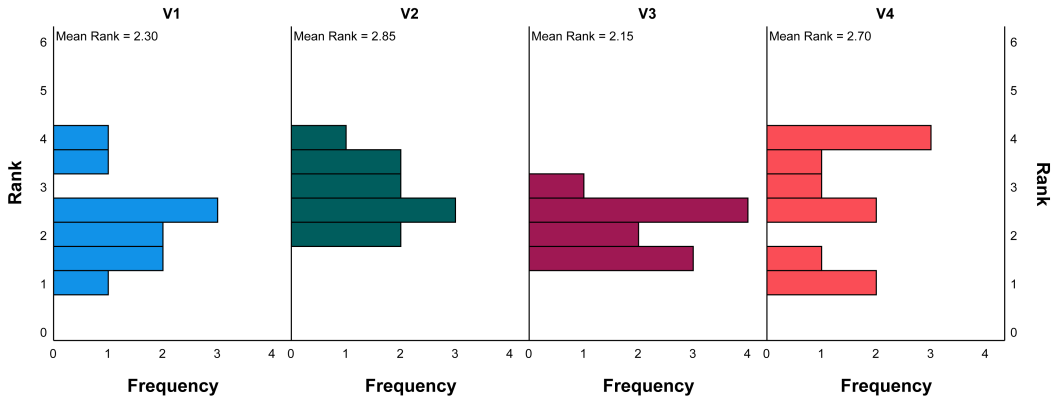

Figure 7.5: Involvement Factor: Composure
Related-Samples Friedman's Two-Way Analysis of Variance by Ranks

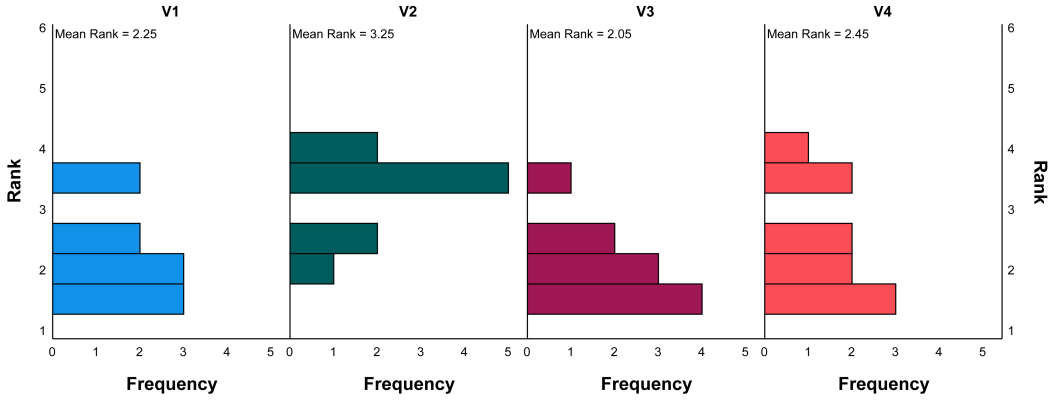

Figure 7.6: Involvement Factor: Posture
Related-Samples Friedman's Two-Way Analysis of Variance by Ranks

7.3.5 Vocal Expressiveness

Most of the participants did not make a single sound while playing. However, there were a few cases in which the player made some sounds and the corresponding variations were rated with more than 1 point. The Friedman test shows no significant difference between game variations in regards to vocal expressiveness ($P = 1.000$).

7.3.6 Use of Hands

The training and the exercises are most effective if the players practice using both of their hands, preferably according to the position of their object of interest. Without enough training, the players would tend to use their dominant or healthy hand more often. We ranked the game variations based on the players' use of hands by giving 5 points in case of playing bi-manually and giving 1 point in case of playing uni-manually.

The result of the Friedman test shows a significant difference ($P = 0.032$), and a post-

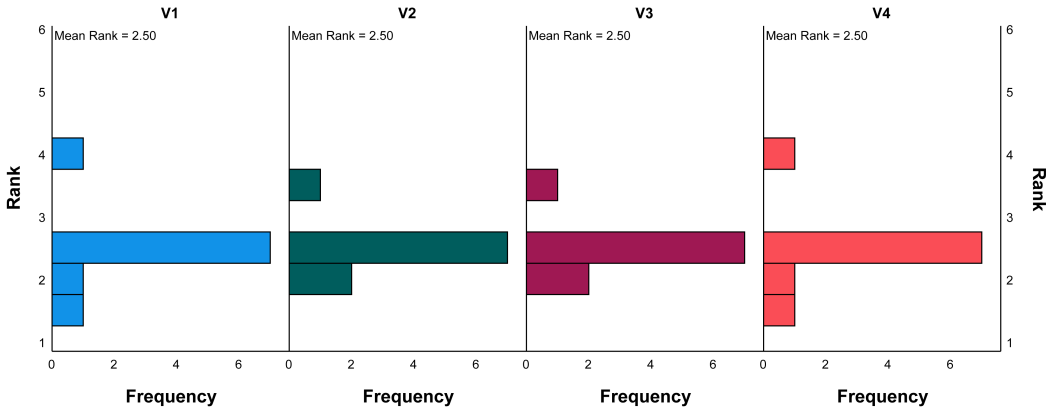

Figure 7.7: Involvement Factor: Vocal Expressiveness
Related-Samples Friedman's Two-Way Analysis of Variance by Ranks

hoc pairwise Wilcoxon signed-rank test shows that the difference is between V1 and V4 (P = 0.046), with V1 having the higher rank.

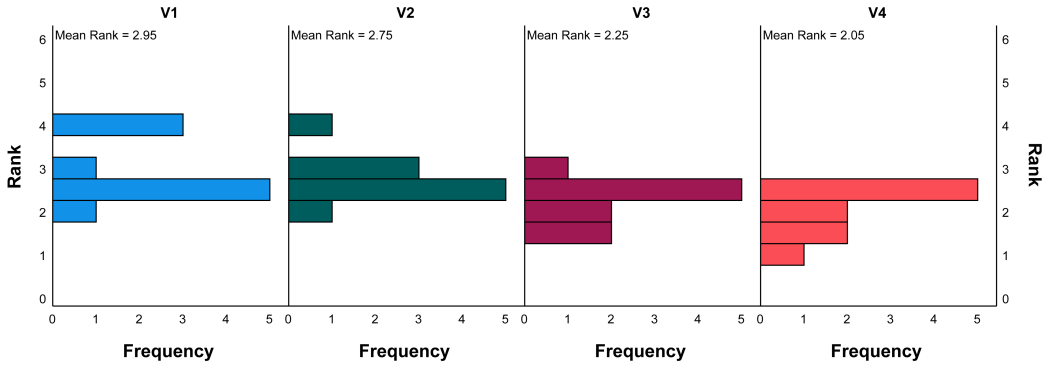

Figure 7.8: Involvement Factor: Use of Hands
Related-Samples Friedman's Two-Way Analysis of Variance by Ranks

7.4 Key Findings and Discussion

As shown in table 7.2, we were able to confirm a significant difference concerning various engagement measures in 3 of the pair comparisons. Interestingly, the game variation that showed a lower level of engagement in all 3 of them was game variation 3, which is featured with a cognitive challenge (color recognition) and includes no motoric challenge. In other words, all the 3 findings that are concerned with measuring engagement suggest that a motoric challenge positively influences the engagement.

Type	Pair	Independent variable	Dependent variable	Finding
Subjective	V3-V4	Cognitive challenge vs. Mixed challenge	Perceived engagement	Motoric challenge positively influences the perceived engagement
Objective	V2-V3	Motoric challenge vs. Cognitive challenge	Observed engagement (Smiling)	Motoric challenge positively influences the observed engagement
Objective	V2-V3	Motoric challenge vs. Cognitive challenge	Observed engagement (Posture)	Motoric challenge positively influences the observed engagement
Objective	V1-V4	No challenge vs. Mixed challenge	Use of both hands	Mixed challenge negatively influences the use of both hands

Table 7.2: Summary of all the confirmed hypotheses

The results show that V2 was significantly more fun to play than V3, as the participants were leaning forward and smiling more. No cognitive challenge was included in V2, but it featured moving balloons to encourage extra physical effort in a shorter time. This finding can be explained by the fact that an exergame, regardless of its theme, requires some form of physical activity, therefore an extra physical challenge is more compatible with the gameplay's nature. Conversely, adding a cognitive challenge that limits the physical activity (such as popping only 1/3 of the balloons that are of a specific color) is in contrast with the main engagement element of an exergame.

We added the use of hands variable to our list of behavioral analysis factors after conducting the tests, as we observed a pattern that could be investigated using the gathered data. The results show that the participants tended to use their both hands when there was neither motoric nor cognitive challenge involved (V1), as opposed to using only their dominant hand when the game is featured with both kind of the challenges (V4). This might be related to the fact that in our test V1 came right after the calibration phase where the participants were encouraged to use both of the hands. In addition to that, this can be because V4 requires high precision as well as fast reaction, therefore using only the prominent hand would be the easier way of playing.

We also observed that a few of the younger children had a bit of difficulty understanding the indirect connection between their hands, the image of their hands in the webcam video stream, and the balloons' positions. It seemed to be unclear to them that the balloons would only pop if the image of the hand overlapped with the balloon, and therefore they could not aim their movements accurately. This was, however, not a blocking issue and could be solved with more guidance and practice.

7.5 Future Work

There have been many ideas that could not be adapted and tried during this thesis, due to the time and scope limitations. Starting with the most impactful ones, the game interaction design itself could be improved by updating the movement recognition module. Since the implemented module was only capable of recognizing the hands' position at a certain point in time, and not relative to the previous positions, we could not track the exercises as a whole. For effective training however, it is crucial for the game to only accept the movements that are rightly done.

In terms of research, it would be beneficial to carry age-specific tests to gain a more accurate understanding of the proper challenge difficulty for each of the sub-groups. It would be also interesting to see how the players would react to different levels of difficulty in the same gameplay.

Concerning the evaluation methods, we believe that there is much room for improvement with regards to subjective measures. We observed a degree of randomness and uncertainty in questionnaire responses that was due to the age of our participants. A deeper investigation in children-specific measurement methods is recommended for any future work.

Conducting a remote experiment did not seem to affect the participants' engagement with the game, but it resulted in a less smooth learning phase. Should the conductor was able to demonstrate how the game is played in a better way, we might had seen shorter learning times and better performances.

All in all, we observed the participants having fun despite the simplicity of the gameplay. Our approach in gamifying physical exercises proved to be working, and the direction we took in identifying the prime type of challenge appeared to be right since the experiment resulted in meaningful outcomes.

Other ideas for further work include adaptive difficulty, personalized experience, different exergame themes, different kinds of cognitive challenges, and multi-session user research.

7.6 Conclusion

This thesis was concerned with the first steps of making a part of the physical rehabilitation program more accessible and playful for children with cerebral palsy. To address that, an exergame was designed to combine physiotherapy exercises with motivational elements. Multiple variations of this exergame featuring different kinds of challenges were compared with each other, both subjectively and objectively. The results of these comparisons suggest that between motoric and cognitive challenges, motoric challenges positively impact the flow experience. The game, as a whole, showed promise in terms of engagement, and we believe that we will see more of similar attempts in rehabilitation games in the future.

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Annex

.1 Thesis Topic Approval

Masterarbeit

Technische Universität Berlin

Fakultät V Verkehrs- und Maschinensysteme
Institut für Maschinenkonstruktion und Systemtechnik
Fachgebiet Medizintechnik
Prof. Dr.-Ing. Marc Kraft

Für
Frau Shamim Karimigolpayegani
Matr.-Nr. 406032

Topic: A sensor-assisted exergame for training the hand and arm function in CP children

The purpose of treatment for cerebral palsy is to promote the most normal and healthy life possible. Physical therapy is one of the most important parts of treatment and it involves exercises and activities that can help children of all ages to (re) establish their motor function. The sharki project aims to foster physiotherapy exercises in everyday life through games and motivational feedback, by providing an interactive wearable system for monitoring and provision of feedback on posture and upper movements.

This Master Thesis is aimed to design and develop a serious game/exergame with the goal of bilateral/unilateral training for CP children. The proposed design includes physical activity as a means of interacting with the game to achieve training goals, as well as engaging game attributes to keep the child motivated. The interactions are designed according to physical and cognitive constraints based on children's age group and the degree of difficulty in movement. In this Thesis we try to broaden the field of designing exergames with rehabilitation purposes by following a user centered design approach, evaluating the results by conducting user studies, and publishing the findings about applied design guidelines and potentially new design suggestions.

The work is divided into the following tasks:

- Familiarization with the topic through literature review
- Defining the research question and analysing the requirements
- Ideation of the research question and designing the mock-up
- Translating the approved design of the mock-up into a prototype
- Conducting a user study in order to evaluate the usability of the prototype
- Analysing the data from user study, summarizing the findings and presenting the results

The work will be supervised by Dipl.-Des. Katharina Lorenz. One copy of the elaboration remains with the medical technology department. After completion of the thesis, a lecture is to be held and an abstract in English is to be prepared.

Berlin, 25.02.2020

Prof. Dr.-Ing. M. Kraft

.2 Thesis Title Change Approval

Masterarbeit

Technische Universität Berlin

Fakultät V Verkehrs- und Maschinensysteme
Institut für Maschinenkonstruktion und Systemtechnik
Fachgebiet Medizintechnik
Prof. Dr.-Ing. Marc Kraft

Für
Frau Shamim Karimigolpayegani
Matr.-Nr. 406032

Topic: Design and Implementation of a Rehabilitation Exergame for Physically Impaired Children

The purpose of treatment for cerebral palsy is to promote the most normal and healthy life possible. Physical therapy is one of the most important parts of treatment and it involves exercises and activities that can help children of all ages to (re) establish their motor function. The sharki project aims to foster physiotherapy exercises in everyday life through games and motivational feedback, by providing an interactive wearable system for monitoring and provision of feedback on posture and upper movements.

This Master Thesis is aimed to design and develop a serious game/exergame with the goal of bilateral/unilateral training for CP children. The proposed design includes physical activity as a means of interacting with the game to achieve training goals, as well as engaging game attributes to keep the child motivated. The interactions are designed according to physical and cognitive constraints based on children's age group and the degree of difficulty in movement. In this Thesis we try to broaden the field of designing exergames with rehabilitation purposes by following a user centered design approach, evaluating the results by conducting user studies, and publishing the findings about applied design guidelines and potentially new design suggestions.

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Berlin, 25.02.2020 *(necessary adjustment of title/topic only!)*

Prof. Dr.-Ing. M. Kraft

.3 Code Snippet: Local Server

```
// UDP CLIENT ----------------------------------------

var HOST = '127.0.0.1';
var PORT = 2000;
var dgram = require('dgram');
var client = dgram.createSocket('udp4');

// HTTP SERVER ----------------------------------------

app.listen(3000, () => {
    console.log('Server started.')
})

app.route('/').post((req, res) => {
    res.sendStatus(200);
    var message = new Buffer.from(req.body.message);
    client.send(message, 0, message.length, PORT, HOST,
      function(err, bytes) {
        if (err) throw err;
        console.log('UDP message sent.');
      });
})
```

Listing 2: Express.js - UDP client and HTTP Server

.4 Code Snippet: Unity UDP Socket

```
public class UDPSocket
{
    ...

    public void Bind(string address, int port)
    {
        _socket.SetSocketOption(SocketOptionLevel.IP,
        ↪  SocketOptionName.ReuseAddress, true);
        _socket.Bind(new IPEndPoint(IPAddress.Parse(address), port));
        Receive();
    }

    private void Receive()
    {
        _socket.BeginReceiveFrom(state.buffer, 0, bufSize, SocketFlags.None,
        ↪  ref epFrom, recv = (asynchResult) =>
        {
            State so = (State)asynchResult.AsyncState;
            int bytes = _socket.EndReceiveFrom(asynchResult, ref epFrom);
            _socket.BeginReceiveFrom(so.buffer, 0, bufSize, SocketFlags.None,
            ↪  ref epFrom, recv, so);
            UDPReceiver.taskQueue.Enqueue(new
            ↪  UDPReceiver.Task(Encoding.ASCII.GetString(so.buffer, 0,
            ↪  bytes)));
        }, state);
    }

    ...
}
```

Listing 3: Unity - C# - UDP Socket Class

.5 Code Snippet: Unity UDP Receiver

```
public class UDPReceiver : MonoBehaviour
{
    public GameObject universe;
    public static Queue<Task> taskQueue = new Queue<Task>();
    UDPSocket receiver;

    void Start()
    {
        receiver = new UDPSocket();
        receiver.Bind("127.0.0.1", 2000);
    }

    void Update()
    {
        if (taskQueue.Count > 0)
        {
            universe.SendMessage("OnMovement",
            ↪  taskQueue.Dequeue().GetMessage());
        }
    }

    public void CloseSocket()
    {
        receiver.CloseSocket();
    }

    public class Task
    {
        readonly string message;
        public Task(string message)
        {
            this.message = message;
        }

        public string GetMessage()
        {
            return message;
        }
    }
}
```

.6 Code Snippet: Unity Live Video Stream Background

```
public class WebcamStream : MonoBehaviour
{
    public RawImage background;
    WebCamTexture webCamTexture;

    void Start()
    {
        WebCamDevice[] devices = WebCamTexture.devices;

        // setting default camera
        webCamTexture = new WebCamTexture(devices[0].name);

        for (int i = 0; i < devices.Length; i++)
        {
            // setting ManyCam as camera if found
            if (devices[i].name == "ManyCam Virtual Webcam")
            {
                webCamTexture = new WebCamTexture(devices[i].name);
            }
        }

        webCamTexture.Play();
        background.texture = webCamTexture;
    }

    public void StopStreaming()
    {
        webCamTexture.Stop();
    }
}
```

Listing 4: Unity - C# - Webcam Stream Class

.7 Code Snippet: Game's Global Configuration Parameters

```
public static class Global
{
    ...
    // performance parameters
    public static float TimerInterval = 0.02f;

    // random color picking parameters
    public static string[] colors = { "green", "red", "yellow", "blue",
    "pink", "cyan" };
    public static string[] mainColors = { "green", "red", "blue" };
    public static float targetColorPercentage = 0.5f;

    // random balloon generation parameters
    public static int maxNumberOfBalloonsOnScreen = 5;
    public static int maxNumberOfBalloonsInTotal = 15;
    public static int timeToNextBalloonMin = 2;
    public static int timeToNextBalloonMax = 3;

    // animation parameters
    public static float balloonAnimationSpeed = 2.0f; //how fast it moves
    public static float balloonAnimationDelta = 0.005f; //how much it moves
    public static float balloonVerticalTranslationDelta = 0.03f;
    ...
}
```

.8 Code Snippet: Game Events Log


```
{
   "events":[
      {
         "timestamp":"0.01551371",
         "type":"generate",
         "position":"MR",
         "color":"green"
      },
      {
         "timestamp":"2.015514",
         "type":"generate",
         "position":"ML",
         "color":"blue"
      },
      {
         "timestamp":"2.435514",
         "type":"hit",
         "position":"DL",
         "color":""
      },
      {
         "timestamp":"4.015513",
         "type":"generate",
         "position":"LL",
         "color":"pink"
      },
      {
         "timestamp":"5.775514",
         "type":"hit",
         "position":"SL",
         "color":""
      }, ...
   ],
   "messages":[
      "DL",
      "SL",
      "SL",
      "SL",
      "SL", ...
   ]
}
```

.9 Ethics Board Positive Vote

Technische Universität Berlin

Berlin, 23.06.20

TU Berlin | Sekr. MAR 5-5 | Marchstraße 23 | 10587 Berlin

Fakultät IV
Elektrotechnik und Informatik
Institut für Softwaretechnik und Theoretische Informatik

Ethikkommission
Vorsitzende

Prof. Dr. Marianne Maertens
Sekr. MAR 5-5
Marchstrasse 23
10587 Berlin

Telefon +49 (0)30 314-24478

Einreichende/r: Shamim Karimi

Eingangsdatum: 05.03.2020

Bearbeitungsnummer: 2020_01

Datum des Beschlusses: 23.06.2020

Stellungnahme der Ethikkommission zu einer Selbstbeurteilung im Fast Track-Verfahren

Für den von Frau Karimi eingereichten Antrag auf ethische Unbedenklichkeit für die Studie mit dem Titel „Effect of cognitive and motor challenges on engagement in exercise gaming" spricht die Ethikkommission eine positive Evaluation für die beschriebenen Verfahren aus.

An dem Experiment nehmen Kinder im Alter von 4-10 Jahren in ihrer häuslichen Umgebung teil. Die Untersuchung dauert ca 45 min, die Teilnahme an der Untersuchung entspricht in etwa der Teilnahme an einem Videospiel. Die Erziehungsberechtigen sind die gesamte Zeit anwesend. Das Ziel sowie der Ablauf der Untersuchung wird zu Beginn sowohl den Erziehungsberechtigten als auch den Kindern erklärt. Die Untersuchung kann jederzeit ohne Angabe von Gründen abgebrochen werden.

Aus der Sicht der Ethik-Kommission bestehen auf der Grundlage der Angaben zum Datenschutz, zur Anonymisierung der erhobenen Daten und zu grundlegenden Aspekten des ethischen Handelns in der Wissenschaft keine Bedenken bezüglich der Studie.

Dieses Votum setzt die wahrheitsgemäße Auskunft im Ethikantrag sowie die gewissenhafte Berücksichtigung sämtlicher Angaben bei der Umsetzung des Forschungsvorhabens durch den/die Antragstellende voraus.

Mit freundlichen Grüßen,

Marianne Maertens

.10 Ethics Proposal

Ethics Proposal

1. Title of the study	Effect of cognitive and motor challenges on engagement in exercise gaming
2. Decisions of other ethics committees in the same case	First submission
3. The subject of the study and its objectives; the hypotheses, broken down into main and secondary hypotheses, as well as the parameters (primary and secondary endpoints) to be used to test the hypotheses	The study is focused on evaluating the engagement of an exergame designed to include physical exercises as the input of the game. Goal of this study: To measure the effect of various game parameters (motoric and cognitive challenges) on the engagement of the exergame according to the flow theory. Primary Hypothesis: Type of game challenges will affect the engagement of the game. Having motoric, cognitive, and mixed challenges in the game will affect the engagement of the game. - Dependent variable: Engagement/fun - Independent variables: Type of the challenge: a) motoric challenge (limits on reaction time), b) cognitive challenge (color recognition), c) mixed challenge, and d) no challenge Secondary hypothesis 1: A challenge (independent of the challenge type) influences flow experience.
4. Explanation of the importance of the study	This study focuses on the motivational factors in a training program. The results can potentially help to understand the motivational elements for home training in the form of an exergame. The results of this study will give us insights on how to adjust the motoric/cognitive challenges in order to provide the optimal experience.
5. Which of the following provisions shall	a) to c) not applicable

apply a) Medical devices Act according to § 23b MPG - exception of clinical use examination b) Radiation Protection Act and Radiation Protection Ordinance c) Genetic Diagnostics Act d) data protection laws: - Specific indication of the data protection law to be complied with by the responsible body -EU Basic Data Protection Regulation (DSGVO). - If applicable, additional national data protection laws or BDSG to be observed according to the group of participants.	d) DSGVO, BDSG The data protection concept (see Annex 1) based on a template provided by the responsible data protection officer of TU Berlin.
6. Where appropriate: name and characterization of the test products	This study will be conducted remotely using an online video conferencing tool called Jitsi Meet (more info in Annex. 5) Tools/apps on the conductor's side: - MacBook Pro and its built-in webcam and microphone - ManyCam app and its "Desktop Capture" feature - Chrome browser - POP Game - made with Unity Tools/apps on the participant's side: - A PC/Laptop equipped with a webcam and a microphone - Chrome browser
7. The essential content and results of the previous studies/applications of the products to be tested in the study	Csikszentmihalyi introduced the concept of flow as "the holistic experience that people feel when they act with total involvement".[1] Flow theory has since been one of the fundamental theories in research focusing on measuring the quality of experience and engagement. Csikszentmihalyi identified eight major components of flow. The balance between provided challenge and one's skills is one of these components. In a gaming setting, if this balance is not well established the player would either feel anxious or bored.

[1] Csikszentmihalyi, Mihaly, "Flow: The Psychology of Optimal Experience" (1990).

	A number of researchers have investigated the correlation between challenges, skills and flow experience in various gaming settings. Among them are Chen's viewpoint on flow[2], Liu et al.'s research on measuring the flow experience of players playing online games[3] and Jin's research on interaction effect of skill and challenge on flow across three video games genres[4]. There has been a few works done on how the flow theory could be applied to exergames, such as Sinclair et al. who proposed dual flow model[5] and Kristian et. al who worked on design principles for exergames[6]. None of these works, however, has investigated the effect of challenge type on flow experience in an exergame.
8. Description of the planned measures/ investigation methods. If validated questionnaires are used for the study, please state the name of the questionnaires and where they are published (references). Please attach non-validated questionnaires.	A maximum 45 minutes session of playing with the designed exergame will be held with each child (for details of the study plan please see Annex. 5). Since on-site testing is not possible due to the Coronavirus pandemic, the Wizard of Oz method is used to facilitate the remote online testing: the JS module used for hand movement recognition is replaced by the test conductor's manual input. There are three main investigation methods used during the user study: - Observation: The session will be video recorded. Any verbal comments on the game or expression of a player's feelings is of interest for the study. (Annex. 1)

[2] Jenova Chen. "Flow in games (and everything else)". (2007). Commun. ACM 50, 4 (2007), 31–34.
[3] Liu, Chuang-Chun and Chang, I-Cheng, "Measuring The Flow Experience Of Players Playing Online Games" (2012). PACIS 2012 Proceedings. 104.
[4] Jin, Seung-A Annie."Toward Integrative Models of Flow: Effects of Performance, Skill, Challenge, Playfulness, and Presence on Flow in Video Games". (2012). Journal of Broadcasting & Electronic Media, 56:2, 169-186.
[5] Sinclair, Jeff and Hingston, Philip & Masek, Martin. "Considerations for the Design of Exergames". (2007). ECU Publications.
[6] Kristian Kiili and Sari Merilampi. "Developing engaging exergames with simple motion detection". 2010. In Proceedings of the 14th International Academic MindTrek Conference: Envisioning Future Media Environments (MindTrek '10).

	- Game scores will be stored for each participant. - After playing, a questionnaire will be used to ask the child to rate game variations based on fun (Annex. 2).
9. Evaluation of the foreseeable risks and disadvantages of participating in the study Benefits for study participant	There is no risk regarding the devices. The game itself is violence-free and there is no item that can be interpreted otherwise. In the case of fatigue, frequent distractions or just refusing to play in general, the session will be terminated immediately. Interacting with the game only requires arm movements and the participants will play the game while sitting which reduces the risk of injuries and incidents such as falling down. By signing the consent form, the parent confirms that it is their responsibility to be present at all times during the study, supervise the child, and take all the safety measures required to prevent any harm or accident. The parent is advised to keep the household items and other objects a safe distance away from where the child is sitting to prevent any accident caused by the child's movements.
10. Risks and burdens for the study participants (list all in detail)	No safety-relevant incidents were reported from similar preliminary studies.
11. Risk control measures	In case of serious adverse events that are causally related to the conduct of the study, the Ethics Committee will be informed of the matter and the investigation will be conducted.
12. Abort criteria	Termination of the study if serious, unforeseen adverse effects occur in the participants, at the personal request of the study participants or their parents or in any other situation wherein the opinion of the study leader, further participation in the study would not be in the best interest of the participant.
13. The number, age, and sex of the persons	Number: 10 - 15 participants

concerned	Age: 4 - 10 years old Sex: male/female
14. Biometric planning, indicating the statistical methodology, including the justification of the number of cases. Indication of the statistician.	Statistical methodology for analysing subjective data from the questionnaire: The non-parametric Friedmann test followed by a post-hoc test will be performed on the ranks of engagement ratings on game variations. Statistical methodology for analysing objective data from the videos: Recorded videos of playing will be analyzed using measurement scales from the Guerrero[7] rating scheme for studying involvement. Seven-point interval scales ranging from "never exhibited" to "constant" will be used to rate these verbal and non-verbal involvement behaviors in each of the game variations for each participant. Then the non-parametric Friedmann test followed by a post-hoc test will be performed on the ranks of ratings on game variations for each behavioral factor. Note: The choice of non-parametric method is due to the fact that the scope of the project does not allow for a large group of participants and the Gaussian distribution cannot be assumed.
15. a. Explanation of the inclusion and exclusion criteria and, if applicable, their explanation	Inclusion criteria: Children between the age of 4 and 10 who are capable of and willing to play exergames and have the consent to participate in the study from the parents or guardian. Exclusion criteria: Any form of limitation in regard to motoric/cognitive abilities.
b. Study information and an indication of how much time between clarification and consent remains (written information as an attachment)	Annex. 3
c. Declaration of consent (written form)	The participant and their parent/legal guardians will receive the study information

[7]

	and instructions in digital format before the start of the session. The consent form is filled, signed by both parents, and sent to the conductor prior to the study. (The consent form and the personal code creation form are also provided in Farsi since the mother tongue of some or all the participants is Farsi.)
d. If applicable, information and consent of the legal representative (if applicable also description of the procedure for the establishment of the judicial assistance)	Since the participants are underage the consent of the legal guardian will be obtained as a substitute.
16. Measures to attract study participants (posters, newspaper advertisements, etc.)	- Personal contact - Invitation in online groups
17. Reason for inclusion, if any, and presentation of the therapeutic benefits for persons who are minors and/or who are are incapable of consent.	The goal of this project is to design an exergame that is fun and engaging for children, and the test should be conducted with the same target group in order for the results to be beneficial for the study.
18. Remuneration or reimbursement of costs of the study participants (amount for which should be paid?)	No fee or reimbursement of costs will be made. There will be a small digital gift card for the children, and it will be given to them at the end of the session.
19. Insurance of the study participants (Insurance confirmation and insurance conditions, insurer, the scope of insurance, duration of insurance)	No insurance will be provided.
20. Documentation procedures: - Reference to CRF sheets - Specification of the data to be collected - Sample handling - Storage / Archiving (incl. deadlines) - Access to data and samples	The data is only accessible to the study personnel. Data sources: - Game scores are saved in a separate file for each participant. - The game session will be video recorded to be analysed afterwards. Any verbal comments on the game or expression of a player's feelings is of interest for the study. These videos

	will be deleted after the study is complete. - A Questionnaire will be provided after playing and the participant will be asked about their opinion on the variations of the game. The data package will be stored under the participant's anonymous profile which includes: - Personal Code - Age of the participant - Gender of the participant Deletion of the raw data takes place after completion of the evaluation of the data, at the latest, however, on 31.01.2022. (more about this in Annex. 1 & 2)
21. methods, if any, to identify and document adverse events, and to communicate (when by whom and how?)	None
22. Procedure to protect the secrecy of stored data, documents, etc. and, if applicable, samples, presentation of the pseudonymization or anonymization of the data, and samples from participants in the study (initials and date of birth as coding scheme are not permitted!) - The naming of access rights including access to subscriber identification lists during and after the study - The detailed specification of the procedures for the transmission, encryption, restriction of processing (blocking) and deletion (including an indication of the network structure, if used, and server used).	Annex. 1
23. Declaration on compliance with data protection - Assurance that everyone will be informed about the study and collected data. (data confidentiality and medical secrecy.) - Assurance that the identifying data will be only visible to the head of the study or persons appointed by him.	Annex. 1

- Indication of measures taken to ensure confidentiality. - Measures to ensure that data is protected. Transmission of data that is required for third parties will not allow for a personal reference to be established. - Information on storing, revocation, correction and deletion options. - Measures to safeguard the rights of the participants. - In the case of transmissions to non-EU foreign countries: Measures for compliance with data protection (e.g. existence of an adequacy decision of the EU Commission or explicit consent of the study participants in such transfers.)	
24. The names and addresses of the institutions involved in the study as study centers or laboratories; and the study leaders. Specification of the external service provider with information on the possibility of data access.	Technical University of Berlin Chair of Medical Engineering: Prof. Dr.-Ing. Marc Kraft Dovestr. 6, 10587 Berlin, Germany Tel.: 030-314-23388, Fax: 030-314-21098 marc.kraft@tu-berlin.de
25. Agreement on the investigator's/principal investigator's/trial supervisor's access to data and principles about the publication. - Publications in a form that does not allow any conclusions to be drawn about the person.	The data is collected centrally by the study staff. The publication rights lie with the Technical University of Berlin. Only anonymised data will be published.
26. Information on the financing of the study: Source of financing (name and location) and Amount of funding in €. - If applicable, specify the cost center for ILV billing of the fee.	This study is not funded.

Name and signature of the applicant(s):

I hereby certify that the information provided in this application is correct. I considered that it is possible to carry out the above study in accordance with the Protocol and national legislation.

Name: Karimigolpayegani
Given Name: Shamim
Service address: Technical University of Berlin
Email: sh.karimi94@gmail.com
Position: Student
Date:
Signature:

Annexes
1. Information on Data Protection
2. Questionnaire
3. Information for Participants and Consent Form
4. Personal Code Creation Form
5. Study Plan
6. Information for Participants and Consent Form - In Farsi
7. Personal Code Creation Form - In Farsi

Annex 1: Information on Data Protection

1. What types of data are stored?

A. Game scores
B. The answers to questionnaires
C. Video recordings:
We will record the playing sessions to collect data on player's facial expressions, hand movements and body posture as well as vocal reactions.
The video recordings are to be analyzed based on involvement behavioral factors listed below:

Factor name	Variable behavioral rating item	
Vocalic expressiveness	Expressiveness	Inexpressive
	High variation	Low variation
	Dull	Full of life
Altercentrism	Distracted	Focused
	Steady	Random gaze
Interaction Management	Many interruptions	No interruptions
Positive Affect	Positive facial expression	Negative facial expression
	Warm facial expression	Cold facial expression
	Much smiling	No smiling
Composure	Large amount of body movement	Small amount of body movement
Vocal Relaxation	Anxious	Relaxed
No Clear Factor Loading	Much laughter	No laughter
	Leans toward	Leans away
	Tense Body	Relaxed Body
	Detached	Involved
	Bored Facial Expressions	Interested Facial Expressions

2. How is the anonymization of the data collected secured?

All data collected from the participants is only coded with a participation number. Neither in the survey material nor in the digital databases are names or other information given that would allow the individual participants to be identified. The participation numbers are related to a personal code by means of an allocation list, which was created by the participants themselves and can only be reproduced by them. This procedure ensures that participants can request the subsequent deletion of their data. There is no list that allows names or other personal data to be directly assigned to participation numbers or personal codes. At no time is there provision for matching the data collected with personal data. The evaluation is exclusively concerned with exemplary settings of the entire target group.

3. When are the stored data deleted?

Deletion of the raw data (non-anonymized video files, contact data, and other personal data) takes place after completion of the evaluation in the Sharki project, at the latest, however, on 31.01.2022 (expiry of the project plus period until the preparation of the final report).

The deletion of further processed data (including publications and final reports) is not foreseen.

4. How can respondents (retrospectively) request the deletion of their data?

Respondents can terminate the user study at any time without giving reasons and immediately or retrospectively revoke their consent and request the deletion of their data at any time. This can concern all recorded data or only parts of it. However, this does not affect the lawfulness of the processing of their personal data that has been carried out on the basis of their consent until the revocation, i.e. the data that has been anonymized up to this point may continue to be used in evaluations and, for example, in publications.

5. Who has access to the experimental data?

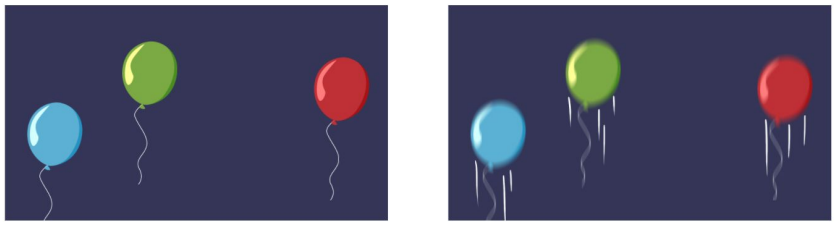
The data collected described above will be treated in strict confidence, kept separate from other data and only accessible to the project staff to the extent necessary for their research work. All project members are subject to the duty of confidentiality and the disclosure of personal data to third parties is excluded. The results of the study are published exclusively in anonymized form.

Annex 2: Questionnaire

Personal Code: ..... Age: ..... Gender: .....

1. How would you feel if you received this game as a birthday present?

2. Which one was more fun?



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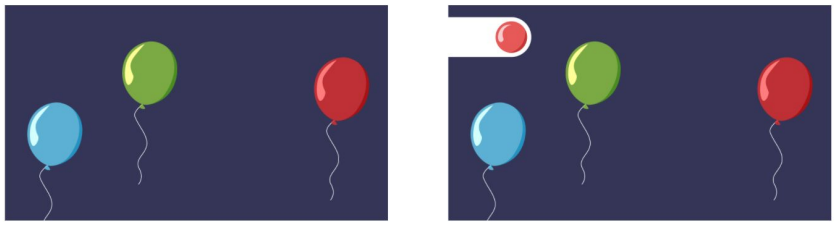
3. Which one was more fun?



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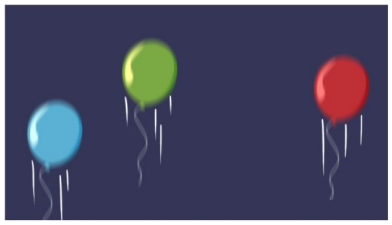
4. Which one was more fun?



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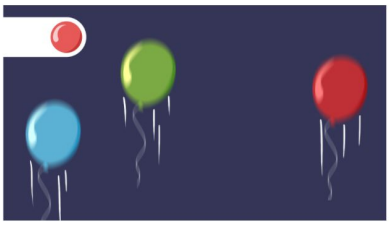

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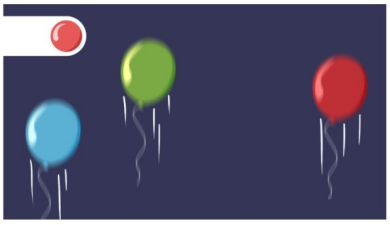
5. Which one was more fun?

☐



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Annex 3: Information for participants

Purpose of the Study

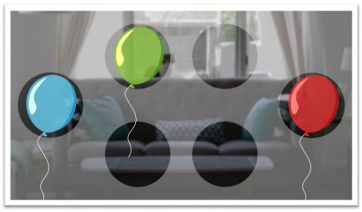
This study is focused on evaluating the engagement of a game called “POP”. This game is designed to promote physical activity in children and requires the player to perform hand/arm movements.

Procedure and Setting

The study is conducted remotely via a video call and requires the following on the participant’s side:

- PC/Laptop equipped with a webcam and a microphone
- Chrome browser
- Stable internet connection

The child needs to sit in front of the PC/laptop in order to play the game. The goal of the game is to pop the balloons that appear on the screen by moving the arms/hands towards the balloon’s position.
The movements include: arms stretched upward, arms stretched forward, and arms stretched to the sides.



An Example of the Game’s Screen

The study session can take up to 45 minutes including the initial setup and the final questionnaire.

Safety

The type and the scope of a child’s activities while playing this game are the same as when the child is playing on their own or with friends. Nevertheless, it is the parent’s responsibility to

supervise the child and take all the safety measures required to prevent any harm or accident. Therefore, the parent should be present at all times during the study.
We advise the parent to keep the household items and other objects a safe distance away from where the child is sitting to prevent any accident caused by the child's movements.

Anonymity and Data Protection

The data and personal information collected during the measurements will be treated confidentially. The project staff members who have personal data through direct contact with the participants are subject to confidentiality. The results of the study will be published in an anonymous form, i.e. without the participants' personal data (or the data of their child or their children) being able to be attributed to them. All personal data that could be used to identify the participants' child will be anonymized in written documentation. During the user study, a video recording is made for evaluation purposes. If excerpts of the video recordings are used for scientific purposes, the areas that allow conclusions to be drawn about the participants' identity (face) will be anonymized (blackened/pixeled). The participants agree that the data collected during the measurements (game scores and questionnaires) will be stored in anonymized form and used for scientific purposes. Personal data will be treated in strict confidence, stored separately from other data, and will only be accessible to the project staff if it is necessary for their research work. The transfer of personal data to third parties is excluded. After completion of the evaluation of the project, but no later than 31.12.2022, the video files, contact data, and other personal data will be deleted.

Voluntariness

Participation in these measurements is voluntary, so the participant or their child can stop the measurements at any time without giving reasons, without any disadvantages for them or their child. The participants can also revoke their consent at any time afterward and demand that the data be deleted. From this point on, further processing of personal data is not permitted for the future. However, this does not affect the lawfulness of the processing that has been carried out on the basis of the consent until the revocation, i.e. the data that has been anonymized up to that point may continue to be used.

Child's Consent

The parent should read this part to the child and only sign the consent form if the child agrees to participate in this study:
"There is a game you can play. In this game, you have to sit in front of the computer. There will be balloons showing up on the computer's screen, and you should try to pop them with your hands. You can of course stop playing whenever you want. after you played the game, there will be 5 questions about how much you enjoyed playing that you can answer. Would you like to play this game?"

Consent Form

What this study is about

This study is focused on evaluating the engagement of a game that requires the player to perform hand/arm movements.

Your participation in this study is voluntary

The participant can take a break or leave at any time without giving a reason.

Information we want to collect

A video recording is made for evaluation purposes, game scores are stored, and a number of questions will be asked in the form of a questionnaire in the end.

How we ensure your privacy

All personal data that could be used to identify you or your child will be anonymized in written documentation. Non-anonymized raw data such as the video recordings will be deleted after completion of the evaluation of the project (but no later than 31.12.2022), or upon your request.

Your consent

I hereby confirm that I have read and understood the provided information, and I consent to have my child participate in this user study, in compliance with the data protection regulations.

Parent 1
Name:
Signature:

Parent 2
Name:
Signature:

* Participants are advised to keep a copy of this document for further reference.

Annex 4: Personal Code

Please use the following instruction to create your personal code:

(If one of the parts is unknown, please enter an X.)

1. The first letter of child mother's first name: _____
2. The first letter of child father's first name: _____
3. The first letter of child's place of birth: _____
4. The last digit of child's year of birth: _____
5. The last digit of child's birthday: _____

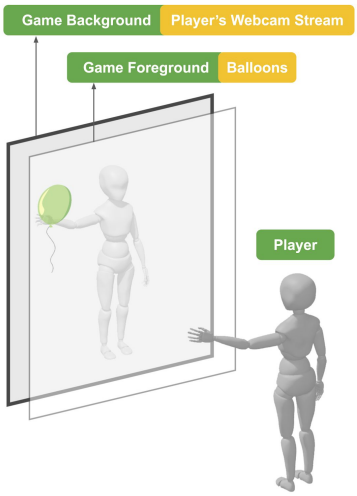
Personal code: _____

* Participants are advised to keep a copy of this document for further reference.

Annex 5: Study Plan - Online Remote Edition

How to play the game:

The goal of the game is to pop the balloons that appear on the screen using hand/arm movements. In order to do so, the player should sit in front of the screen and try to move their arms towards the position of the balloons. The intention is that the player actually touches the balloons - but in an indirect way and through the game background which displays the webcam stream of the player. That means that the player should not try to touch the screen, instead, they should try to move in a way that the projection of their hands touches the balloons, similar to having an avatar in a video game. The adults whom we tested the game with seemed to have no problem understanding this instantly, but if we find out that making this indirect connection is not easy to understand for a child, that also counts as an interesting finding. This research has a qualitative nature to it and there is a lot to learn and see as this is the first step in a broader ongoing research project.
As for the written documents, we would like to avoid explaining these in the consent form as it will introduce a kind of bias to the research depending on how the parents understand and interpret this information and then explain it to their child. And if we add illustrations and paragraphs to explain this fully, that would still overcomplicate things. In the end, learning to play the game should not be that hard. This is one of those cases that take so much effort to explain in words but it's easy to grasp once you see it.



General Info:

- Tools:
  - Jitsi Meet (Video conferencing tool):
    Service link: Jitsi Meet instance of MayFirst
    This tool is recommended on the TU Berlin website: link
    This instance is recommended on the Systemli.org website: link

    * This tool can be directly started in a web browser and does not require either installing an extra application nor registration in the service.

    * On the conductor's end, the screen-sharing and video recording features will be used during the session.

- User requirements:
  - PC/Laptop equipped with a webcam and a microphone
  - Chrome browser
  - Stable internet connection

- Time: the study will happen at participants' requested time.

- The consent form is filled, signed, and sent to the conductor prior to the study.

Step 1: Starting the Meeting

The conductor initiates a Jitsi Meet and sets a password, then sends the link and the password to the participant. The conductor will begin the next step once the participant joins the meeting.
The conductor asks if the parent has any questions before starting the study.
The conductor asks if it is okay to begin the recording.
After starting the recording the conductor asks the parent to read the personal code.

Step 2: Setup

- Starting the game
- Setting the participant's webcam stream as the game input stream
- Sharing the game screen with the participant

Step 3: Calibration

- Asking the child to sit in front of the webcam
- Selecting "calibration" from the game's menu
- Asking the parent to adjust the webcam frame or the child's distance from the webcam

- Clearly explaining how the game works, emphasizing on the hand movements and how to perform them in order to interact with the game
- Letting the child play in calibration mode until they feel comfortable playing the game

Step 4: Play

- Giving a short explanation on how the 1st variation of the game differs from calibration mode
- Starting the 1st variation of the game once the participant is ready
- Once the 1st variation is finished, asking the participant if they are ready to play the next variation
- Repeating the steps above for all 4 variations of the game

Step 5: Questionnaire

- Sharing the questionnaire via screen sharing
- Asking the questionnaire's questions from the participant and filling their answers on the questionnaire

Step 6: Ending the meeting

- Stop the meeting
- Save the recording

اطلاعات پژوهش برای شرکت‌کنندگان (Annex 6)

هدف پژوهش

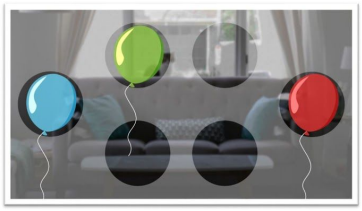
این پژوهش به بررسی میزان سرگرم‌کنندگی یک بازی به نام «POP» می‌پردازد. این بازی با هدف تشویق فعالیت بدنی در کودکان طراحی شده است و با استفاده از حرکات و بازو دست انجام می‌شود.

نیازمندی‌ها و روش انجام پژوهش

این پژوهش از راه‌دور و از طریق تماس ویدیویی انجام می‌شود. موارد زیر برای شرکت در این پژوهش لازم است:

- کامپیوتر شخصی یا لپتاپ مجهز به دوربین (وبکم) و میکروفون
- مرورگر کروم (Chrome browser)
- اتصال به اینترنت پرسرعت

برای انجام بازی کودک باید در مقابل کامپیوتر یا لپتاپ بنشیند و با حرکت دادن دست به سمت بادکنک‌هایی که روی صفحه ظاهر می‌شوند آن‌ها را بترکاند. دراز کردن دست‌ها به سمت بالا، دراز کردن دست‌ها به سمت جلو و دراز کردن دست‌ها به دو طرف از جمله‌ی این حرکات هستند.



نمونه‌ای از صفحه‌ی بازی

انجام این پژوهش با احتساب آمادسازی اولیه و پاسخگویی به پرسشنامه در آخر، حداکثر ۴۵ دقیقه به طول می‌انجامد.

نکات ایمنی

نوع و میزان فعالیت‌های لازم برای انجام این بازی همانند فعالیت‌هایی است که کودک در هنگام انجام بازی به تنهایی و یا با دوستان انجام می‌دهد. با این حال، مسئولیت نظارت بر کودک و مراقبت از او در طول انجام پژوهش بر عهده‌ی والد است. والد موظف است در طی انجام پژوهش در کنار فرزند حاضر باشد.
توصیه می‌شود که والد لوازم خانه و اشیاء دیگر را در فاصله‌ی دور از کودک قرار دهد و محیط اطراف کودک را خلوت کند تا از هرگونه صدمه در نتیجه‌ی حرکات کودک جلوگیری شود.

ناشناس بودن اطلاعات و حفاظت از داده‌ها

داده‌های جمع‌آوری شده در طی پژوهش و همچنین اطلاعات شخصی شرکت‌کنندگان محفوظ نگه داشته خواهند شد. دست‌اندرکاران این پژوهش که به اطلاعات شخصی شرکت‌کنندگان دسترسی دارند ملزم به محرمانه نگه داشتن اطلاعات هستند. نتایج این پژوهش به صورت ناشناس منتشر خواهد شد و امکان شناسایی شرکت‌کنندگان وجود نخواهد داشت. تمامی اطلاعات شخصی شرکت‌کنندگان که می‌تواند جهت شناسایی آن‌ها استفاده شود به فرم ناشناس تبدیل شده و در مستندات درج خواهد شد. تصاویر ویدیویی ضبط شده در طی انجام پژوهش به منظور ارزیابی‌های بعدی نگهداری خواهند شد. در صورت استفاده از بخش‌هایی از ویدیوهای ضبط شده با مقاصد علمی، صورت شرکت‌کنندگان به فرم ناشناس تبدیل شده و شطرنجی یا سیاه می‌شود. شرکت‌کنندگان توافق دارند که داده‌های جمع‌آوری شده طی پژوهش (امتیازات بازی و پرسشنامه) به صورت ناشناس ذخیره شده و برای مقاصد علمی مورد استفاده قرار گیرند. اطلاعات شخصی شرکت‌کنندگان به صورت محرمانه و جدا از داده‌های دیگر ذخیره شده و فقط در صورت نیاز در اختیار دست‌اندرکاران پژوهش قرار می‌گیرند. اطلاعات شخصی شرکت‌کنندگان در اختیار شخص یا موسسات ثالث قرار نخواهد گرفت. پس از بررسی نتایج پژوهش و اتمام پروسه‌ی تحقیق، و یا در دیرترین حالت در پایان سال میلادی ۲۰۲۲ (دهم دی ماه سال ۱۴۰۱)، فایل‌های ویدیویی، اطلاعات تماس، و دیگر اطلاعات شخصی شرکت‌کنندگان به طور کامل حذف خواهند شد.

داوطلب بودن شرکت‌کنندگان

شرکت در این پژوهش داوطلبانه است، به همین دلیل شرکت‌کنندگان و یا کودکان آن‌ها می‌توانند در هر زمان دلخواه و بدون نیاز به ارائه‌ی دلیل از شرکت در پژوهش انصراف دهند. انصراف از شرکت در پژوهش هیچ تبعاتی برای شرکت‌کنندگان و یا کودکان آن‌ها نخواهد داشت. شرکت‌کنندگان همچنین می‌توانند توافق پیشین خود را لغو کرده و حذف اطلاعات شخصی و داده‌های جمع‌آوری شده را درخواست کنند. پس از درخواست حذف اطلاعات شخصی، امکان استفاده از اطلاعات وجود نخواهد داشت. با این حال، اطلاعاتی که پیش از درخواست حذف بررسی شده و به صورت ناشناس ذخیره شده‌اند می‌توانند همچنان مورد استفاده قرار گیرند.

رضایت کودک

والد موظف است نکات آمده در این بخش را برای کودک بخواند و فقط در صورتی فرم رضایت را امضا کند که کودک با شرکت در این پژوهش موافقت کرده باشد:

«یک بازی هست که می‌تونی بازی کنی. توی این بازی، باید بشینی جلوی کامپیوتر. چندتا بادکنک روی صفحه‌ی کامپیوتر میاد که باید سعی کنی با دستات بترکونی. البته هر موقع خواستی می‌تونی دیگه بازی نکنی. بعد از این که بازی کردی، می‌تونی ۵ تا سوال در مورد این که چقدر بازی رو دوست داشتی جواب بدی. دوست داری این بازی رو بازی کنی؟»

فرم رضایت

هدف از این پژوهش:
این پژوهش به بررسی میزان سرگرم‌کنندگی یک بازی که با استفاده از حرکات دست و بازو انجام می‌شود می‌پردازد.

شرکت شما در این پژوهش داوطلبانه است:
شرکت‌کننده می‌تواند هر زمان در طی انجام پژوهش درخواست استراحت کند و یا از انجام ادامه‌ی پژوهش انصراف دهد.

اطلاعاتی که جمع‌آوری خواهد شد:
تصاویر ویدیویی ضبط شده در طی انجام پژوهش، امتیازات حاصل از بازی، و نتایج پرسشنامه به منظور ارزیابی‌های بعدی نگهداری خواهند شد.

چگونه از اطلاعات شما حفاظت خواهد شد:
تمامی اطلاعات شخصی که می‌تواند در جهت شناسایی شما به کار گرفته شود به فرم ناشناس درآمده و سپس در مستندات درج خواهد شد. داده‌هایی مانند فایل‌های ویدیویی که به فرم ناشناس تبدیل نشده‌اند، پس از بررسی نتایج پژوهش و اتمام پروسه‌ی تحقیق، یا در دیرترین حالت در پایان سال میلادی ۲۰۲۲ (دهم دی ماه سال ۱۴۰۱)، و یا بنا بر درخواست شما حذف خواهند شد.

رضایت شما:
بدین وسیله گواهی می‌دهم که اطلاعات ارائه شده در مورد پژوهش را خوانده و متوجه شده‌ام، و رضایت می‌دهم که فرزندم، مطابق با مقررات حفاظت از داده‌ها، در این پژوهش شرکت کند.

والد ۱
نام:
امضاء:

والد ۲
نام:
امضاء:

* توصیه می‌شود که شرکت‌کنندگان یک نسخه از این فرم را جهت ارجاع بعدی نزد خود نگه دارند.

رمز شخصی (Annex 7)

لطفا از این فرم برای ساختن رمز شخصی خود استفاده کنید:

(در صورت مشخص نبودن هریک از موارد زیر از حرف X استفاده کنید)

۱. حرف اول نام مادر (به انگلیسی): _____
۲. حرف اول نام پدر (به انگلیسی): _____
۳. حرف اول محل تولد کودک: _____
۴. رقم آخر سال تولد کودک: _____
۵. رقم آخر روز تولد کودک: _____

رمز شخصی (متشکل از ۵ حرف/رقم بالا): _____

* توصیه می‌شود که شرکت‌کنندگان یک نسخه از این فرم را جهت ارجاع بعدی نزد خود نگه دارند.