Master's thesis

NTNU
Norwegian University of Science and Technology
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Department of Computer Science

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Tangible Interactive Games for Use in Physiotherapy

Master's thesis in Master of Science in Informatics
Supervisor: Yngve Dahl
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Abstract

Physiotherapy often requires patients to perform repetitive exercises over an extended period of time, and it can be challenging for patients to stay motivated. Serious games have been used to increase motivation in many domains but have not yet become a part of most physiotherapists' "toolbox". This thesis aims to explore the potential of using tangible interactive games in physiotherapy and has been motivated by the following research questions: (1) What can we learn from existing research literature concerning the design of game-based solutions for physiotherapy? and (2) How do physiotherapists experience using concepts from gamification in the treatment of patients? A structured literature review was conducted to answer the first research question, where nine main trends in existing physiotherapy games were discovered and discussed. The second research question was answered by drawing on a user-centered design process where a functional prototype of a tangible interactive game called *ColorCube* was designed and evaluated. Patients and physiotherapists were involved throughout the process by providing insights essential to the design of the game concept and evaluating the prototype. The evaluation resulted in seven design recommendations: (1) Design for versatility, (2) Facilitate movement quality, (3) Design for positive diversion, (4) Design for adjustable difficulty, (5) Ensure a quick and easy setup, (6) Design durable and safe tangible interfaces, and (7) Involve both physiotherapists and patients in the design process. To conclude, the thesis shows that there is a great potential for using tangible interactive games in physiotherapy and that such games could become a part of the physiotherapists' "toolbox" to increase patients' motivation.

Sammendrag

Fysioterapi krever ofte at pasienter utfører repetitive øvelser over en lengre periode, noe som kan gjøre det utfordrende å opprettholde motivasjonen. Seriøse spill (*serious games*) har blitt brukt for å øke motivasjonen i mange domener, men har ennå ikke blitt en del av de fleste fysioterapeuters «verktøykasse». Denne oppgaven har som mål å utforske potensialet for bruk av taktile interaktive spill i fysioterapi og er motivert av følgende forskningsspørsmål: (1) Hva kan vi lære av eksisterende forskningslitteratur vedrørende design av spillbaserte løsninger for fysioterapi? og (2) Hvordan opplever fysioterapeuter å bruke konsepter fra spillifisering (*gamification*) i behandling av pasienter? En strukturert litteraturstudie ble gjennomført for å besvare det første forskningsspørsmålet, hvor ni hovedtrender i eksisterende fysioterapispill ble identifisert og diskutert. Det andre forskningsspørsmålet ble besvart gjennom en brukersentrert designprosess der en funksjonell prototype av et taktilt interaktivt spill kalt *ColorCube* ble designet og evaluert. Pasienter og fysioterapeuter var involvert i hele prosessen gjennom å gi innsikt som var essensiell for utformingen av spillkonseptet og å delta i evalueringen av prototypen. Evalueringen resulterte i syv designanbefalinger: (1) Design for allsidighet, (2) Tilrettelegg for bevegelseskvalitet, (3) Design for positiv avledning, (4) Design for justerbar vanskelighetsgrad, (5) Sikre et raskt og enkelt oppsett, (6) Design holdbare og sikre taktile grensesnitt og (7) Involver både fysioterapeuter og pasienter i designprosessen. Avslutningsvis viser oppgaven at det er et stort potensial for bruk av taktile interaktive spill i fysioterapi og at slike spill kan gi fysioterapeuter et verktøy for å øke pasienters motivasjon.

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Acronyms

CP cerebral palsy. 17, 74, 99, 138

FPV first-person view. 25, 34, 36

IoT Internet of Things. 93

SLR structured literature review. x, 2, 11–14, 36, 68, 77, 126, 135, 137, 138

TPV third-person view. 25, 34

Chapter 1

Introduction

Interactive games have become a source of entertainment for an increasing amount of people, with 3.24 billion gamers worldwide (Statista, 2021). One specific type of interactive games that has become more widespread in recent years is *serious games*, which are "games used for purposes other than only mere entertainment" (Wattanasoontorn et al., 2013, p. 1). There are many application areas for serious games, such as education, healthcare, government, corporate, and military (Wattanasoontorn et al., 2013). Serious games focusing on health, and training promoting physical movements, are referred to as *exertion games* or *exergames* (Oh and Yang, 2010), and various fields have looked at the potential of using exergames. One field that has shown promising results for using exergames in the treatment of patients is physiotherapy (Hocine et al., 2015, Paraskevopoulos et al., 2014, Elor, Teodorescu et al., 2018), which will be the focus of this thesis.

In traditional physiotherapy, patients are often required to perform a large number of repetitive motions and exercises, and many do not complete the training plans provided by the physiotherapist (Campbell et al., 2001). When undergoing long treatments with repetitive exercises, it can be challenging for patients to stay motivated (Lohse et al., 2013). Finding a way to maintain this motivation is important since motivation, along with the patients' willingness to perform the required exercises, greatly affect the effectiveness of the treatment (Geurts et al., 2010).

Studies have shown promising results indicating that interactive games can have a positive effect on motivation (A. I. Wang, 2021), including for use in physiotherapy (Goh et al., 2017, Henschke et al., 2012) and that such games can increase patients' compliance (Lange et al., 2009) and enjoyment (Burke et al., 2009). However, Subramanian et al. (2020) hypothesize that games are not yet a part of most physiotherapists' "toolbox", possibly because many games are commercial games that are not adapted to the physiotherapists' way of working.

The motivational effect of games has inspired the research goal to further explore the potential of using tangible interactive games in physiotherapy and discover important design considerations for such games. To reach this goal, we aimed to answer following research questions:

- **RQ1: What can we learn from existing research literature concerning the design of game-based solutions for physiotherapy?**
  The first research question consists of three sub-questions:
  RQ1.1: What types of interactive, game-based design solutions are developed for use in physiotherapy?
  RQ1.2: What are the purposes of the design solutions?
  RQ1.3: What are the methodological approaches for designing and evaluating the solutions?
- **RQ2: How do physiotherapists experience using concepts from gamification in the treatment of patients?**

To answer the first research question (RQ1), we conducted a *structured literature review* (SLR). It explores existing physiotherapy games, what kind of patients those games were designed for and which game elements and technology were used. Then, a functional prototype of a tangible, physiotherapeutic exergame was designed and evaluated using a user-centered design approach, to answer the second research question (RQ2). The prototype was based on findings from the SLR and insight gained from involving physiotherapists throughout the whole project.

The main contribution of this thesis is a set of recommendations for developing tangible interactive games for use in physiotherapy.

This thesis is structured as follows: we continue in Chapter 2 which provides information about the background for this project. Chapter 3 presents the findings from the SLR, and Chapter 4 outlines the research design. Chapter 5 describes the preliminary study, Chapter 6 describes the ideation phase of the project, Chapter 7 explains our game solution, and Chapter 8 outlines a user evaluation of the game prototype. Further, Chapter 9 discusses the project's findings and presents recommendations for designing games for physiotherapy, before limitations are explained in Chapter 10. Finally, the thesis is summarized and concluded in Chapter 11.

Chapter 2

Background

This chapter explains important terms that will be further used throughout this thesis. First, the terms *games*, *serious games*, and *exergames* are defined. These definitions are followed by a description of the GameFlow model and the Dual Flow model, frameworks and models used to develop and evaluate games. Then, an introduction to tangible computing is given, and finally, physiotherapy, compliance, and movement quality are defined.

2.1 Games and Game Elements

As *games* is a core element of this thesis, defining the term as used is important. There are several relevant types of games for this research, and definitions will be provided for three of them: *games*, *serious games* and *exergames*. Then, game elements relevant to this project will be briefly explained.

2.1.1 Games

Games can be defined in many ways, but a popular definition is: "that gaming and games – in contrast to playing and toys – are characterized by explicit rule systems and the competition or strife of actors in those systems towards discrete goals or outcomes" (Deterding et al., 2011, p. 11).

2.1.2 Serious Games

Serious games can be seen as a subcategory of games often used when looking at "games used for purposes other than mere entertainment" (Susi et al., 2007, p. 1). Zyda (2005) defines a serious game as "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" (p. 26). According to this definition, games used for physiotherapy can be defined as serious games, as entertainment is used to further health objectives.

2.1.3 Exergames

Serious games that focus on physical exertion are often referred to as *exergames*. One way of defining exergames, by Oh and Yang (2010), is: "An exergame is a video game that promotes (either via using or requiring) players' physical movements (exertion) that is generally more than sedentary and includes strength, balance, and flexibility activities" (p. 9). This definition was chosen because it highlights physical movements and activities which are also important in physiotherapy.

2.1.4 Elements of Game Flow

Csikszentmihalyi (1990) defines flow as "a state of concentration so focused that it amounts to absolute absorption in an activity" (p. 1). Research done by Nakamura and Csikszentmihalyi (2014) shows that when a person experiences flow, it can be a "powerful motivating force" (p. 233). Not all games are enjoyable, but certain elements can be accounted for to achieve enjoyment and flow while playing. Sweetser et al. (2005) constructed a model of GameFlow that consists of eight such elements which are described in this section. Each element can be used in the design process when developing games, and to measure to what extent a game achieves flow.

Concentration

The first element of game flow, *concentration*, states that a game requires the player's concentration to be enjoyable. The game should quickly get the player's attention and preserve that attention as long as they are playing. Distracting and unnecessary tasks should preferably be avoided to help the player concentrate on the main tasks. However, the game's workload should be demanding enough to

require a high concentration level but not exceed the player's abilities (Sweetser and Wyeth, 2005).

Challenge

An essential element that motivates players to continue playing a game and return to it is *challenge*. The game should have a difficulty level appropriate to the player's skills and increase this difficulty over time as the player's skills develop. This will help the player stay engaged in the game, and experience progress (Sweetser and Wyeth, 2005).

Player Skills

Player Skills refers to making sure the game facilitates skill development throughout the game. Learning how to play the game should be enjoyable, which for instance, can be done through engaging the player in an interactive tutorial. For this to be possible, the usability and user-friendliness of the game are important. Finally, the player should get feedback on their ongoing skill development, which for instance, can be accomplished through points, other rewards, or progressing in the game story (Sweetser and Wyeth, 2005).

Control

When playing a game, players should feel like they have *control* over their actions in the game environment. Such control can be moving an avatar; starting, stopping, or pausing a game; or freedom to choose a game strategy. Another part of control is to ensure that the game is developed so that errors fatal to the game or gameplay cannot be made accidentally by the player (Sweetser and Wyeth, 2005).

Clear Goals

A part of the game definition itself implies that a game should have a *clear goal* or an objective. A game can have larger and smaller goals, where the primary goal should be known to the player from the beginning, while sub-goals may appear at fitting times, motivating the player to achieve the primary goal (Sweetser and Wyeth, 2005).

Feedback

Feedback is mentioned as one of Don Norman's usability principles (Norman, 2013) and it is also an important element in games. Specifically, players should get instant feedback when doing an action to let them know the system registered it, and they should be informed of the progress they are making towards their goal (Sweetser and Wyeth, 2005).

Immersion

When a player experiences *immersion*, they are fully involved in the game and tend to shift the focus away from time, their surroundings, and their everyday life with its concerns and worries (Sweetser and Wyeth, 2005).

Social Interaction

Social interaction does not necessarily contribute positively to flow and can even interrupt or disturb it. Nevertheless, social interaction can be highly enjoyable for players as it opens the possibility for competition, cooperation, and sharing an experience with someone else (Sweetser and Wyeth, 2005).

2.1.5 Intrinsic Motivation

Malone (1980) identified three categories of intrinsic motivation that make games fun to play. These categories are *curiosity*, *challenge*, and *fantasy* and the two latter categories will be briefly explained. According to Malone, a game "must provide a goal whose attainment is uncertain" (p. 162) to be challenging. Examples of ways to achieve challenge are providing variable difficulty levels, which can be automatically or manually determined, or randomness, which introduces an element of uncertainty. Overcoming challenges can positively affect players' self-esteem, but to achieve that, the challenge level must match the skills and abilities of the player (Malone, 1980).

The second category, *fantasy*, is a way to introduce a different dimension that can make games more interesting. It can be divided into *intrinsic* and *extrinsic* fantasy. Extrinsic fantasy is the most relevant for this thesis and is fantasies that "depend only on whether or not the skill is used correctly (i.e., whether the answer is right or wrong)" (Malone, 1980, p. 164).

2.1.6 Rewards

Rewards are often used in games to motivate players and give them positive experiences. H. Wang and Sun (2011) proposes eight forms of rewards, which include among others, *score systems, feedback messages*, and *plot animations and pictures*. Examples of score systems can be points or high score lists and can be used to compare results and monitor progress. Feedback messages can give the players rewards immediately and can, for instance, take the form of rewarding pictures or sound effects. Finally, there is plot animation and pictures, which often appear after important occurrences or achievements, for instance, when completing a level or game (H. Wang and Sun, 2011).

2.1.7 Dual Flow Model

The Dual Flow model proposed by Sinclair et al. (2009), embraces two aspects of flow: *attractiveness* and *effectiveness* (see Figure 1). Attractiveness is about matching the game challenge according to the player's skill level. If the game is too challenging, it may leave the player stressed and anxious, but if it is not challenging enough, it will lead to boredom. This is true for most games. Effectiveness is an essential aspect for an ExerGame to succeed, which is about matching the intensity level with the player's fitness level. This way, the player will achieve a sense of flow and, at the same time, have a health outcome.

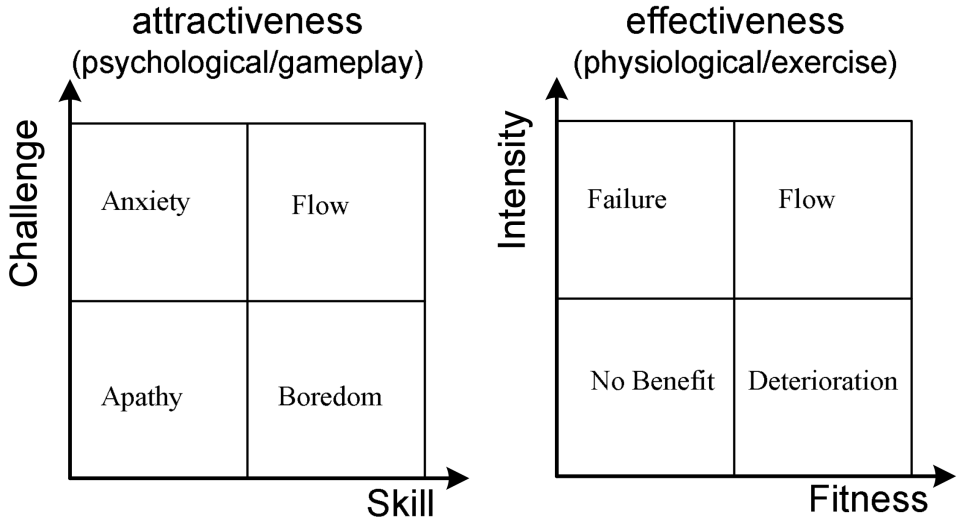


Figure 1: The Dual Flow model. Reprinted from *Exergame development using the Dual Flow model* by Sinclair et al., (2009).

2.2 Tangible Computing

Tangible computing is an opportunity for physical interaction with objects or environments with an incorporated computer (Cheok et al., 2002). The computer plays an active role in the interaction, but does not necessarily include the use of a screen. Tangible computing creates opportunities for using gestures, touch, lifting, turning or other movements that are executed by manipulating physical objects.

2.3 Physiotherapy

Many will at some point need to see a physiotherapist, for different reasons. They treat a wide range of injuries like pain in the neck, back or shoulders or rehabilitation after a stroke or a heart attack. Physiotherapy may also be needed due to sport injuries, and neurological disorders such as Parkinson's disease (NHS, 2018).

The Merriam-Webster dictionary defines *physical therapy* as "therapy for the preservation, enhancement, or restoration of movement and physical function impaired or threatened by disease, injury, or disability that utilizes therapeutic exercise, physical modalities (such as massage and electrotherapy), assistive devices, and patient education and training" (Merriam-Webster.com Dictionary, n.d.). Physical therapy can also be referred to as *physiotherapy*, which is the term that is used in this thesis.

2.3.1 Compliance

Compliance can be defined as "the extent to which patients adopt the behaviours and treatment recommended by their practitioners" (Bassett and Petrie, 1999, p. 130). Patients are often given exercises to do at home between sessions with the physiotherapist. However, research shows that up to half of the patients do not go through with the exercises (Campbell et al., 2001).

2.3.2 Movement Quality

Fdili Alaoui et al. (2011) defines *movement quality* as "the distinctly observable attributes or characteristics produced by dynamics independently of movement trajectory or shape" (p. 1466). Another definition states that "movement quality is assessed by identifying whether a normal range of motion of specific joints occurs"

(Demers and Levin, 2017, p. 631). Different exercises have different qualities and result in different movements. How these exercises and movements are executed matters, and physiotherapists often consider the movement quality.

Chapter 3

Related Work: A Structured Literature Review

This chapter contains a structured literature review (SLR), conducted by the authors in the fall of 2021, in a preparatory project. The goal of this chapter is to answer the first research question:

RQ1: What can we learn from existing research literature concerning the design of game-based solutions for physiotherapy?

3.1 Objective and Research Questions

This SLR aims to make an overview of game design insights, which would be beneficial to facilitate an expansion of the physiotherapy game market. Designers, developers, and physiotherapists could learn from these insights and use them to create quality games and experiences for both patients and physiotherapists. A wider variety of such games will enable physiotherapists to find alternatives suitable for their patients and treatments. There is existing research in the area, but an overview of the articles providing design knowledge is lacking. This literature review aims to create an overview of such articles and games created to be used in physiotherapy.

Before conducting the SLR, existing SLRs were investigated and will be further explored in Section 3.2. However, none of the SLRs found focused specifically on physiotherapy, games, and the design process. Our SLR was initiated to bridge this gap by mapping out and presenting an overview of studies regarding games used for physiotherapy where the design process and design knowledge outcomes were

important factors. The goal was to find patterns in previous studies and determine what areas would need more research. Additionally, a goal was to identify some key findings on game development for physiotherapy (see Section 3.5.2), which was implemented and used later in the process.

RQ1 is decomposed into the following research questions:

- **RQ1.1: What types of interactive, game-based design solutions are developed for use in physiotherapy?**
  The first research question looks at the types of technology the games use, the game objectives, themes, metaphors, and the player modes presented in the studies.
- **RQ1.2: What are the purposes of the design solutions?**
  The second research question looks at the purposes the games serve, like which patients they are developed for, and if they are meant to, for instance, increase engagement and motivation, or have a more physiotherapeutic focus.
- **RQ1.3: What are the methodological approaches for designing and evaluating the solutions?**
  The third research question looks at the process and how the games are designed and evaluated.

3.2 Existing SLRs

Before deciding on the topic for the SLR, research on previous reviews was done to discover which topics were already covered. Reviews that focus specifically on the design process of games developed for physiotherapy were searched for, and are listed in Table 1. None of the SLRs found focused specifically on physiotherapy, games, and the design process. Most of them narrowed down the aspect to one type of condition, such as stroke (Garbaya et al., 2018, Mirza-Babaei et al., 2014) or pediatric patients (Jurdi et al., 2018). Some of them only focused on a specific technology, such as AR (Virgínia C Cavalcanti et al., 2018) or VR (Ayed et al., 2019). Several literature reviews about the use of games in physiotherapy (e.q.Molina et al., 2014, Bonnechère et al., 2016, Kyriakidou, 2016) focused on the health effect instead of the design process.

Table 1: Previous reviews focusing on the design process of interactive games used for physical rehabilitation.

Study	Technology/ Game Type	Disorder/ Body Part	Specific Patient Group
Mirza-Babaei et al., 2014		Stroke	
Kamkarhaghighi et al., 2017		Stroke	
Korhonen and Halonen, 2017		Health care in general	
Cavalcanti et al., 2018	AR		
Garaya and Tamayo-Serrano, 2018	Gamified	Stroke	
Jurdi et al., 2018		Pediatric	Children
Ayed et al., 2019	Vision-based and VR systems		

3.3 Research Methods

An SLR is a way of getting an overview of research done in a specific field or topic and this review is based on the guide byKofod-Petersen (2012). Some of the steps included specifying research questions, developing a review protocol by selecting a database, deciding upon search terms and defining inclusion and exclusion criteria, going through a selection process with multiple screening iterations, before finally an analysis was conducted on the remaining studies.

3.3.1 Databases and Search Terms

We started creating a search string by thinking of relevant terms to include. Considering our main focus of physiotherapy and game, these were two inevitable search terms. Similar terms were added to our search string, but some terms such as 'exercise game' or 'game-based' made no difference to the number of results and were therefore omitted. The terms used for our final search string are found in Table 2. 'OR' was put between the terms, whereas 'AND' was put between the term categories 'game' and 'physiotherapy'.

Table 2: Search terms.

Physiotherapy	Game
physiotherapy	game
physical therapy	gamification
physical rehabilitation	exergame

The search was carried out on the 15th of September 2021 in the search engine Engineering Village, outputting 1019 recordings. Several filters were used when searching, taking into account the first four exclusion criteria set in Table 3. The language was set to English, the date was set to recordings published after the

year 2000, and conference proceedings were omitted. The search was conducted in the fields *subject*, *title*, and *abstract*. A research information systems (RIS) file was downloaded and inserted into an EndNote library. There, duplicates were removed, leaving 682 articles.

As the search was done only in Engineering Village, articles that are not found in their database were omitted. For instance, the study done by Burke et al. (2009) fits perfectly with our inclusion criteria but does not appear in a search in Engineering Village. Therefore, it was not included in our review.

Table 3: Inclusion and exclusion criteria.

Inclusion	Exclusion
1. The study offers empirically based insights on how interactive games for physiotherapeutic or physical rehabilitation of patients can be designed. 2. The study offers insights on how games for physical therapy and rehabilitation should be designs as part of its key contributions.	1. Non-English articles. 2. Articles published earlier than the year 2000. 3. Review articles. 4. Non-peer-reviewed articles, books, and dissertations. 5. Articles with less than 5500 words excluding references, acknowledgements, appendices (i.e., short papers and extended abstracts). 6. Studies that focus on the design of physiotherapeutic devices (e.g., sensors) that are evaluated as part of an interactive game context. 7. Studies that provide measured health effects of interactive game solutions used in physiotherapy or physical rehabilitation as a key contribution. 8. Studies that focus on platforms for design and development of gamified solutions for physiotherapy. 9. Studies that describe the same game as another study but contain less design knowledge or less details on the game objective.

Inclusion and Exclusion Criteria

Table 3 shows the inclusion and exclusion criteria created by both authors and the supervisor for this SLR. Inclusion criterion 1 attended to include empirically-

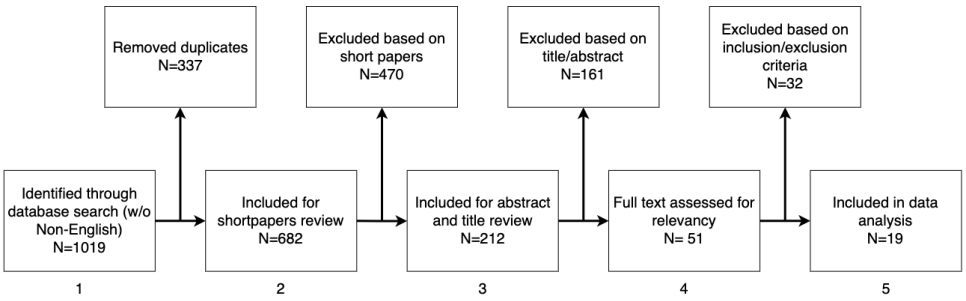


Figure 2: Flowchart showing the different stages of the review.

based articles, and inclusion criterion 2 was created to ensure the article offered design insights. Exclusion criterion 1 excludes non-English articles because translating them costs time. Exclusion criterion 2 excludes articles published earlier than 2000, as technology from that time would be far behind and not relevant in this review. Exclusion criteria 3 and 4 excludes review articles, non-peer-reviewed articles, books, and dissertations to ensure that the studies included met certain standards. Exclusion criterion 5 removes all articles with less than 5500 words, also known as *short papers* because these papers often do not have a significant impact in scientific research. Exclusion criterion 6 excludes studies that focus on hardware and devices, where the main goal is to evaluate for instance, a sensor and not the game itself. Exclusion criterion 7 excludes studies that focus on the health effects of the game rather than the user experience. Exclusion criterion 8 excludes articles that focus on a platform for developing gamified solutions instead of specifically designed games. The last exclusion criterion was created to guide handling articles describing games already included in another study. Examples of excluded articles based on these criteria will follow.

Selection Process

Figure 2 shows the different stages of the selection process. The first step of retrieving articles and removing duplicates was explained in Section 3.3.1. Next, short papers were excluded based on exclusion criterion 5 in Table 3: "Articles with less than 5500 words". The two authors went through about half of the articles each, doing a word count where 470 of the 682 recordings were found to be short papers. These were then removed, resulting in remaining 212 papers.

Title and Abstract Screening

The remaining 212 papers were screened based on their title and abstract. Both authors and the supervisor inspected the abstract of all the papers while deciding

whether or not they fulfilled the inclusion and exclusion criteria from Table 3. 77 of the papers were more challenging to decide whether to include or exclude and were therefore discussed in plenary. In total, 161 of them did not meet the defined criteria and were found irrelevant, which resulted in 51 papers for full-text screening. One example of a paper omitted in this step was (d'Ornellas et al., 2014), which, based on the abstract, did not fulfill inclusion criterion number 1 because there was no indication of an empirical evaluation.

Full-Text Screening

The full-text screening revealed more papers not complying with the inclusion criteria. Especially, many papers focused on the design of physiotherapeutic devices, and evaluated them as part of an interactive game context. An example of such a paper was a study by Bouteraa et al. (2019), which describes the development of a hand exoskeleton device. Although it looked relevant based on the abstract, the full-text screening revealed that it met the exclusion criterion 6 in Table 3. We also discovered two pairs of papers describing the same game. One such pair was papers by Vandermaesen, De Weyer, Coninx et al. (2013) and Vandermaesen, De Weyer, Luyten et al. (2014). They described the same game, but the one from 2013 had the most details in terms of the game objectives and design insights. Based on inclusion criterion 9, we decided to keep the one by Vandermaesen, De Weyer, Coninx et al. (2013). The two authors examined all of the papers, and the supervisor examined ten of the papers that later were discussed in plenary. In total, 32 papers were excluded in this step, leaving 19 papers for the final analysis.

3.3.2 Analysis

All 19 papers included in the final review were read by both researchers and organized in an Excel sheet. Based on what seemed relevant to the research, columns for different categories of information were added to the Excel sheet in advance of the analysis. Some additional columns were added later as new relevant patterns and categories were discovered. The final table can be seen in Table 7. The first column in the table shows which studies are included, the second, *Disorder/Body Parts*, gives an overview of the type of patient disorders, diseases, or body segments for which the games were designed. The third column, *Technology*, states which technology is used in the game. The fourth column, *Game Objective*, states the in-game goal(s) of each game, and the column *Design Intended Movements* provides information about which movements the patients are meant to perform while playing the game. The column *Methodology and Test Population* states the methodology used in the studies, what type of users, and how many of them were involved in the design process. Finally, the column *No. of physiotherapists Involved* gives an overview of how many physiotherapists participated in each study.

3.4 Results

This section will present the results from the analysis of the 19 studies remaining after the final round of screening. The goal of this research was to look at what types of games for physiotherapy were presented in the included studies (RQ1.1), what the purposes of those games were (RQ1.2), and what methodological approaches were chosen to design and evaluate the solutions (RQ1.3). To answer these research questions, the review focuses on the following aspects:

- Publications
- Target disorders and body parts
- Input/output technology
- Game purpose, objective, elements, player modes, and metaphors
- Design intended movements
- Mapping of movements
- Methodology and user involvement

which can be seen in Table 7 and Table 8.

3.4.1 Publications

A total of 19 papers (see Table 5 for an overview) were included in the final collection of papers in this review. The database search included 21 years of research papers, from 2000-2021. However, the oldest papers included in this final review were published in 2012, and 53% (10/19) of them were published between 2018 and 2021. There was a great variation in publishing place and no clear trend in where the papers were published. However, nine papers (47%) were published in a conference proceeding, nine papers (47%) in journals, and one paper (5%) in a workshop proceeding.

3.4.2 Disorders and Body Parts

All of the games were designed for specific patient groups, body parts or disorders. Six studies (32%) focused on upper limbs (Van Delden et al., 2012, Hocine et al., 2015, Elor, Teodorescu et al., 2018, Cuthbert et al., 2019, Turp et al., 2019, Elor, Powell et al., 2021), four (21%) on stroke (Hocine et al., 2015, Pyae et al., 2015, Madeira et al., 2017, Feingold Polak and Tzedek, 2020) two (11%) on cerebral palsy (Henschke et al., 2012, Van Delden et al., 2012) and two (11%) on PD (Smeddinck et al., 2013, Paraskevopoulos et al., 2014). There were also seven other rehabilitation targets that were the focus of one study each. Details can be found in Table 4.

Table 4: Disorders and body parts designed for in the studies.

Disorder/Body Part	No. of Studies	Studies
Upper Limb	6	Van Delden, Aarts & Van Dijk (2012), Hocine et al. (2015), Elor, Teodorescu & Kurniawan (2018), Cuthbert, Turkay & Brown (2019), Turp et al. (2019), Elor et al. (2021)
Stroke	4	Hocine et al. (2015), Pyae, Luimula, & Smed (2015), Madeira et al. (2018), Polak & Levy-Tzedek (2020)
Cerebral Palsy	2	Henschke, Hobbs & Wilkinson (2012), Van Delden, Aarts & Van Dijk (2012)
Parkinson's Disease	2	Smeddinck, Gerling & Tiemkeo (2013), Paraskevopoulos et al. (2014)
Neurological Disorders	1	Vandermaesen et al. (2013)
Muscle-Strength	1	Richards & Gramham (2016)
Neck	1	Mihajlovic et al. (2018)
Motor Rehabilitation	1	Cavalcanti et al. (2019)
Low Back Pain	1	Alazba, Al-Khalifa & AlSobayel (2019)
Use of Prosthetic Arms	1	Smith et al. (2018)
Lower Limb	1	Goh, Tan & Lee (2017)

3.4.3 Input/Output Technology

Table 5 shows an overview of the input/output technologies, the technology that registers the signals created by the player, and that which gives feedback to the user used in the studies. 84% (16/19) were screen-based, and five of these used VR. In this thesis, screen-based is defined as output shown on a conventional screen that is essential for the gameplay. For instance, Vandermaesen, De Weyer, Coninx et al., 2013 has small screens on the cubes but is not considered as a screen-based game. 32% (6/19) used motion capture cameras, Kinect being the most popular used by four.

3.4.4 Game Purpose

All papers described the *game purpose*; the intended results or effects from playing the designed game (listed in Table 6). 63% (12/19) of the studies emphasized that the purpose of creating a game was to increase either the enjoyment during the rehabilitation exercises or the motivation for completing the recommended number of exercises. Three highlighted the goal of assisting the therapist, wanting the game to provide support and be a tool the therapists could use to further expand their options. Six mainly focused on the outcome or health effect as the primary purpose, such as doing the correct movements or simply the rehabilitation goal itself. Finally, one had the purpose of guiding and correcting the movements.

Table 5: Input/output technologies used in the studies.

Study	VR	Motion Capture Camera	Tangible	Screen-based
Henschke, Hobbs & Wilkinson, 2012				X
Van Delden, Aarts & Van Dijk, 2012			X	
Smeddinck, Gerling & Tiemkeo, 2013		X		X
Vandermaesen et al., 2013			X	
Paraskevopoulos et al., 2014				X
Hocine et al., 2015				X
Pyae, Luimula, & Smed, 2015		X		X
Richards & Gramham, 2016		X		X
Goh, Tan & Lee, 2017			X	X
Elor, Teodorescu & Kurniawan, 2018	X			X
Madeira et al., 2018		X		X
Mihajlovic et al., 2018	X			X
Smith et al., 2018				X
Alazba, Al-Khalifa & AlSobayel, 2019	X			X
Cavalcanti et al., 2019		X		X
Cuthbert, Turkay & Brown, 2019	X			X
Turp et al., 2019		X		
Polak & Levy-Tzedek, 2020			X	X
Elor et al., 2021	X			X
Total:	**5**	**6**	**4**	**16**

Table 6: Purpose of the game.

Study	Enjoyment/ Motivation	Assisting Therapist	Health Effect	Correcting Movements
Henschke, Hobbs & Wilkinson, 2012	X		X	
Van Delden, Aarts & Van Dijk, 2012	X			
Smeddinck, Gerling & Tiemkeo, 2013			X	
Vandermaesen et al., 2013	X			
Paraskevopoulos et al., 2014	X			
Hocine et al., 2015			X	
Pyae, Luimula, & Smed, 2015			X	
Richards & Gramham, 2016	X		X	
Goh, Tan & Lee, 2017	X			
Elor, Teodorescu & Kurniawan, 2018	X			
Madeira et al., 2018		X		
Mihajlovic et al., 2018			X	
Smith et al., 2018	X			
Alazba, Al-Khalifa & AlSobayel, 2019	X			
Cavalcanti et al., 2019				X
Cuthbert, Turkay & Brown, 2019	X			
Turp et al., 2019	X			
Polak & Levy-Tzedek, 2020	X	X		
Elor et al., 2021		X		
Total:	**12/19**	**3/19**	**6/19**	**1/19**

Table 7: Overview of the included studies.

Study	Disorder/ Body Parts	Technology	Game Objective	Design Intended Movements	Methodology and Test Population	No. of Physio-therapists Involved
Henschke, Hobbs & Wilkinson, 2012	Cerebral Palsy	Analogue joystick, screen	*Space stuntz*: Navigate a spaceship through rings *Biplane*: Fly and barnstorm a civil aviation	*Not specified*	1 Pilot study. 1 real user	0
Van Delden, Aarts & Van Dijk, 2012	Upper Limb Cerebral Palsy	Tagtiles	*Hitting game*: Hit blinking squares. *Animal game*: Place correct animal on the board *Boat shooting game*: Aim to destroy target. *Quiz game*: Answer questions correctly	*Hitting game*: Rotation of the hand backwards *Animal game*: Extension of the elbow and training of several grasps *Boat shooting game*: Rotation of the hand backwards *Quiz game*: Pincher grasp, rotating the arm	Participatory design approach 6 rounds of interactions with users. in total: 10 children w/CP 10 participants: without CP 9 children (*Not specified*)	8
Smeddinck, Gerling & Tiemkeo, 2013	Parkinson's Disease	Webcam, PC (Windows 7)	*Fish Harvester*: Catch fish with hook and net	Therapy- appropriate wide and fluent movements	Within-subjects design 15 with/Parkinson's Disease	0
Vandermaesen et al., 2013	Neurological Disorders	Sensor board, sifteo cubes, screen display	*LiftACube*: Open locks with correct key	Lifting and stabilizing an object on a predefined height	Patient-centric design 4 w/Neurological Disorders	4
Paraskevopoulos et al., 2014	Parkinson's Disease	Nintendo Wiimote, Motion capturer, Local computers, remote terminal	*The Rowing Game*: reach a destination in time by rowing a boat *The Steam Mini-golf Game*: Push the ball into the hole within a given time	Rowing game: Arm reaching Steam Mini-golf game: "Rolling a ball" exercise	Patient-led design 5 w/Parkinson's Disease	0
Hocine et al., 2015	Upper Limb Stroke	Graphics tablet	*PRehab*: Protect nature by collecting gems.	Upper-arm rehabilitation through pointing tasks using mouse of a graphics tablet.	User-centered approach In total: 8 healthy 8 post-stroke patients	7

Table 7: Overview of the included studies (continued).

Study	Disorder/ Body Parts	Technology	Game Objective	Design Intended Movements	Methodology and Test Population	No. of Physio-therapists Involved
Pyae, Luimula, & Smed, 2015	Stroke	Extreme Reality, regular webcam, Xbox console, PlayStation console, Microsoft's Kinect, 2 large-screen TVs.	*Puuha's SportWall*: Ride a skateboard and avoid obstacles *Climbing game*: *not specified* *Tennis game*: *not specified*	*Puuha's Sport Wall*: Side-swaying, sit-to-stand, jump actions	User-centered design & rapid prototyping 7 post-stroke patients	Yes
Richards & Gramham, 2016	Muscle-Strength	Kinect camera, screen	*Brains & Brawn*: Defeat their opponent by reducing all enemy characters' health to zero.	Repetitive-motion exercises	Iterative design process 8 persons (*not specified)*	0
Goh, Tan & Lee, 2017	Lower Limb	Heel raise measurement device, Android mobile phone.	*Running game*: Avoid obstacles and collect stars *Jumping game*: Jump and get as high as possible	Heel raises	Using heuristic guidelines created for video games and digital games designed for elderly persons 8 older adults (*not specified)*	2
Elor, Teodorescu & Kurniawan, 2018	Upper Limb	HTC Vive system (headset, controllers, lighthouses), screen	*Project Star Catcher*: Catch falling stars	Rehabilitative arm movements with weak arm	User-centered design method 15 with need of training Upper Limb.	Yes
Madeira et al., 2018	Stroke	Microsoft Kinect Natural User Interface, LeapMotion sensors, screen	*Eco*: Collect and sort waste material *Noir*: Identify objects *Bill*: Harvest metals *Game4*: Follow and reach objects that appear sequentially on screen	A set of upper-limb (hand/finger) movements while the patient is seated	Best practices in UI, UX and NUI design 18 healthy	Yes

Table 7: Overview of the included studies (continued).

Study	Disorder/ Body Parts	Technology	Game Objective	Design Intended Movements	Methodology and Test Population	No. of Physio-therapists Involved
Mihajlovic et al., 2018	Neck	Oculus Rift DK2 VR headset, PC, audio headphones	Catch butterflies	Combinations of sudden high-speed head-neck movements and smooth movements, including static positioning.	Comprehensive user study 30 healthy	Yes
Smith et al., 2018	Use of Prosthetic Arms	Flex control, keyboard control, screen	*Who nose?:* Discovering items in the nose *Smash bro:* Smash buildings and enemies *Sushi Slap*: Slap customers interested in squid *Crazy Meteor*: Clear a space area of meteors with small spaceship *Beeline Border Collie*: Control a dog to jump over fences	Flexing of the arm.	Design method *not specified* 3 children in need of prosthetic arms 40 healthy	0
Alazba, Al-Khalifa & AlSobayel, 2019	Low Back Pain	Android/iOS Mobile Phone, VR headset	*RabbitRun*: Avoid obstacles and collect points.	Trunk flexion (forward bending), trunk extension (backward bending), lateral flexion, trunk rotation.	Design method *not specified* 16 healthy	4
Cavalcanti et al., 2019	Motor Rehabilitation	ARkanoidAR, Kinect sensor	*ARkanoidAR*: Hit the bricks to score	Shoulder and elbow flexion exercises	Design thinking methodology 45 healthy	0
Cuthbert, Turkay & Brown, 2019	Upper Limb	HTC Vive headset	*Throw ball:* Throw a ball into a goal	Simple mechanics of throwing a ball that shares similarities with upper-body rehabilitation exercises	A randomized between-subjects experimental design 60 healthy	0
Turp et al., 2019	Upper Limb	Robot	*Robotic Simon*: Repeat the robot's poses	For example: straight flexion, arm up, extension, touch head	Two evaluations 14 healthy adults 56 healthy children	0

Table 7: Overview of the included studies (continued).

Study	Disorder/ Body Parts	Technology	Game Objective	Design Intended Movements	Methodology and Test Population	No. of Physio-therapists Involved
Polak & Levy-Tzedek, 2020	Stroke	Robot, robot screen	*Kitchen game*: Ordering a set of jars *Cup game*: Ordering a set of colored cups *Target game*: Ordering a set of colored cups *Keys game*: Ordering a set of colored keys *Wallet game*: Take keys out of wallet. *Drawer game*: Take objects out of drawers *Card game*: Manipulation of cards	Reach to grasp movements *Target game*: spatial perception and a multidimensional movement of the hand in different directions on the plane of the table. *Keys game*: holding and manipulating a set of keys *Drawer game*: Combination of spatial perception and movement as well as manipulation of small objects.	Participatory design study 4 post-stroke patients	12
Elor et al., 2021	Upper Limb	Vive Hand Controller, VR	*PBF*: Protect a butterfly	Forward Arm Raise, Side Arm Raise, Shoulder Rotation, External Rotation, Abducted Rotation, Mixed Press, and Mixed Circles.	A user study 5 with need of training Upper Limb.	Yes

3.4.5 Game Objective

An overview seen in Table 8 was created to study the games further. The column *Game* contains the names of the games in the studies and the column *Theme/Game Metaphor* provides information about the game world or setting of the game. The *game objective* refers to the in-game goal, like defeating the enemy or reaching a destination, and must not be confused with *game purpose* in the previous subsection, which describes the intended effects of the game. Most of the studies had only brief descriptions of their games, and it was not evident in all of them what the main objective was. However, information on what was found about the game objectives can be seen in the *Game Objective* column in Table 8. Many of the games seem to be mini-games or arcade games that do not have a storyline, different levels, or advancement in difficulty, but some, like *PRehab* (Hocine et al., 2015), describe a game with multiple levels and quests.

3.4.6 Game Elements

The columns to the right in Table 8, *Precision, Time*, and *Points*, describe some of the *game elements* or characteristics we found in the games. Game elements or mechanics can be timers, points, rewards, levels, winning, collaboration, creating or other factors that make a game a game (Ferro, 2021). 55% (22/40) of the games include the game element of *points* as a type of feedback. Some games had other types of feedback, for instance, the *Animal Game* by Van Delden et al. (2012). When a player places the proper animal, he is rewarded by a sound, for instance, *'Well done, a dog'* or an animal sound is played. Where no X is represented in the table cell, the study did not state anything that points to the corresponding characteristic being included in the game. Eight games included a time aspect, like needing to reach a destination in time or catching or hitting something before it disappeared or moved.

3.4.7 Player Mode

In this study, *player mode* refers to the option of playing single- or multiplayer mode. Only two of the studies (Elor, Powell et al., 2021 and Henschke et al., 2012) explicitly stated the game to be a single-player game. None of the other articles stated whether the game was a single- or multiplayer game. When looking at the game description and the embodiment of the user tests, it was obvious that none of them had the option of playing multiplayer. Nevertheless, one did mention the game having *opponents* (Richards and Graham, 2016), and another said it had competitive scores (Vandermaesen, De Weyer, Coninx et al., 2013).

3.4.8 Player View and Player Representation

Player view, which can be found as a column in Table 8, refers to the in-game perspective of the player. The games can have two different player views: first-person view (FPV), where the player is involved in the game from their own point of view, and third-person view (TPV) where they control someone or something else in the game. These categories are mainly used for screen-based games, but seven of the games in this study were tangible games. For simplicity, all the tangible games were categorized as FPV since the player experiences what is happening from their own perspective. This categorization results in 24 FPV games, nine TPV games, and seven games where the studies had insufficient information about the game view.

The player controls an avatar in seven of the TPV games, and a plane or a spaceship in the remaining two. For the FPV games, examples of what the player controls are a spaceship (Henschke et al., 2012), a hook and net (Smeddinck et al., 2013, Mihajlovic et al., 2018), a finger (Smith et al., 2018) oars (Paraskevopoulos et al., 2014), and a bubble shield (Elor, Powell et al., 2021).

3.4.9 Themes and Game Metaphors

The themes and game metaphors can be seen as the game world the player immerses in or the gameplay setting. There was a great variety in themes and metaphors; however, some themes were seen in multiple games. For instance, a theme of completing everyday tasks was seen in nine games (Feingold Polak and Tzedek, 2020 [eight games], Vandermaesen, De Weyer, Coninx et al., 2013), animals were found in nine games (Van Delden et al., 2012, Smeddinck et al., 2013, Hocine et al., 2015, Richards and Graham, 2016, Mihajlovic et al., 2018, Smith et al., 2018 [two games]), Alazba et al., 2019, Elor, Powell et al., 2021), sports was a theme in four games (Pyae et al., 2015 [three games], Paraskevopoulos et al., 2014) and space was a theme in three games (Henschke et al., 2012, Elor, Teodorescu et al., 2018, Smith et al., 2018).

3.4.10 Design Intended Movements

Design intended movements are movements the designers facilitate through the game. Playing the game should result in the player performing one or more of those intended movements. Ten of the studies (53%) (Van Delden et al., 2012, Paraskevopoulos et al., 2014, Pyae et al., 2015, Goh et al., 2017, Turp et al., 2019, Mihajlovic et al., 2018, Alazba et al., 2019, Virgínia Carrazzone Cavalcanti et al.,

2019, Feingold Polak and Tzedek, 2020, Elor, Powell et al., 2021), described specific movements they had considered and designed for when creating the games. Examples of such movements are *pincher grasp*, *trunk flexion*, *trunk extension*, *forward arm raise*, and *shoulder rotation*. Eight studies (42%) (Smeddinck et al., 2013, Richards and Graham, 2016, Elor, Teodorescu et al., 2018, Madeira et al., 2017, Cuthbert et al., 2019, Vandermaesen, De Weyer, Coninx et al., 2013, Hocine et al., 2015, Smith et al., 2018), mentioned more general movements, such as *repetitive-motion exercises* and *therapy-appropriate wide and fluent movements*, while one study (5%) (Henschke et al., 2012) did not specify any design intended movements.

3.4.11 Mapping of Movement

How the player's movements affect what happens in the game, the *Mapping of Movement*, depends on the technology used in the game. An overview of the mapping of movements in the games in this study can be seen in Table 8. Some tangible games required lifting and placing physical objects, like *the Animal Game* (Van Delden et al., 2012) or *the Kitchen Game* (Feingold Polak and Tzedek, 2020). In others, buttons must be pressed, or movements must be copied. Some of the games have natural movement mapping, like in *Space Stuntz* (Henschke et al., 2012), where moving a joystick to the left moves the spaceship to the left , or in *Puuha's SportWall* (Pyae et al., 2015), where moving the player's body left or right makes the avatar and its skateboard steer right or left . Other games have a more indirect mapping of movements, like the *Jumping Game* (Goh et al., 2017), where the player performs heel raises to charge the jumping power.

3.4.12 Methodology and User Involvement

89% of the studies (17/19) used a qualitative methodology, and 26% (5/19) used a quantitative methodology. However, only eight of them explicitly stated their methodology. 42% (8/19) of the studies had only one evaluation with users and did not describe an iterative process. Three other studies did not describe any user involvement apart from a user evaluation, but these three studies conducted multiple evaluations, allowing them to improve their solutions between the evaluations. The last eight studies included more steps in their process, like interviews with physiotherapists and observational studies of therapy sessions (Van Delden et al., 2012) or focus groups with physiotherapists (Alazba et al., 2019). All of the studies involved users in the process, but seven of them did not involve, or specify the involvement, of physiotherapists. There was a great variation in the names used for their design approaches, but many of them focused on involving users.

3.4.13 Context of Use

The intended context of use, when and where the games are intended to be played, was not specified in most papers. However, ten (53%) specifically stated or indicated that the games were designed for use at home, while only two papers (11%) specified that the games were designed for use in a clinic.

Table 8: Overview of games in the study.

Study	Game	Theme/ Game Metaphor	Game Objective	Mapping of Movement	In-Game Player View	Precision	Time	Points
Henschke, Hobbs & Wilkinson, 2012	*Space Stuntz*	Space, flight	Navigate a spaceship through rings,	Moving joystick up, down, left, and right translates to absolute movements	FPV: in space-ship	X		X
	Biplane	Flight	Fly and barnstorm a civil aviation.	Full force on joystick will case plane to move left or right.	TPV: Plane	X	X	X
Van Delden, Aarts & Van Dijk, 2012	*Hitting Game*	NS	Hit blinking squares.	Raise palm and hit the square to gain points.	FPV*	X	X	X
	Animal Game	Animals	Place correct animal on the board.	Pick a miniature animal and place it on the board at the square lit in this color	FPV*	X		
	Boat Shooting Game	Pirates/boat	Aim to destroy target.	The rotation of the boat requires rotating the hand backwards	FPV*	X		
	Quiz Game	Knowledge, game show	Answer questions correctly.	Multiple choice answers can be heard by rotating a block over the board. Select the correct answer by placing an answer disc onto the board.	FPV*			X
Smeddinck, Gerling & Tiemkeo, 2013	*Fish Harvester*	Animals, fish, sea	Catch fish with hook and net.	NS	FPV: hook, net	X	X	X
Vandermaesen et al., 2013	*LiftaACube*	Lock & key, everyday task	Open locks with correct key.	A patient needs to lift and stabilize the key cube at the level of the lock cube for three seconds before the lock is opened	FPV*	X	X	X
Paraskevopoulos et al., 2014	*The Rowing Game*	Boat/rowing	Reach a destination in time by rowing a boat.	Arm reaching to row.	FPV: oars	X	X	X
	The Steam Mini-golf Game	Sports	Hit a target.	Rolling a ball exercise to rotate the valve	FPV	X	X	X
Hocine et al., 2015	*PRehab*	Protect nature, animals	Protect nature by collecting gems.	Using the mouse of a graphics tablet, the patient has to reach virtual targets through pointing tasks.	TPV: avatar	X	X	X

Table 8: Overview of games in the study (continued).

Study	Game	Theme/ Game Metaphor	Game Objective	Mapping of Movement	In-Game Player View	Precision	Time	Points
Pyae, Luimula, & Smed, 2015	*Puuha's SportWall*	Sports/ skateboarding	Ride a skateboard and avoid obstacles.	*Puuha's SportWall*: Control the movement of skateboard by moving the body from left to right. Avoid the obstacles by jumping or sitting position.	TPV: Avatar on skate-board			X
	Climbing Game	Sports	NS	*Climbing Game:* NS	NS			
	Tennis Game	Sports	NS	*Tennis Game:* NS	NS			
Richards & Gramham, 2016	*Brains & Brawn*	Strategy card game, circus theme, animals	Defeat their opponent by reducing all enemy characters' health to zero.	Strategy mode: Player controls game using gesture controls. Combat mode: Player attacks enemy (arrows flying to enemy) while exercising.	FPV: card player			
Goh, Tan & Lee, 2017	*Running Game*	NS	Avoid obstacles and collect stars.	Perform heel raises to build up power for high jumps, more heel raises result in higher jumps, and to time the jump of the character that moves sideways.	TPV: avatar			
	Jumping Game	Platformer game	Jump and get as high as possible.		TPV: avatar	X		
Elor, Teodorescu & Kurniawan, 2018	*Project Star Catcher*	Space	Catch falling stars.	Stars are caught when the player touches them with a Star Catcher (HTC Vive controllers), resulting in haptic feedback as the controller vibrates.	FPV: Star catcher in hand	X	X	X
Madeira et al., 2018	*Eco*	Nature	Collect and sort waste material.	One or more primary movements are executed to reach the object and drag it to the appropriate container.	NS	X		X
	Noir	Detective	Identify objects..		NS			X
	Bill	Wild west	Harvest metals	The required hand for a movement must be used for it to be recognized as valid.	FPV	X		X
	Game 4	NS	Follow and reach objects that appear sequentially on screen.		NS	X		X
Mihajlovic et al., 2018	*NS*	Animals	Catch butterflies.	Align the view orientation to the target butterfly sufficiently fast. Then track the moving butterfly as accurately as possible for a few seconds to catch it.	FPV: net	X		X

Table 8: Overview of games in the study (continued).

Study	Game	Theme/ Game Metaphor	Game Objective	Mapping of Movement	In-Game Player View	Precision	Time	Points
Smith et al., 2018	*Who Nose?*	Humor, nose-picking	Discovering items in the nose.	*Who nose?:* A flex acts as an input and flexing is not matched one to one to the players input. As the user flexes various activities occur. *Smash bro:* Punching while walking. *Sushi slap:* Time flexing at the same time as inputting a direction by pushing an arrow key for directional slap. *Crazy meteor:* Shoot a main gun by flexing in the EMG controller. *Beeline Border Collie:* Each flex input causes the dog to jump over obstacles. Stop flexing to line up for the next jump.	FPV: finger	X		
	Smash Bro	Smash'em up side-scrolling game	Smash buildings and enemies.		TPV: Hulk avatar			X
	Sushi Slap	Restaurant, defense style game, animals	Slap customers interested in squid.		NS	X		X
	Crazy Meteor	Space, asteroids arcade game	Clear a space area of meteors with small spaceship.		TPV: spaceship			X
	Beeline Border Collie	Animals, endless running and jumping	Jump over gates to avoid hitting them.		TPV: dog avatar	X		X
Alazba, Al-Khalifa & AlSobayel, 2019	*RabbitRun*	Animals, rabbit walking on the village road	Avoid obstacles and collect points.	Each exercise is mapped to one game challenge e.g., to avoid the concrete block, the player has to perform lateral flexion exercise to move the Rabbit to the left or right.	TPV: Rabbit avatar	X		X
Cavalcanti et al., 2019	*ARkanoidAR*	Breakout at atari classic game	Hit the bricks to score.	Uses the Kinect sensor to track body joints and this way to measure angles and recognize movements. The first version of ARkanoidAR works only with movements at the sagittal plane.	NS	X		X
Cuthbert, Turkay & Brown, 2019	VR game	NS	Throw a ball into a goal.	The VR game has simple mechanics of throwing a ball into a goal located in front of the player.	FPV: ball in hands	X		
Turp et al., 2019	*Robotic Simon With Poses*	Robot therapist, simon game.	Repeat the robot's poses.	The robot comments whether your pose is correct or not. If correct, the robot moves on to the next sequence.	FPV*	X		

Table 8: Overview of games in the study (continued).

Study	Game	Theme/ Game Metaphor	Game Objective	Mapping of Movement	In-Game Player View	Precision	Time	Points
Polak & Levy-Tzedek, 2020	*The Kitchen Game*	Everyday task (arrange jars on shelves)	Ordering a set of jars.	Arrange a set of actual physical jars on shelves at three different heights according to a picture displayed on the robots' tablet. In each session, the patient collects points for the number of objects they correctly arranged. Push a button to signal having finished the task.	FPV*	X		
	The Cup Game	Everyday task (order cups)	Ordering a set of colored cups.		FPV*	X		
	The Target Game	Everyday task (order cups)	Ordering a set of colored cups.		FPV*	X		
	The Keys Game	Everyday task (order keys)	Ordering a set of colored keys.		FPV*	X		
	The Wallet Game	Everyday task (take keys out of wallet)	Take keys out of wallet.		FPV*	X		
	The Drawer Game	Everyday task (take objects out of drawers)	Take objects out of drawers.		FPV*	X		
	The Card Game	Everyday task (cards)	Manipulation of cards.		FPV*	X		
Elor et al., 2021	*Project Butterfly (PBF)*	Animals, protect a butterfly	Protect a butterfly.	Use a translucent protective "bubble shield" that is controlled by the player through the Vive Hand Controller to protect the butterfly. The user must follow the path of the butterfly with a 0.1 meters error.	FPV: bubble shield	X		

FPV: First Person View
TPV: Third Person View
* FPV in a physical/tangible game

3.5 Discussion

This section discusses the trends and findings we consider the most interesting among the results from Chapter 3.4. The following trends will be discussed:

- Disorders and Body Parts
- Screen-Based vs. Tangible Technology
- Design Intended Movements
- Game Objective
- Player View and Player Representation
- Player Mode
- Game Context of Use
- Methods
- Involvement of Physiotherapists in the Design Process

To conclude the discussion, four takeaways based on the findings will be presented: *Increase Focus on Game Design*, *Include Information About Game Design Process*, *Involve Physiotherapists* and *Consider the Context of Use*.

3.5.1 Trends

This section discusses some of the trends from Chapter 3.4.

Disorders and Body Parts

As much as six of the papers (32%) developed games specifically designed for patients to train upper limbs (see Figure 4), and four (21%) were developed for post-stroke rehabilitation. All studies specified a disorder, disease, or functional body unit, which the game was designed for, and did not seem to develop solutions meant to be used of a broad group of patients. These findings indicate that the greatest amount of research has been done on rehabilitation games for a specific type of patient and that there might be potential for further exploration and research about games designed to fit more than one type of patient.

Screen-Based vs. Tangible Technology

Interestingly, but not surprisingly, only four (21%) of the papers included in this study describe tangible games, while 84% (16/19) describe screen-based games. One reason may be the concern of developing low-cost applications, mentioned by

Paraskevopoulos et al. (2014), and for the games to be easily available for all users. However, using these off-the-shelf platforms, like screens, does put constraints on the user's interaction and the movements the user can perform. As movement is important within physiotherapy, this is a major concern. Screens force the user look in a certain direction or be connected by a cable. Without a screen, the user would have more freedom in terms of movements, as well as where the exercises can be performed.

Design Intended Movements

Most of the studies provided some information about the design intended movements. Some studies designed games for very particular movements, while others for more general movements. Of the eleven studies that mentioned the involvement of physiotherapists, seven (64%) described specific design intended movements, and four (36%) described more general movements. The one study that did not specify design intended movements did not mention the involvement of physiotherapists. This might indicate that the involvement of physiotherapists leads to more specific design intended movements. However, there was not found a correlation between which disorders or body parts the games were designed for and how specific the design intended movements were.

Game Objective

Many of the games in this study seemed to be arcade-like mini-games with only one level, where the player competes with their own high score. Since progress, challenge and curiosity are important game concepts needed to make engaging games that people will enjoy playing (Malone, 1980), it would be helpful to see how the games in this study performed as a motivational factor after having been played for an extended period of time. One of the games included in this study that is not an arcade/mini-game is *PRehab* where they have clearly considered this aspect. They state in the study: "*since rehabilitation is a long process, the challenge for game designers is to create games which can generate patient excitement and sustain their motivation throughout the entire duration of the therapy.*" (Hocine et al., 2015, p. 9). The time and expenses required to design and evaluate such long-lasting games may be why many of the games in this study are mainly short mini-games. However, another reason may be that the researchers have paid more attention to the physiotherapy effects and the developed technology than the game design itself.

Player View and Player Representation

The majority of the games, 60% (24/40), were from a first-person view (FPV). This might be because the target users of rehabilitation games do not necessarily have much gaming experience. An FPV can be easier for an inexperienced player since the mapping of movements often is closer to reality and movements they are used to doing than a third-person view (TPV) where the movements are more indirect. A TPV can be more challenging because it often requires more motor skills and guidance for how to play. Among the games with a TPV, the player controlled an avatar in seven of the games.

Player Mode

All games were evaluated in single-player mode, and did not mention any multiplayer aspect, indicating that there was no option for multiplayer. One study reflected on the importance of socializing for the elderly (Pyae et al., 2015); however, they did not seem to include this aspect in their game design.

Game Context of Use

While some studies explain that their game is developed to be used at home or the clinic, most studies do not explicitly state their context of use. It is not clear whether the reason for this is that the games are intended to be used regardless of context, or if the authors simply did not consider this aspect. One explanation for the lack of information about the intended context of use could be that many research projects and experiments are conducted at universities and tested in laboratories. Also, most of the games included in this study are only prototypes and not commercial games and are created for experimental purposes.

Methods

The majority of the studies used a qualitative method, although only a few explicitly stated their chosen method. A reason for using a qualitative method might be that it is a good way to measure usability. It is also interesting to note that only three of the studies did more than one user test that allowed them to improve their design solution. One explanation can be time constraints on the project.

Involvement of Physiotherapists in the Design Process

Another observation is the varied involvement of physiotherapists. All studies involved users in some form of evaluation. Some included actual patients, while others included, for instance, university students. A reason for this might be the inclusion criteria requiring the studies to be empirically based. Some also included physiotherapists early in the process through interviews (Pyae et al., 2015) or brainstorming sessions (Elor, Teodorescu et al., 2018), and some physiotherapists participated in evaluations with patients (Hocine et al., 2015). However, as many as eight studies did not mention the inclusion of physiotherapists in any point of their design process. This lack of inclusion may be because recruiting both patients and physiotherapists can be very demanding. Additionally, physiotherapists may have limited availability; thus, including them would increase the complexity of the study.

3.5.2 Takeaways Based on Findings

Findings from the results and discussed aspects are summarized in four key takeaways.

Increase Focus on Game Design

Motivation and engagement of serious games and exergames can benefit from good game design and motivational affordances (Kappen et al., 2019). Therefore, research on motivational games for physiotherapy should include information about the game design and motivational affordances that are used and considered in the design, not only the technology used or the health effects.

Include Information About Game Design Process

Providing an explanation and overview of how the games are designed, and the game design process, can be advantageous in order to identify which processes are efficient and convey that information to others working to develop similar types of games.

Involve Physiotherapists

Research about physiotherapy games should provide information about physiotherapist involvement. When games are designed for physiotherapy, physiotherapists are needed to ensure that the games fulfill their therapeutic purposes and are

safe and effective for the patients involved. Also, when actively involved, physiotherapists can contribute with valuable guidance, knowledge, and ideas that can improve the design solutions.

Consider the Context of Use

The context of use should be considered in the research since this factor could greatly affect the design of a game. For instance, a game intended for use in a clinic could include settings and equipment, calibration, and monitoring needed to be done by the physiotherapist. In contrast, a game designed for home use should be simple and affordable enough for regular patients to set up and play the game independently.

3.6 Summary of Key Findings

The goal of this SLR was to find patterns in previous studies done, find out what areas would need more research, and answer the first research question (RQ1). An SLR was conducted to achieve this goal, starting with 1019 takeaways and finally accepting 19 that were read and analyzed. The review resulted in some takeaways and findings for the three research questions.

The studies in this review showed that *types of interactive, game-based design solutions are developed for use in physiotherapy* (RQ1.1), consisted mainly of single-player games with an first-person view and more than half of the games included points as a game element. In addition, most studies focused on games using a conventional screen, or VR, while very few had developed non-screen based, tangible interactive games.

The purposes of the design solutions (RQ1.2) were for the majority of the studies to increase enjoyment and motivation for completing rehabilitation exercises. Other goals were to assist the therapist, get a positive health effect, or guide and correct movements. All of the games were designed for one specific disorder or body part. Finally, our findings show that *the methodological approaches for designing and evaluating the solutions* (RQ1.3) vary greatly and are often vaguely explained in the studies. However, most of the studies used a qualitative methodology, and all of them included users at some point in the process.

There is still a great potential for further research on games used in physiotherapy. Specifically, this SLR identified a gap concerning non-screen-based games and games designed for a great variety of patients. These types of games should be further explored.

Chapter 4

Research Design

4.1 User-Centered Design

User-centered design is a design process and philosophy where users are involved in the design process in some way and affect the outcomes and the design (Abras et al., 2004). This involvement of users is considered crucial to achieving usefulness and usability (Mao et al., 2005) and can be accomplished in many ways. There is usually more than one type of user where some might use the product directly, while others use it more indirectly or are affected by it somehow.

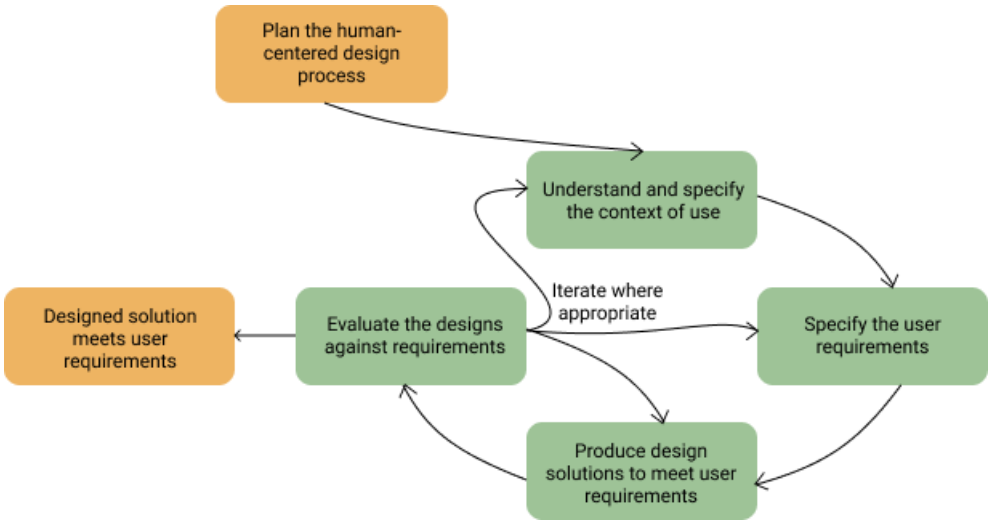


Figure 3: Design process according to the ISO standard 9241-210 (2010).

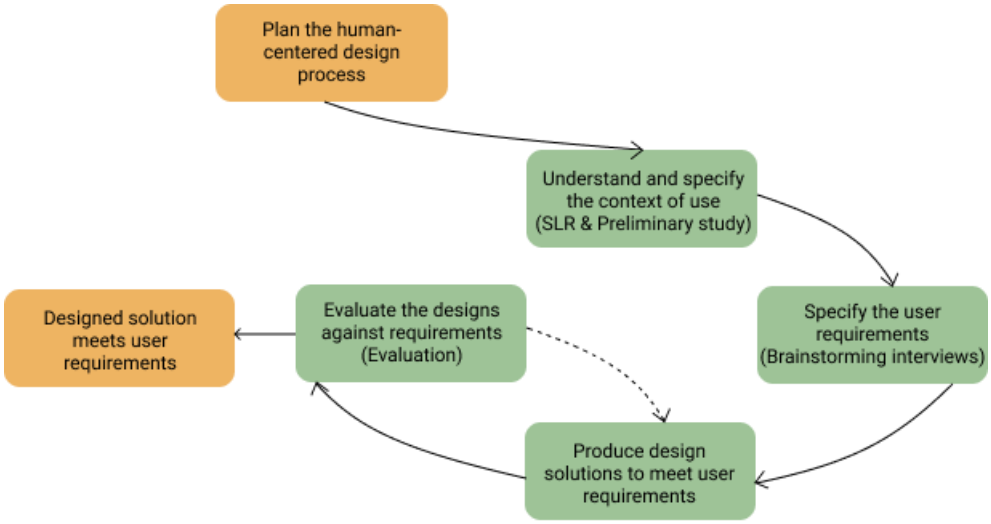


Figure 4: Overview of design process, adapted from the ISO standard 9241-210 (2010).

4.1.1 Planning

The ISO standard 9241-210 (2010) proposes a way to ensure a user-centered design process (shown in Figure 3). This process suggests how to include users and which activities to engage them in and inspired the researchers. However, the time limitations of the project (20 weeks) and national restrictions enforced due to the COVID-19 pandemic had to be taken into account to maintain a feasible plan. This resulted in a modified version of the design process which can be seen in Figure 4.

4.1.2 Implementation and Research Activities

In this project, physiotherapy patients and physiotherapists were the target users. To meet their needs and ensure a user-centered approach, it was essential to involve representatives from both groups in the design process. Physiotherapists and patients were involved from the beginning to understand and specify the context of use. Persons from both user groups were interviewed in a preliminary study, and physiotherapists participated in game idea brainstorming. Knowledge acquired from the first research activities was used in the solution design phase to create a functional prototype. Finally, in the evaluation phase of the project, both physiotherapists and potential physiotherapy patients were involved in evaluating the prototype. The results from the evaluation were used to suggest adjustments

for further development and propose some recommendations for the design of tangible interactive games for use in physiotherapy. An overview of the thesis' research activities can be seen in Figure 5.

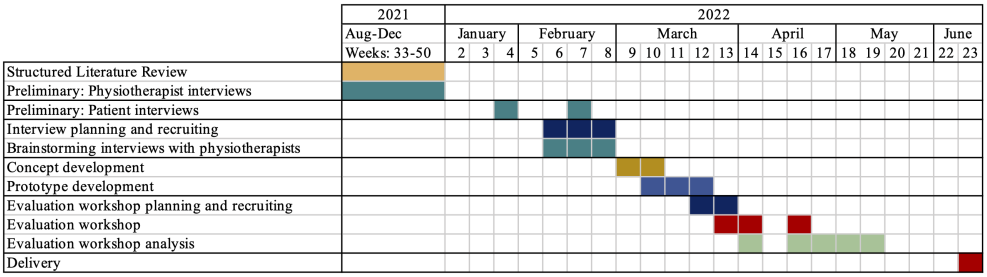


Figure 5: Gantt chart: Overview of research activities.

4.2 Data Collection

Various data collection methods were applied in this project and will be defined and described in this section. How they were implemented will be described later in the thesis.

4.2.1 Semi-Structured Interviews

An interview is a specific kind of conversation between people where the researcher's goal is to obtain detailed information from the interviewee. They are commonly used in research when the researcher wants to ask questions that are more complex and open-ended, as the corresponding answers are more easily expressed orally (Oates, 2006).

There are three types of interviews: structured, semi-structured, and unstructured. A structured interview is when the researcher reads the same question to each interviewee without engaging in a conversation. A semi-structured interview is when the researcher has a list of themes and questions to explore, but the order may differ depending on where the conversation goes. This type of interview allows the interviewee to go more into detail and opens to other topics introduced by the interviewee and is also the chosen interview type for this thesis. However, in an unstructured interview, the researcher would introduce some topics, and the interviewee can freely talk about their ideas, events, and behaviors. In such interviews, the researcher interrupts as little as possible (Oates, 2006).

Preliminary Interviews

Designing applications for a specific field requires the designers to obtain knowledge about that field and understanding the common challenges in the domain can be helpful later in the process. Semi-structured interviews with physiotherapists and patients were conducted to achieve such an understanding. Using this method, all planned topics were covered in each interview while also leaving room for relevant follow-up questions and individuals' interests, thoughts, and ideas. Further details can be found in Chapter 5.

Brainstorming Interviews

The initial plan was to hold a Co-Design Workshop to let the physiotherapist create, demonstrate and discuss different game design solutions. However, because of difficulty in recruitment due to limited access to target users and the COVID-19 situation, the workshops were replaced by *brainstorming interviews*. The brainstorming interviews were semi-structured interviews with the main goal of learning more about what physiotherapists view as important when designing games for use in physiotherapy and to explore ideas and find inspiration for a game concept. Further details can be found in Chapter 6.

4.2.2 User-Centered Evaluation

Van Velsen et al. (2008) defines a *user-centered evaluation* as "an empirical evaluation obtained by assessing user performance and user attitudes toward a system, by gathering subjective user feedback on effectiveness and satisfaction, quality of work, support and training costs or user health and well-being" (p. 262). Conducting such an evaluation can reveal issues in time to fix them and substantiate design decisions, which can lead to an improved user experience and adaption of a potential product (Van Velsen et al., 2008).

To allow for testing and evaluation of an early prototype within the limited time of this project, a *Wizard of Oz method* was chosen. When using this method, a researcher takes the role of a *wizard* and controls the prototype. The wizard provides an illusion of the prototype's intended functionality in order to get feedback on a concept from users (Dow et al., 2005).

A workshop was chosen as an evaluation method to allow users to actively participate in the evaluation of the concept and allow them to come up with their suggestions and ideas for improvement. Ørngreen and Levinsen (2017) defined a *workshop* as "an arrangement whereby a group of people learn, acquire new knowledge, perform creative problem-solving, or innovate in relation to a domain-

specific issue" (p.71). Further details on the evaluation can be found in Chapter 8.

4.3 Qualitative Analysis

This thesis is a qualitative study with qualitative data collection methods. Therefore, qualitative data analysis is the only analysis method used. Qualitative data analysis is not a straightforward task, but the main idea, as presented by Oates (2006), is: "*abstracting from the research data the verbal, visual or aural themes and patterns that . . . are important . . .*" (p. 267).

When analyzing qualitative data, the first step is to categorize each segment. There are two different approaches to selecting the categories: *a deductive approach* and *an inductive approach*. The deductive approach uses existing theories from the literature. A pitfall with this approach is overlooking other themes in the data. The inductive approach is about creating categories based on what can be found in the data and is also the chosen approach for analyzing this study's interviews. The main idea is to observe and let the data itself decide what categories to use. A possible disadvantage of using this approach is that the researchers' experiences and prejudices may affect the categories (Oates, 2006). When structuring data this way, the next step is to create tables or diagrams to visualize the data, making it easier to discover patterns, which again leads to theories.

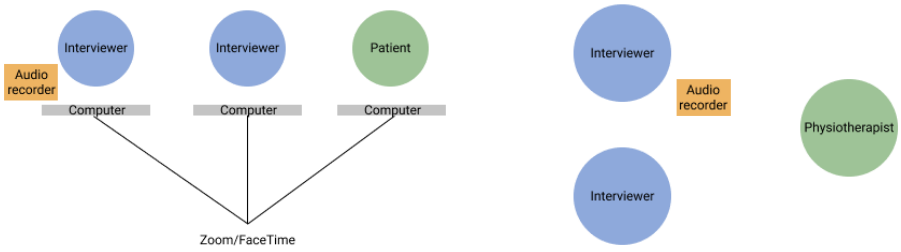
Chapter 5

Preliminary Study

A preliminary study was conducted to gain a broader understanding of the field of physiotherapy. Nine semi-structured interviews were completed with a two-on-one setup, some in-person (Figure 6b) and some digitally (Figure 6a). This chapter describes the process of preparing the interviews, recruiting participants, collecting and analyzing the data, and finally we present and discuss the findings.

5.1 Purpose

The purpose of the preliminary study, was to gain a broader understanding of the context of use. The first objective was to gain insight into how physiotherapists work, typical challenges they face, and what tools and equipment they typically use during patient treatment. Since physical therapy involves both physiotherapists and patients, a second objective was to get a better understanding of patients'



(a) Digital interview. **(b)** In-person interview.

Figure 6: Interview setups.

experiences, challenges and motivations when undergoing physical therapy.

5.2 Participants and Recruitment

To recruit participants to the physiotherapist interviews, *snowball sampling* was used. This is a process were one participant is interviewed first, and then the participant gives contact information of other potential participants (Oates, 2006, p. 98). A total of four participants were interviewed, three physiotherapists and one former physiotherapist (three female and one male). Table 9 numbers the physiotherapists that participated, and shows their specialization. These interviews were held in-person (Figure 6b) at the physiotherapists' workplaces so that the equipment they use could easily be shown and demonstrated. For the patient interviews, patients were recruited using *convenience sampling*, a sampling technique were the researchers select participants who are willing to help, and is therefore convenient for them (Oates, 2006, p. 98). However, the researchers ensured a certain difference in gender and age among the participants to achieve some variety. A total of five patients (three female and two male, aged 19 to 79) were interviewed, and are numbered in Table 10. The patient interviews were held digitally using the video conference meeting software FaceTime and Zoom (Figure 6a).

Table 9: Overview of the physiotherapists and their specialization.

Physiotherapist	Type / Specialization
Physiotherapist 1 (Phy1)	Former psychomotoric physiotherapist
Physiotherapist 2 (Phy2)	Psychomotoric physiotherapist
Physiotherapist 3 (Phy3)	Special physiotherapist
Physiotherapist 4 (Phy4)	Physiotherapist and personal trainer

Table 10: Overview of the patients interviewed.

Patient	Time Spent Seeing a Physiotherapist	Reasons to See the Physiotherapist
Patient 1 (P1)	On and off for the last 20 years.	Backpain, pain elsewhere in the body.
Patient 2 (P2)	9 months.	Fractured ancle and a damaged tendon in shoulder.
Patient 3 (P3)	Used to go to a physiotherapist some years ago.	Back and shoulder problems.
Patient 4 (P4)	First time 4 years ago, has seen one regularly for the last 6 months.	Overloaded shoulder and periostitis in one leg.
Patient 5 (P5)	6 months.	Jumper's knee.

When presenting the results in Section 5.5, the physiotherapists and patients will be referred to with the corresponding number from Tables 9 and 10. For simplicity, the physiotherapists are sometimes referred to as "Phy" and the patients are referred to as "P" both followed by a number.

5.3 Preparation

Two interview guides with questions and possible issues to discuss were made to prepare for the interviews, one for the interviews with the physiotherapists (see Appendix A.1.1), and one for the interviews with the patients (see Appendix A.1.2). The questions were designed to be open-ended and trigger conversation while also covering the topics needed to reach the interview goal.

5.4 Data Collection and Analysis

Data was collected through a semi-structured interview. This method was chosen because, as stated by Wilson (2013), this guarantees certain topics to be covered in each interview, but also gives freedom for particular issues to be further explored. The interviews with the physiotherapists were followed by an equipment demonstration, with the exception of the interview with the former physiotherapist (Phy 1) which did not include a demonstration. Notes were taken and equipment was photographed to collect data from the first two interviews, while the final six were audio-recorded with the consent of the interviewees and later transcribed. When transcribing, a decision was made to anonymize all parts of the interviews that revealed the interviewees' location, workplace, or identity to protect the participants involved.

To analyze the interviews, a qualitative data analysis was conducted. The raw material was kept on separate files, and a duplicate was made to add notes and highlight specific categories or topics from the interviews. An inductive approach was chosen where categories were created from what was observed in the data, with a particular focus on the interview goals.

5.5 Main Findings

This section will present what we consider to be the key findings and takeaways from the qualitative analysis. First, the findings from the physiotherapy interviews will be presented, then the findings from the patient interviews.

5.5.1 Findings from Physiotherapy Interviews

The main findings from the physiotherapy interviews are grouped into five categories: *Physiotherapy Equipment*, *Great Variety in Types of Patients*, *The Problem*

of Low Compliance, *The Importance of Positive Experiences*, and *The Value of Feedback and the Physiotherapist's Presence* which will now be presented.

Physiotherapy Equipment

Various equipment was mentioned and demonstrated by the physiotherapists (Table 11). All four interviewees mentioned balance cushions (Figure 7b), resistance bands, and general gym exercise equipment. Other equipment, like treatment benches, yoga balls, stepping platforms, and weights were demonstrated or mentioned by three interviewees. Equipment like bosu balls (Figure 7a), and spiky trigger balls (Figure 7c), were mentioned by two physiotherapists. In addition to objects designed for exercise or rehabilitation, some everyday objects like wooden rolling pins, post-its, chairs, or soda bottles were mentioned.

Key Takeaway: Physiotherapists use a variety of tools and equipment. Many of them are simple, can be used in many different ways and can aid in adjusting the challenge level of exercises.

Table 11: Equipment demonstrated or mentioned by the interviewees.

Equipment	Phy 1	Phy 2	Phy 3	Phy 4	Total
Treatment bench		x	x	x	3
Arm sling	x		x		2
Balance cushion (rectangular and/or round)	x	x	x	x	4
Balance board		x		x	2
Yoga ball	x	x	x		3
Bosu ball			x	x	2
Tennis ball			x	x	2
Weighted ball		x		x	2
Spiky trigger ball	x	x			2
Ball (rubber/plastic)		x	x		2
Ball (soft, foam)			x		1
Resistance band (wide band)	x	x	x	x	4
Resistance band (slim, rope-shaped)	x	x		x	3
General gym exercise equipment (spinning bike, etc.)	x	x	x	x	4
Dumbbells		x		x	2
Jump rope				x	1
Stepper/stepping platform		x	x	x	3
Stool/chair		x	x	x	3
Weights (to wear, soda bottles with water, etc.)	x	x	x		3
Wooden rolling pin		x			1
Post-its	x				1


(a) Bosu ball.


(b) Balance cushion.

(c) Spiky trigger ball.

Figure 7: Examples of physiotherapy equipment.

Great Variety in Types of Patients

When the physiotherapists were asked about what types of patients they treat, all of them stated that there was a great variety. Physiotherapist 4 mentioned several examples:

> "I would say we have a big variation, both young and grown-up and older humans, so we have a broad spectrum. Maybe the clinic, or our clinic has a rumor of being a bit more of a sports clinic, that there might be some more with sore knees and ankles and such, but basically, we actually experience that there are all sorts of patients, I would say."
>
> Physiotherapist 4

Regarding the patients' injuries or type of pains, physiotherapist 2 highlighted that the patients' pain is often complex, consisting of several factors. For example, even though a patient comes due to back pain, that might not be the main problem. Instead, it is a combination of problems connected to anxiety, fatigue, or eating disorders. The physiotherapist also said that strain or tension often preserves the pain.

Key Takeaway: These findings indicate that because of the great variety of patients, a solution should be versatile and possible to adjust and customize according to the patient's needs.

The Problem of Low Compliance

Physiotherapists 1 and 4 explicitly mentioned the term *compliance*, a term frequently used in physiotherapy (explained in Section 2.3.1). Physiotherapist 4 stressed the importance of compliance and claimed that it is essential for patients'

improvement. The physiotherapist stated that it could be challenging to get patients to do what is necessary but suggested that involving the patient in the planning of the treatment, giving them tools, and following them up well could help with compliance:

> "That is something very, very important really, and that is what we call the *degree of implementation* or *compliance*. Because from research, it turns out that if compliance increases, meaning the degree of implementation is high, then there is a greater chance that the patient will get well. . . . So if there has not been good compliance, then one must acknowledge that okay, that's how it is, and then one must then ask oneself, why? And then it's about daring to ask the patient a little bit, and let the patient be allowed to tell, about why [the given tasks] have not been completed. There can be a thousand reasons for it. Also, we must then try to somehow moderate it then, and start... Not restart, but we change it, so that we try to get a higher compliance. So yes, it is a challenge to get people to do what you think is good for that person. But again, it's about a lot of things, but it's primarily about involving the patient in the train of thought. . . . It is also about giving tools to the patient or tasks that one should work with. Also follow them up on it, in a good way."
>
> Physiotherapist 4

The physiotherapists were asked about reasons for low compliance and mentioned examples like repetitive or hurtful tasks, lack of motivation, and that some patients struggle to find time to complete the given exercises. A measure some physiotherapists took to help their patients with their motivation was getting the patient to express their own goals and making that the primary focus of the exercises:

> "So I always want to find the patients' goals that should not be that they want to be stronger, or get better balance, but something a little... what should I say? A little deeper than that. I often dig a little: 'What is it that you are going to get stronger for? Are you going to take part in a competition?' 'No, I'm not doing that', but they want to be able to get up from the toilet, or they want to be able to walk the stairs. Then that is the goal. It's not really getting stronger, but it's about being able to function in your own home, being able to get up from the toilet."
>
> Physiotherapist 3

Key Takeaway: Since compliance seems to be an issue among physiotherapy patients, it could be beneficiary if a solution would help motivate the patient to complete the exercises.

The Importance of Positive Experiences

All physiotherapists highlighted the importance of accommodating positive experiences for the patients. Three factors facilitating good experiences identified from the interviews were: diverting the focus, making customized exercises, and arranging group exercises.

Diverting the patient's focus can be helpful if the patient experiences pain or finds the exercises exhausting. Physiotherapist 3 explained how shifting the patient's focus by talking about the weather could increase their endurance:

> "Some, for example, get tired on the bike after three minutes, but if we only talk a little about the weather, then we have suddenly cycled for eight minutes."
>
> Physiotherapist 3

Physiotherapist 1 also mentioned that it is wise to divert the patient's focus, and suggested connecting the exercises with something they would normally enjoy doing. For children it could be play and fun, or for instance dancing or music.

Physiotherapist 4 highlighted how customizing the exercises by adjusting the weight and the intensity can help divert the patient's focus. If an exercise is too simple or boring, the patient will have time to feel and think about the pain. On the other hand, if the exercise requires the patient to be present and attentive, the pain seems to disappear.

Since there are many types of patients with different needs and preferences, being able to customize exercises can be an advantage. Physiotherapist 4 explained the importance of involving the patient in the process of making the exercises, and finding something they enjoy doing, while it is the physiotherapist's job to find a way to use those interests in the treatment:

> "It is the physiotherapist's task then, primarily. To guide the patient, to facilitate good experiences by giving sensible advice, and now we are talking about something else that is very important. It is getting the patient involved in this process and, to explore: 'What do you like to do? What do you think is fun about exercise?' That can then be your starting point. Further, it is important that the physiotherapist must understand how to change or moderate it, that movement, that activity so that it becomes a good activity. And it can be about controlling the load and intensity, it can be about range of motion, it can be about rhythm and flow. Finding good activities, which gives the

> greatest probability of mastery and positive experience."
>
> Physiotherapist 4

Physiotherapists 1 and 3 expressed that they have good experiences with group exercises. Physiotherapist 1 said that many patients find it easier to exercise in a group, as it is more social and makes them more committed. The social aspect can have a big impact on the motivation and if the patients see the others doing ten more repetitions, they feel like they have to do them too, even if they feel tired.

Key Takeaway: These findings propose that a solution should be an immersive game that diverts the patients' focus from the pain over to the game. There should also be ways to adjust the difficulty of the game to suit individual patients' needs, and a multiplayer mode could be advantageous to engage and motivate social patients.

The Value of Feedback and the Physiotherapist's Presence

Physiotherapist 3 mentioned that some exercise equipment becomes so popular among patients that they want to have it at home. However the physiotherapist suspected that a lot of the equipment will not be used:

> "They prefer guidance, yes. So, and this is what I wonder: if they had gotten a bike, how much would it have been used? Because we have... There are a lot of older people today who have an exercise bike like that in some room that is not in use."
>
> Physiotherapist 3

The physiotherapist also expressed that it could be challenging for patients to remember to do their exercises at home, but that the presence of a physiotherapist could help them complete their exercises:

> "Yes, I think that it is both difficult to remember [to do the exercises] and there is something about that. . . . When they're exercising [at the clinic], there is someone who tells them all the time what they have to do."
>
> Physiotherapist 3

Physiotherapist 3 pointed out that when using equipment and doing exercises, patients prefer guidance and appreciate having a person who keeps an eye on them and tells them what to do next. Physiotherapist 1 stated that when people get affirmative feedback, there is a greater chance that they will complete the exercise. All this indicates that the feedback from the physiotherapist, and a person following their progress is important, and a strong motivator for physiotherapist patients.

Key Takeaway: Patients are motivated by feedback and the physiotherapists' presence. Therefore, there is a potential to explore a solution that can be used in cooperation with the physiotherapist to motivate and give feedback to the patient.

5.5.2 Positive Aspects Identified from Patient Interviews

Based on the analysis of the interviews with the patients, two main topics were explored: *Advantages of Social Interaction* and *Positive Factors of Exercises*.

Advantages of Social Interaction

The majority of the patients were positive to the idea of doing physiotherapy exercises together with another person. One advantage mentioned was to have someone that could hold them accountable. Patient 3 suggested that introducing a social aspect could make exercising more fun and increase the chances of completing the prescribed exercises:

> "[Doing exercises with another person] might have been more fun, because then you get more like... Yes, then you are held more responsible. You get someone else to work with, and complain with. A bit like motivating yourself to exercise in general, it can be, at times, more fun to go and exercise with someone else, because then you have a deal, and then it is harder to say 'Ehh... No, we'll skip it today'. Having someone to hold you accountable and someone to do [the training] with and possibly someone to complain with."
>
> Patient 3

Another mentioned advantage of doing exercises with someone was that social interaction might enhance the experience during the exercises. In addition, exercising with someone else might make the patients push themselves harder and complete the exercises more thoroughly because they know that another person is watching. Patient 2 expressed it like this:

> "Doing something together with someone creates a completely different kind of motivation. You get an agreement, first, and second, that you have someone to talk to along the way, or ask, or look at, or... Yes, that communication. Presence, communication... It's something completely, completely different than standing alone doing it at home . . . I think that I probably would have put more into the exercises. So, I might have pushed myself a little more than I do when I'm alone, in terms of efficiency, in the exercises I do. Now I do [the exercise] just to do it, but if I had been standing there with someone else, I might have pushed myself a little more."
>
> Patient 2

Key Takeaway: Based on these findings, it could be interesting to look at the possibilities for incorporating multiplayer elements like cooperation or competition into the solution.

Positive Factors of Exercises

When asked about their favorite exercises and what made them enjoyable, the patients responded that they liked exercises that were not painful and that did not immediately become boring. Another positive aspect was when exercises had the possibility to be adjusted and customized according to the patients pain levels, motivation and preferences. Patient 2 appreciated how the physiotherapist adjusted the exercises if they became boring or painful:

> "So [the physiotherapist] is pretty good at saying, 'Yeah, but if you're tired of it, you can do it a bit differently.' So, finding the exercises that, one: do not hurt, but that I can also stand to do over time... It's really a bit, yes, important. With some exercises I can find out after two to three weeks that 'Oh, ouch, this one made me get worse'. And then, then he tries to find another way to get to that muscle group."
>
> Patient 2

Being able to challenge themselves and see a clear and quick progression was mentioned as an important aspect of exercises, because of how it boosts motivation. Patient 5 explained how squats was a favorite exercise because of the prominent progress and the possibility to challenge oneself:

> "I think squats was probably the most enjoyable [exercise], really. Yeah, when you kind of push yourself a little extra and you can see the progression much faster. . . . It's squats with barbells, and it's, in a way,

> a bit fun to train with heavy weights and test some limits. And then if you feel that it is easy one day, then you can, in a way, increase, you just see that like 'Wow, today I managed to take that and that much in squats' and in a way see progress from there, which helps to keep pushing on and, in a way, push the envelope. So I think it's very, in a way, fun to challenge oneself, in that field."
>
> Patient 5

Key Takeaway: Variation, appropriate difficulty, clear progression status and a bearable level of pain appeared to be important factors impacting the enjoyment of an exercise. Some of these positive elements should be considered implemented into the game.

5.5.3 Challenges Identified from Patient Interviews

In addition to the positive aspects, some challenges were identified.

Difficult to Find Exercise Partners with Similar Needs

Although the responses to the idea of completing exercises together with someone else were mainly positive, the patients also mentioned some things they perceived as challenging. Especially, they had trouble finding someone else who was prescribed similar or identical exercises and their prescribed exercises did not seem useful or relevant for their healthy friends:

> "Now I don't have someone I exercise regularly with, but when I exercised in [the patient's former place of residence], I had a friend whom I exercised with. But I felt in a way that the physio exercises were so specific to me, that it might not be very fun for her to participate in them. So it was often that we did some exercises together, and then I did, in a way, my physio stuff, by myself. So maybe it would have been motivating... At least, maybe especially if there was someone who had a bit of the same type of problem then, it had been a bit... Yeah, motivating."
>
> Patient 4

> "So here at school, there are many people who exercise all the time, but they train to get strong, and I train to get well. So it's not the same thing."
>
> Patient 5

Key Takeaway: To solve the challenge of finding someone to play with, it could be interesting to look at a solution that is fun to play individually, or a multiplayer mode where people with unequal physical abilities can play together. Another take on this matter could be to find a way to make it easier to connect with other patients with similar needs.

Lack of Motivation

All five patients expressed that they often or occasionally struggled to find the motivation to complete the exercises prescribed by the physiotherapist. For example, patient 1 said that the training was demanding and that it was hard to prioritize it, which led to rarely completing the exercises:

> "That's not what I prioritize the most, no, hehe. . . . I generally have such poor ability to take action, and I feel quite weak and very tired. So there is not much individual training at home . . . That [motivation] is exactly what I don't find. Not very much anyway. Must make an effort to accomplish it, yes."
>
> Patient 1

Another patient (P5) claimed that the motivation was high to begin with, but gradually faded as he could not see the results of his efforts:

> "Yes, well, in the beginning, the motivation was at its peak because I wanted to get well. But, in a way, the more you train and see less progress or progression, in a way, it erodes the motivation a little, of course. That you spend so much time and energy training the body and then for me it did not work. . . . So the motivation curve is declining. And it quickly becomes like that when you do not see the results you want..."
>
> Patient 5

A third patient (P2), brought up how the motivation decreased due to the exercise program being too time demanding:

> "It has mostly gone well, but then, eventually, when it takes a long time, you lose a bit of that motivation. There is something about being able to do it three or four times a week, right? Yes, that motivation to do it at home, that one, it's demanding. Hehe, but it's necessary. Because you know, in a way, that this is what helps. If you want to get

> better, then you have to do it. So it has a lot to do with your own will to be able to complete it, to be able to get better."
>
> Patient 2

To summarize, reasons given for lack of motivation were, for instance: boring exercises, too time-consuming, did not see any progress and lack of feedback, and prioritizing more fun activities instead. This lack of motivation caused patients to skip exercises or entire sessions or complete only a part of the program, and some patients admitted that they rarely did any exercises between physiotherapy appointments.

Key Takeaway: When designing a solution, one should consider the aspects that can negatively affect patients' motivation and explore ways to handle or avoid them.

Boring Exercises

All five interviewed patients mentioned that exercises given by the physiotherapists were boring, as stated by patient 1:

> "There is nothing fun about any of these [exercises]."
>
> Patient 1

One example of a boring exercise, given by patient 2, was an exercise that was very repetitive and that required doing similar movements again and again, first with one hand, and then again with the other hand. The repetitions had to be counted, and the patient expressed dissatisfaction about having to count all of the repetitions:

> "It's this, yeah, about lots of repetitions too, right? So let's say, like for me when there are hands, then, it often becomes both right and left. So first you have to do it 12x2 [times] on one hand, and then you have to do it 12x2 [times] on the other hand, and then you have to do it in four different angles. When it comes to the hands, you have to do it forward, you have to do it on the side, you have to do it at an angle, and you have to do it up too. Right? And it's a bit boring. Yes, 1, 2, 3, 4, 5, 6, 7... Yes, then... Standing somewhere counting and counting and counting and counting. Yes, haha. It gets a little like eh... boring, actually."
>
> Patient 2

Other reasons patients found exercises to be boring were that they were often repetitive, similar or monotonous, too difficult or not challenging enough. The

patients expressed that the boring exercises affected their motivation negatively.

Key Takeaway: A game solution should have appropriate difficulty and help divert the patients with engaging elements so that they forget that they are doing repetitive movements and exercises.

Lack of Feedback and Progress

The majority of the patients (P1, P2, P4, P5) struggled to see progress or improvement of their condition and wished for more feedback, especially on the exercises they completed at home. The lack of feedback and not knowing if the exercises helped, affected their motivation negatively. Patient 2 explained how feedback was her main motivation when participating in another research project:

> "I participated in another health project as well, in relation to activity. Eh, yeah. Activity among adults in a certain age group had to wear an activity band for a period of time. And then you got one where they register your activity and then you had to fill out such a form, and then you get feedback. And I did not mainly do it because I want to compare myself to someone else, but I want feedback and advice, and tips to help me onward. Therefore, that is my motivation, really."
>
> Patient 2

Another reason for wanting feedback was the need for confirmation that they completed the exercises correctly. If the exercises were executed incorrectly, feedback would be essential to be able to make the necessary adjustments. Patient 4 emphasized that more frequent feedback on the exercises could have helped her execute the exercises more correctly:

> "When I only went once and got exercises, then when I came back, after about two years, I realized that I had done an exercise like completely... Quite... Not completely wrong, but not quite right either. But it was because I did not go to get any follow-up then."
>
> Patient 4

Finally, when patients do not receive much feedback, it can be challenging to see progress, as this patient explained:

> "For my part, I think it has been in my best interest. Without there being any great results, that... I can't see that I have had any [results] but I think first and foremost of maintenance. I think it will be a key word for what I seek, and what I get now. To maintain the functioning of the body."
>
> Patient 1

Key Takeaway: These findings indicate that feedback is important to evaluate correctness and progress, and a solution should therefore provide necessary and motivational feedback.

Lack of Space and Storage for Equipment

Two of the patients (P2, P4) expressed concerns about space requirements for a game or equipment. It was important to them that objects were easy to store and that owning or using such equipment would not require much additional free space. Patient 2 explained how she could not obtain certain equipment due to lack of space:

> "It would have been wise of me to have such a spinning bike or like an exercise bike thing, or an elliptical machine or something like that. Had probably been wise. But that... Our house is too small. I simply can't bear to have it inside the house. Because then it takes up the whole TV room and I'm not interested in that."
>
> Patient 2

Also, when discussing the idea of using game technology for training, the patient explained that her TV room was built in such a way that it was not possible for her to look at the TV and exercise at the same time:

> "There's something with, maybe it has something to do with the design of our home, here where we live now. Because I have access to for instance yoga on YouTube or in other such places where you can watch things, but at our place, it's like I have to have the TV next to me. So it's tricky to see her do it, and then for me to try to do it at the same time."
>
> Patient 2

Key Takeaway: This indicates that the solution should not require a lot of space and should preferably be easy to store and move around.

Table 12: Summary of the interviews with the physiotherapists.

Topic	Findings	Takeaways
Patients	Great variety in types of patients, both age and needs. Their needs may be complex.	Find ways to adapt the game to fit several patient groups.
Low Compliance	Explains the importance of the exercises and makes the patient express their own goal.	Have a clear game goal.
Positive Experiences	Diverting the focus during the exercises, making customized exercises, and arranging group exercises.	Make the game immersive, find ways to adjust the game to individuals, and look at the option for multiplayer.
Feedback and Physiotherapist's Presence.	The patients value feedback of doing the exercises correctly and having the physiotherapist tell them what to do.	Implement feedback.

5.6 Summary of Findings

This preliminary study was conducted to understand more about the context of use, learn more about physiotherapists' work, tools and challenges, and patients' experiences, needs and motivations. This section summarizes the findings from the interviews with the physiotherapists and the patients and points to key takeaways from the study.

Summary of Interview With Physiotherapists
First, the physiotherapists stated that there is a great variety of patients of different ages with individual challenges, abilities, and needs. Second, they experienced that low compliance is a vast problem and that patients could benefit from contributing to defining their therapy goals. Further, it is crucial for the patients to have positive experiences associated with the exercises, and finally, the patients value feedback and instructions from the physiotherapist. A summary of the interviews with the physiotherapists can also be found in Table 12.

Summary of Interview With Patients
First, patients value social interaction while exercising, although it may be difficult to find exercise partners with similar needs. Patients enjoy exercises with variation, an appropriate difficulty, and where they can see a clear progression. However, exercises become dull if they are repetitive and monotonous. No matter the exercise, lack of feedback and not seeing any progress can negatively affect patients' motivation. Lastly, the patients lack space for equipment. A summary of the findings from the patient interviews can be found in Table 13.

Table 13: Summary of the interviews with the patients.

Topic	Findings	Takeaways
Social Interaction	Positively affects motivation, compliance, and effort. Helps hold patients accountable.	Explore possibilities for multiplayer games.
Positive Aspects of Exercises	Variation, appropriate difficulty, clear progression, not painful.	Incorporate the positive aspects into the game.
Boring Exercises	Repetitive and monotonous exercises. Unsuitable difficulty.	Make patients forget that they are making repetitive/monotonous motions. Adaptive difficulty.
Finding Exercise Partners	Challenging to find others with similar needs and prescribed exercises.	Find a solution that is fun alone, engaging for healthy people, and/or makes it easier to connect with other patients.
Motivation	Patients struggle with motivation.	Find ways to increase patients' motivation.
Feedback and Progress	Lack of feedback might cause incorrect execution of exercises, negatively affect motivation, and prevent patients from seeing progress.	Facilitate receiving feedback.
Space and Storage	Patients lack space for equipment.	Games/equipment must not take up too much space. Should be easy to store/carry.

Key takeaways from the preliminary study:
A game solution should be possible to play by different types of patients and positive aspects of the exercises should be attempted implemented in the game. The game should be immersive to make the patients forget that they are exercising and provide sufficient feedback to encourage the players' motivation and indicate their progress. The equipment should not take up too much space.

Chapter 6

Ideation

This chapter describes the ideation phase of the project, in which five brainstorming interviews were held online, and the initial concepts were created. First, the purpose of the interviews will be presented, followed by information about the participants, the procedure, and the method used for data collection and analysis. Lastly, the main findings will be presented, along with two concept ideas created based on the data.

6.1 Purpose

The purpose of the brainstorming interviews was to learn about physiotherapists' perspectives on what is important when designing tangible games for physiotherapy patients, which target group or challenge could benefit the most from incorporating game technology in the treatment, what games and elements of play they already use in their sessions, as well as discovering ideas for game concepts and solutions.

6.2 Participants and Recruitment

The physiotherapists that participated in the brainstorming interviews were recruited by self-selection sampling through a post in a physiotherapy group on Facebook. A total of five participants; two children's physiotherapists, an assistant professor, a physiotherapy student and a special physiotherapist (three female, two male), volunteered. Table 14 numbers the physiotherapists that participated, and shows their specialization. The number will be used to refer to the physiotherapists when presenting data from the interviews.

Table 14: Overview of the physiotherapists and their specialization.

Physiotherapist	Type / Specialization
Physiotherapist 5 (Phy5)	Children's physiotherapist
Physiotherapist 6 (Phy6)	Professor
Physiotherapist 7 (Phy7)	Children's physiotherapist
Physiotherapist 8 (Phy8)	Student
Physiotherapist 9 (Phy9)	Special physiotherapist

6.3 Procedure

An interview guide was prepared in advance of the interviews so that the interviewees responded to a similar set of questions. However, since the interviews were semi-structured, individual follow-up questions and modifications were made during the interviews when appropriate. The interviews were audio recorded and conducted digitally on Zoom, with both researchers and one physiotherapist participating per interview (see Figure 6a in Chapter 5).

6.4 Data Collection and Analysis

The audio-recorded interviews were transcribed and analyzed. Using an inductive approach, the researchers looked for patterns and important design considerations and grouped quotes according to themes. Then, keywords in the quotes were highlighted. The collaborative, online whiteboard tool *Miro* was used to sort and get an overview of the data, as seen in Figure 8. Finally, the data was formulated into key findings and design considerations which was used to guide the concept development.

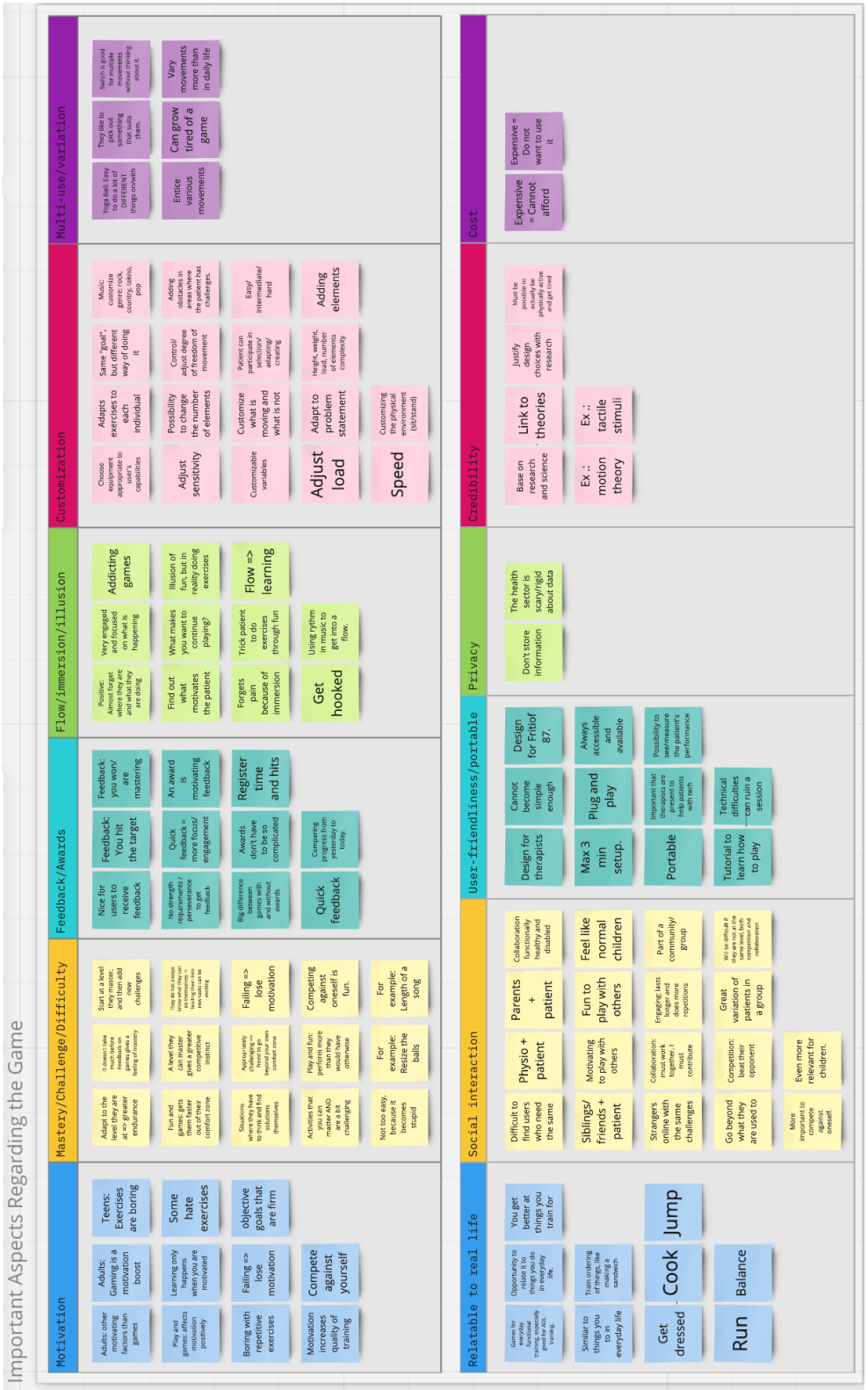


Figure 8: Screenshot from Miro: Grouping of data.

6.5 Main Findings

In this section, the findings from the analysis of the brainstorming interviews will be presented. First, some important aspects and considerations that were identified, followed by some game ideas that the physiotherapists came up with during the interviews.

6.5.1 Important Aspects and Considerations

The identified aspects and considerations for designing physiotherapy games were grouped into eight categories: *Patient Group or Target Exercise, Individual Customization and Multi-Use, Adapting Difficulty to Achieve Flow, Receiving Feedback and Seeing Progress, Space Requirement and Portability, Social Interaction, Relatable to Real Life*, and *Physical Activity and High Intensity*.

Patient Group or Target Exercise

When asked which patient group to design a game for, physiotherapist 5 suggested that the focus should rather be on what skill to train than on a diagnosis, and that the physiotherapists could decide which of their patients the game would be suitable for:

> "I do not think you need to limit [the game] to one type of patient group, so rather think about the purpose of the game. So in this game, we train like this and like that and like that, then the type of problem will be, that is, the need to train for different children regardless of diagnosis. So I would rather start with and think that, okay, this is a game where you train balance, or this is a game where you train maybe fine motor skills or not to mention precision. And then that is the starting point. It will also then in a way be the physiotherapist's task to find which children this can be appropriate for, or where this can be a beneficial measure."
>
> Physiotherapist 5

The suggestion is in line with the findings from the preliminary study that described a great variety of patients with complex challenges. Therefore, targeting a skill or exercise could be more beneficial than a specific type of patient or condition. Throughout the brainstorming interviews, several abilities targeted in the physiotherapy treatments were mentioned. Among those were:

- Sorting/matching
- Reaction
- Balance
- Coordination
- Strength
- Attention
- Precision
- Weight Transfer
- Proprioception
- Eye-hand-coordination

The physiotherapists also mentioned examples of exercises used to train different abilities:

- Hold-let-go (tension and relaxation exercise)
- Walking (high knees, on a line, on heels, on toes)
- Obstacle Courses
- Dancing to music
- Keep an item (like a balloon) in the air
- Aim and hit something
- Reach for items
- Stroop test
- Balance tasks

Key Takeaway: Find a target exercise or skill training for the game rather than a target patient group.

Individual Customization and Multi-Use

One aspect that several physiotherapists (Phy 5, Phy7, Phy8, Phy 9) mentioned was individual customization. Some level of individual adaption of the exercise was important as there is such a great variety of patients. Physiotherapist 7 indicated that having the opportunity to add and remove elements in the game, could be one way to customize the game to suit a patient:

> "And I think it's nice in relation to games and game technology as well, that you have the opportunity to add a few parameters at a time, and in a way replace or add or remove small elements in the same game, so that it works."
>
> Physiotherapist 7

Key Takeaway: The game should be customizable to fit the patient's needs.

Adapting Difficulty to Achieve Flow

One way of customizing a game, is through adjusting difficulty. Since there is a great variety of patients, and their motivation can benefit from experiencing a sense of achievement, it is important that the difficulty of the games can be personalized. Physiotherapist 9 explained that optimally, tasks should not be too easy or too difficult for the patients:

> "And apart from that, it is very much about trying to facilitate the level the patient is at. So neither give them too difficult tasks, but nor so easy that it somehow becomes 'too stupid' in a way, you know? And then it's about having fun."
>
> Physiotherapist 9

Physiotherapist 7 explained how she would include the children when making obstacle courses to suit their abilities:

> "Those who may withdraw a little from activity, for them it is very harmless and easy to do those... I call it obstacle courses or balance trails, which are adapted to them, where they get to help build it. And then we have a certain amount of equipment and then they get to choose. The vast majority of kids and young people like that: to find something that suits them."
>
> Physiotherapist 7

This physiotherapist's observations are supported by the *Challenge* element from the Flow Theory (Section 2.1.4), which states that a game should be sufficiently challenging and match a player's abilities and skills to give the experience of flow.

Key Takeaway: It should be possible to adjust the game's difficulty to fit the patient's abilities.

Receiving Feedback and Seeing Progress

Similarly to the findings from the preliminary interviews, physiotherapists in the brainstorming interviews also pointed out the importance of seeing progress and receiving feedback. One of the physiotherapists (Phy9) explained that they had been using the VR game *Beat Saber* at the clinic, and mentioned the benefit of receiving a score as an objective measurement of the patients' effort:

> "It was one thing to, like have to be hospitalized to try exciting technology, but another thing was what competition actually gave them, and playing against themselves, and really getting a score on the exercising they did. It's a little difficult to say that 'Yes, today you came three degrees further out when you stretched than last time!' but here it was like a real score afterwards, on the effort you put into it."
>
> Physiotherapist 9

The physiotherapist explained that measurable results were missing in the workouts they used at the clinic, and that registering data like time and number of hits could help communicate performance and progress to the patients:

> "But I think that it can be important if you get the opportunity to register both time and number of hits and, that you get some kind of quick feedback on how the performance was. Maybe it's what I miss a bit about what we do in our workouts that... Okay, you can: 'today you stretched ten times, yesterday you stretched only five', but it is at least an objective measure of something you have done."
>
> Physiotherapist 9

Key Takeaway: Give the patients measurable feedback on their performance.

Space Requirement and Portability

An aspect mentioned by physiotherapist 7 was the importance of portability. This is especially important for physiotherapists who travel and visit their patients rather than having the patients visit the clinic.

> "It's great if it's also something that is portable because many of us go around from place to place, at least we who work in the municipality, and at least with children and young people, we work in different arenas, and it has been so nice to be able to come in and guide and adapt and try out some type of game or activity that you can easily take with you."
>
> Physiotherapist 7

A related aspect is that the product should be easy to store, and not take up much space, and that the game does not require much extra time for setup:

> "If it takes more than three minutes to set it up and get ready, then the threshold is quite high to use it. So it must be very plug and play,

> preferably it can be available all the time, but more set aside, stored next to a wall or something like that."
>
> Physiotherapist 6

The statements about space requirement and portability align with the findings in the preliminary study (Section 5.5.3), where patients stressed the importance of equipment being of an appropriate size, so that it would be possible to easily store and use it at home. Further, these needs motivated finding a solution that was portable, small in size and could easily be transported and stored compactly.

Key Takeaway: The solution should be portable and easy to store.

Social Interaction

Multiple physiotherapists (Phy5, Phy7, Phy8, Phy9) were positive to the thought of patients playing together with someone else, and believed it could have a positive effect on their motivation. Physiotherapist 7 suggested that playing with someone else, did not necessarily mean having to play with another patient, but could also include playing with family members or the physiotherapist:

> "I think everyone benefits very much from and thinks it is very fun to play with others. And it may be that the user groups I have, maybe have some siblings or friends who are in the same position, so it's very nice to be able to play together. . . . I think it is very motivating at least to play with someone else."
>
> Physiotherapist 7

In addition to the motivational factor, physiotherapist 5 suggested that playing with someone else could help patients challenge themselves and expand their comfort zone:

> "Because I think it can be very like that for motivation, right, if it's two-player, then you can actually make an interaction, and then I think you can really get the kids to go beyond what they are used to, or yes, there are many who are used to such toys, but at least, I can control it at the same time as it is fun then."
>
> Physiotherapist 5

Findings from the SLR indicated that there is a lack of research on multiplayer games for use in physiotherapy. These statements from the physiotherapists suggest that there is indeed a potential for such game modes and that they could be further explored and incorporated in a game solution.

Key Takeaway: Multiplayer games have a motivational potential that could be explored.

Relatable to Real Life

The physiotherapists explained that patients often train to regain functionality or maintain it. This functionality can be everyday actions like standing up, picking up something from the ground or reaching and grabbing an object. Physiotherapist 7 explained that it can be beneficial when exercises and training are related to everyday tasks, so that the training can help the patient regain functionality they need in their daily life:

> "That you are able to create tasks or opportunities that allow you to relate them to functional things, things that you should achieve otherwise in your everyday life. But that could be so much, you need both balance, coordination and strength, and endurance, but we see that things you practice you become good at, so if it has... If it is close to things that you usually do, whether it's getting dressed and cooking or yes... Jump, run, balance, it very much depends on the age group though."
>
> Physiotherapist 7

There are many everyday actions that can be done with or on physical objects, and many such actions are also used in physiotherapy tasks, like turning and reaching (English et al., 2014). Some other examples that were mentioned by the physiotherapists were:

- Bending
- Grabbing
- Matching
- Sorting
- Moving an object

Key Takeaway: Patients could benefit from a game with tasks that are relatable to real life.

Physical Activity and High Intensity

In several of the interviews (Phy5, Phy7, Phy8, Phy9), physiotherapists talked about patients that needed to move their body and get more exercise. Physiother-

apist 9 stressed that is was important that games for use in physiotherapy enabled patients to get tired and sweaty by playing them:

> "And then there is the fact that you can do it actively. I think if you were to play PlayStation with controls and stuff, there is very little you can do physically. Which can be good in other contexts, such as occupational therapy for fine motor skills or other things. But it really became crucial that one could be so physical and actually be able to get physically tired and use the body actively. Which made us think that [VR games] could be exciting and relevant to try."
>
> Physiotherapist 9

Key Takeaway: The game should facilitate physical activity with high intensity.

6.5.2 Physiotherapists' Game Ideas

At the end of the brainstorming interviews, the physiotherapists were asked if they had any ideas for tangible games that could be used in physiotherapy treatment. Some of their ideas, and the key takeaways incorporated in our solution will now be presented.

Portable Blocks with Light

Physiotherapist 7 suggested having elements, like blocks, that were mobile and possible to move around and arrange according to their needs:

> "Something more mobile that we could put together ourselves and remove again, that is not permanently pasted on the floor and walls, but if you had had some types of blocks..."
>
> Physiotherapist 7

Through the interviews, it was discovered that physiotherapists often use their creativity to adapt exercises and equipment to the patient's needs. Since the physiotherapists often treat a great variety of patients, as described in Section 5.5.1, the possibility of individually customizing the game solution could be very advantageous. One advantage of the blocks suggested by the physiotherapist is that they can be moved around and positioned at different heights by placing them on flat surfaces like shelves, tables, chairs or on the floor.

In continuation, the physiotherapist added that the blocks could have lights or a signal that instructs the movements of the patient, and that you could place the blocks in a chosen pattern:

> "...maybe with light, maybe with a signal. Or if you could have customized a signal like a hand or foot or frog or something... You could have put it together in a certain pattern."
>
> Physiotherapist 7

This idea could be incorporated into a game by letting the physiotherapist select a variety of movements or exercises that should be performed by the patient when a certain signal is provided by the game.

Explosive Training with Light and Distance

Physiotherapist 6 suggested using moving lights that the patients should either move between or follow:

> "Think about, kind of, light and response –explosive training. Then we are back to this about, yes, having a wall with lights that you should follow, either colors arranged in order, or reaction and things like that . . . The advantage of such a concept, it is that you can set it up to to have a distance, so that you have to run, and jump, and bounce and catch, and you can collect the elements and select an easy difficulty so that it actually turns into working on functionality, and mobility."
>
> Physiotherapist 6

Physiotherapist 9 also suggested using lights, for instance to train reaction, arm functionality, focus and speed:

> "And, then you can do a lot of good in terms of reaction with, ehm... And, yes as you say, use buttons and lights on a panel in front of you to get both arm functionality, and vision, and focus, and speed in."
>
> Physiotherapist 9

Dancing Game

Pyhsiotherapist 5 suggested a dancing game where the patients should shift their weight based on the music and the tempo:

> "You can in a way maybe have a bit like, a dancing game. That if you connect it to music for example... And it could be that you should kind of push it... Use your feet and push different... It can have something to do with tempo, it can have something to do with how you place your feet, it can... Yeah. Also, maybe you should just stand on one leg. And there you can also include the part with how much weight you have on the foot, if you press it down."
>
> Physiotherapist 5

6.6 Concept Ideas

To come up with ideas for a concept, the data from the interviews was organized in Miro. In addition to the factors grouped in themes (Figure 8), small cards with elements like exercises, skills to train, and game elements were created (Figure 9). The cards were combined in multiple ways to inspire ideas and create a foundation for game concepts. Some of the discarded concepts are briefly described in this section.

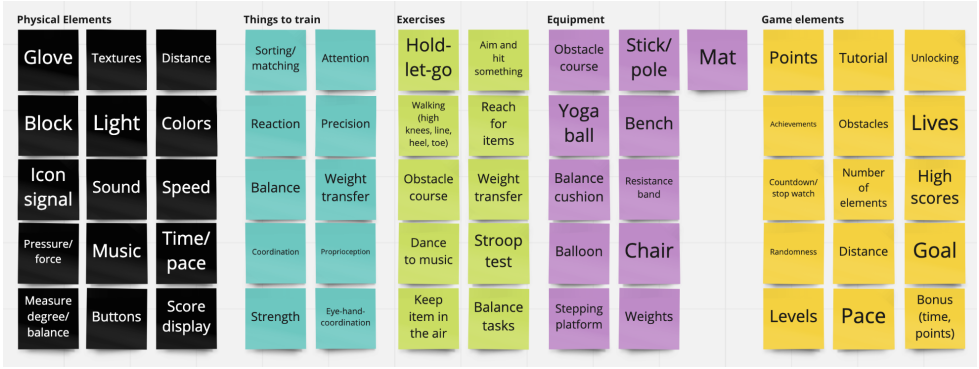


Figure 9: Screenshot from Miro: Brainstorming cards.

6.6.1 Light Mat

One of the first ideas for a concept was a large light mat inspired by a combination of several ideas by the physiotherapists. The idea was to have several small touch sensors with light on the mat that could be triggered by touch of hands, feet or for instance hitting it with a ball.

> "Finger motions. So if, for example, you have a board where there is light, and you should like run your finger, then either with the light...

> And then, in the end, you get a shape for example."
>
> Physiotherapist 5

> "I do not know if I have seen it or if it exists, that you could have a projector or something that projected on the floor and that you should go to, ehm... In time with music, I think it could have been nice."
>
> Physiotherapist 9

Some perceived disadvantages of this concept were:

- Similar to existing solutions
- Can be hard to mount and transport

6.6.2 Rolling on a Stick

This concept was based on one of the physiotherapists' game idea of having a rod or a rail with a weighted ball, where the goal is to control the ball and make it go where the game prompts you to:

> "If we could have some sort of long rod, with like a weight or a ball that rolls, but instead of it rolling off, so like, now you get so and so many points and then the goal is to keep it in the middle. Also, you could hold it while cycling or running, and in a way get like a visual designation of their balance, but for them, it becomes points, in a way, plus or minus."
>
> Physiotherapist 8

The concept was further explored by the researchers in Miro, as seen in Figure 10.

Perceived disadvantages of this concept was:

- Not very customizable
- Possibly hard to incorporate with existing exercises

Although this concept did not become the solution, it helped discover and inspire the color changing concept of the final game solution presented in Chapter 7.

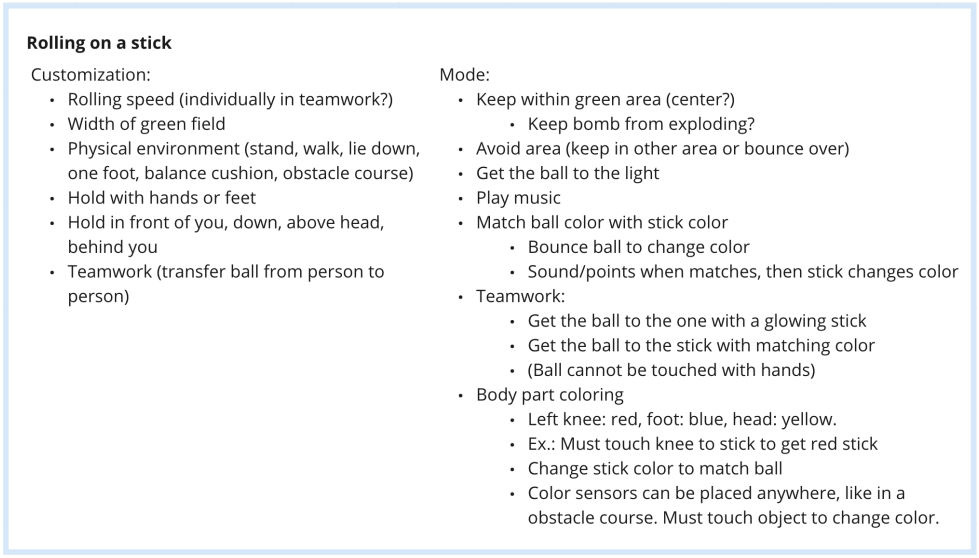


Figure 10: Screenshot from Miro: *Rolling on a stick* brainstorming.

6.7 Summary of Findings

The brainstorming interviews were conducted to discover important design considerations for physiotherapy games, identify a target user group and get ideas for game concepts. Table 15 shows an overview of eight main findings from these interviews, and the key takeaways for the next step in the process of developing a prototype.

The physiotherapists suggested that games have a target exercise, like training balance or fine motor skills, rather than games aimed at a specific patient group like for instance patients with CP. Due to the patients' individual needs, the physiotherapists advised having a way to custom-tailor the games to suit each patient, as well as adapting the difficulty of the game for the patients to get a sense of accomplishment without making it too boring.

It is also important that the patients see progress, and as it is not always easy to notice, the game should give them feedback on how they perform. As physiotherapists do not have a lot of storage space and sometimes travel with the equipment, it is important that it is portable and small in size. The possibility of multi-player games could also be explored as the physiotherapists see the advantage of playing together. However, an option to adjust the difficulty for each player to suit their abilities should be considered. Especially for game solutions intended to enable patients to play with family members, friends or the physiotherapist. Games with tasks that are relatable to real life may be beneficial as this often is the main goal of patients going through rehabilitation.

Additionally, some game ideas were given by the physiotherapists. Examples of these ideas were portable blocks with light and dancing to music with pressure sensors for the feet. The physiotherapists' ideas inspired two initial game concepts. The first one was a light mat that users could interact with in various ways, however, it was not very portable and was quite similar to existing solutions. The second idea was a long rod with a weighted ball where the goal was to balance the ball. The researchers thought of ways to incorporate technology and game elements into this idea by adding colored lights that could give feedback and points that could be awarded. Both of these ideas were discarded, but worked as a starting point for the idea that became the final game concept presented in the following chapter.

Table 15: Summary of the brainstorming interviews.

Topic	Findings	Takeaways
Target Exercise	The physiotherapists prefer games with a specific purpose, like training balance or fine motor skills, rather than a specific patient group like stroke rehabilitation.	Find a target exercise or skill training for the game rather than a target patient group.
Customization	Physiotherapists want the opportunity to adjust, add or replace elements of the game to suit each patient.	The game should be customizable to fit the patient's needs.
Adapting Difficulty	Tasks should not be too difficult so that the patient never gets a sense of accomplishment and loses motivation, nor so easy that it becomes boring.	It should be possible to adjust the game's difficulty to fit the patient's abilities.
Feedback and Progress	Patients like seeing their progress visually. It is not always easy for physiotherapists to make them realize their progress.	Give the patients measurable feedback on their performance.
Portability	Physiotherapists might want to travel with equipment and do not have a lot of storage space.	The solution should be portable and easy to store.
Social Interaction	Playing together with someone else can positively affect the patients' motivation. It does not have to be played with another patient but could be the physiotherapist or a family member.	Multiplayer games have a motivational potential that could be explored.
Relatable to Real Life	Many patients need to regain functionality to do everyday actions.	Patients could benefit from a game with tasks that are relatable to real life.
High Intensity	Some patients need high-intensity training.	The game should facilitate physical activity with high intensity.

Chapter 7

ColorCube

This chapter presents the concept called *ColorCube*, a game tool with two accompanying games.

7.1 The ColorCube Concept

The early phases of this research revealed several aspects that were important to consider when designing games for use in physiotherapy. The SLR showed that there is limited research on tangible games that are not screen-based and that such games could be further explored. In addition, the SLR suggested that the context of use should be considered and the preliminary study pointed out the importance of the physiotherapist's presence. Further, the preliminary study suggested that positive aspects of exercises should be incorporated, that the concept should create a positive diversion during monotonous motions, and increase patients' motivation. The brainstorming interviews indicated that it was important to make games suitable for various patients and needs, enable customizable difficulty, provide sufficient feedback about status and progress, and ensure portability. Based on these insights, we aimed to create a versatile, tangible, engaging tool that could be used to assist the physiotherapist at the clinic and motivate a wide variety of patients. This resulted in a game concept called *ColorCube* (Figure 11).

This section will introduce the three parts of the concept, The ColorCube, The ColorLabels, and The ColorCube App, and explain important design decisions made for each part.

Figure 11: ColorCubes and ColorLabels.

7.1.1 The ColorCube

Table 16 gives an overview of the technology used in the ColorCube. The cube can light up in specific colors and be turned on and off. It also has a built-in speaker and can make a victory sound, an error sound, and play music. The cube shape was inspired by physiotherapist 7's suggestion of blocks with light and chosen because of the shape's numerous advantages:

- The colored light can be seen on all six sides and from different heights and angles.
- A cube can be placed on any surface without needing additional equipment for mounting.
- A cube is easy to carry and move around and can be stacked and combined with different cubes.

Table 16: Technology used in the cube and their properties.

Technology	Properties
Light	Change color Switch on/off
Sound	Victory sound Error sound Music
Sensor	Recognize color label Recognize hit/touch Recognize being lifted
Registering	Correct touch/reaction Wrong touch/reaction Time

7.1.2 The ColorLabels

In addition to the ColorCube itself, some *ColorLabels* are used to interact with the cube. A ColorLabel is a colored elastic strap that can be strapped around furniture, equipment, or body parts like arms and legs. The ColorLabels have velcro on each end, making them easy to adjust, fasten and remove. A ColorCube can register the touch and the color of a ColorLabel.

7.1.3 The ColorCube App

An app is connected to the ColorCube to display status during gameplay and allows changing the customizable factors. In addition, the app can register scores, give feedback, and show motivating graphics during gameplay. How the ColorCubes, ColorLabels, and the ColorCube App are used during gameplay will be further explained for each game.

7.2 Games

This section will present game concepts designed for the ColorCube. Because of the game focus of this section, the patients will here be referred to as *players*. Another reason is that the games can be played by healthy people or physiotherapists, not just patients. For instance in multiplayer modes, the game could be played by two patients, one patient and one physiotherapist, or a patient and another healthy person.

Two games will be presented in this section:

- Hit the Cube
- Defuse the Bomb

Three additional games, *React and Act*, *Tap to the Rhythm*, and *Run For It*, were created for the ColorCube, but were not tested during the evaluation due to time restrictions and a limited prototype. These can therefore be found in Appendix A.3.

7.2.1 Hit the Cube

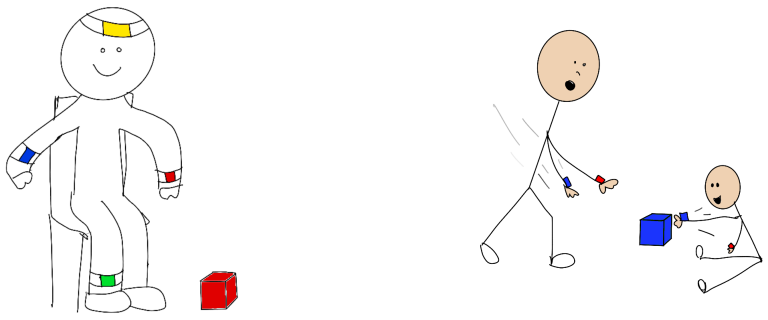
One ColorCube is required to play this game. The player wears the ColorLabels on different body parts, for example, one on each hand, one on the right foot, and one on the head, as illustrated in Figure 12a.

Physiotherapy Goal and Target Group

The target group of this game is players that need to improve their ability to react. However, it can also be used to train cognitive skills, and, as explained later in this section, it can be customized to suit the player's abilities and needs. By customizing certain variables, this game can be used as a supplement to existing rehabilitation exercises, and thereby be used by different types of patients.

Game Objective

In *Hit the Cube*, the player must touch the ColorCube with the corresponding ColorLabel that matches the cube's color as quickly as possible.



(a) Single player. **(b)** Competitive multiplayer mode.

Figure 12: Hit the Cube.

Gameplay

In this game, a timer is shown on a screen in the app while playing. The cube will give the player a task by lighting up in one color. The player then has to touch the cube with the ColorLabel that matches the color of the cube. When the correct label touches the ColorCube, it provides feedback by giving a victory sound, and the cube goes on to the next task by changing to another color. If the wrong label touches the ColorCube, it plays an error sound and continues to the next task by changing color. Points are awarded each time the correct matching is done. The ColorCube keeps changing color until the preset number of tasks are completed, and the player can see their final score in the app. The final score is calculated based on time used and the number of correct hits. Although it is not possible to lose the game, it is possible to complete a game without gaining a single point, which only happens if the player responds to all tasks with the wrong color or does not respond at all.

User Interface and Game Controls

The ColorLabels work as controllers used to deliver answers to the ColorCube. The ColorCube functions as a task-provider and checks if the answer is correct or not.

A countdown and the player's current score are displayed during the game in the ColorCube app. When not playing, it is possible to see a high score list which works as an element of competition, encourages the patient to come back to beat their old high score, and as a way to monitor progress. Additionally, there is a statistics view meant for the physiotherapists. These statistics show potential variation in the performance of different body parts, both in terms of speed and number of correct answers and the player's progress over time.

Game Elements

Section 2.1.4 describes several game elements which can be used in games to achieve enjoyment and flow when playing. Feedback, challenge and concentration are three game elements from the GameFlow model presented by Sweetser and Wyeth (2005) which are incorporated into Hit the Cube. First, the light of the ColorCube gives visual feedback, which instructs the patient on which body part to use, and auditory feedback to indicate whether the patient hit the cube with the correct ColorLabel or not. Second, to incorporate challenge, the option to adjust the difficulty will ensure an appropriate balance between boredom and the patient giving up on a task. This can for instance be done through adjusting the number of

colors in play or the placement of the ColorCube and ColorLabels. Furthermore, what color lights up next is random to provoke curiosity and add variation to the game. Lastly, to increase the patient's concentration on the game, the ColorCube will grab the patient's focus by providing different sources of stimuli such as the color of the cube, the feedback sound, and the score and timer displayed in the app.

In addition to the elements of GameFlow, one of the forms of reward, *score systems*, presented by H. Wang and Sun (2011) is incorporated. Receiving points and seeing a high score can motivate the patient to perform well and return to the game to beat the high score. An overview of the game elements, how they were applied to the game, and their intended effects are explained in Table 17.

Table 17: Game elements and theory used in *Hit the Cube*.

Game Element	Sub-Category	Application and Intended Effect
Feedback	Visual feedback	Light: Gives task, changes color when hit. Color: Tells you which body part to use. Guides movements and gives feedback on performance.
	Auditory feedback	Victory sound: Hitting the cube with the correct label. Error sound: Hitting the cube with the wrong label. Player gets feedback on their performance, motivating them to perform well and correct errors.
Challenge	Adjustable difficulty	Adjusting difficulty to players' abilities will keep them from getting bored and prevent an impossible level.
	Randomness	What color lights up is random. When playing with two cubes: which cube lights up is random. Randomness can provoke curiosity and variation in the game so that every time the game is played, there are some variations.
Concentration	Grab and maintain focus	The player will have to stay concentrated and focus on the cube(s) to react quickly. Such concentration can lead to immersion in the game and flow.
	Stimuli from different sources	Light and color: from the cube(s). Sound: Feedback from the cube(s). Score: points and score in the app. Stimuli from different sources keep the game more interesting.
Reward	Points	Points for each correct hit and a bonus for a streak of correct hits. These points are meant to motivate the player to hit the cube(s) and perform well.
	High score	A competitive element that can motivate the player to return to the game.

Customization

The game is very customizable to ensure an appropriate difficulty level for each player and the opportunity to increase the challenge over time as the player pro-

gresses. The physiotherapist can adjust settings to ensure the best form of exercise for the patient. For instance, the physiotherapist can choose the placement of the ColorLabels and the ColorCube, and customize the frequency of colors to target specific movements and body parts and to adjust the difficulty. Further, they can adjust the number of ColorLabels and ColorCubes, as well as select a color-combining mode to regulate the cognitive load. Finally, the timer can be turned off to reduce the stressful aspects of the game. Table 18 provides an overview of the customizable elements and their intended effects.

Table 18: Customizable options in Hit the Cube.

Customizable	Effect
Placement of the ColorLabels	The physiotherapist can choose where the ColorLabels are to be placed. For example, if a patient only needs to train arms and not the feet, ColorLabels can be placed only on the arms.
Number of ColorLabels	Affects how many body parts are part of the game and cognitive complexity.
Number of cubes	Two cubes increase the possibilities for exercising at different heights and encourage more movements if they are further away from each other.
Timer on or off	The timer can be turned on or off, depending on what is most motivating for the patient.
Placement of the ColorCube	Affects the difficulty and can be adjusted according to the patient's needs. For example, the cube can be placed high up, as difficult to reach, or right in front of the patient, making it easier to reach.
Frequency of colors	If the physiotherapist knows that the patient needs to train the right arm more than the left arm, he can adjust the game to choose the color corresponding to the right arm more frequently.
Cognitive element: combining colors	Affects difficulty, suitable for patients that need a higher cognitive challenge. The player can wear the three prime colors (red, blue, and yellow). If the cube lights up green, both the blue and the yellow labels have to touch the cube.

Multiplayer Mode

This game has two multiplayer modes:
1) Competition: In the competition mode, both players wear labels, and the cube is placed between them. The first one to touch the cube with the correct color as it lights up gets the points (Figure 12b).

2) Collaboration: In the collaboration mode, the game becomes more cognitive. For example, one player wears blue and red ColorLabels, and the second wears yellow. If the cube turns green, the players have to collaborate to create that color by combining blue and yellow. This is done by having the first player touch the cube with their blue ColorLabel and the second player touch the cube with their yellow one.

Hit the Cube with Two ColorCubes

Hit the Cube can also be played with two ColorCubes (Figure 13). In this version of the game, a minimum of one color (ColorLabel) is required. Having two cubes can add to the cognitive complexity and creates possibilities for larger and longer movements by placing the cubes at a distance from each other. On the other side, complexity can be decreased since the game only requires one color in play. When playing with two ColorCubes, one cube will light up at a time. When hit by the player, it will make a victory sound or an error sound, and the light will immediately be turned off before either the other cube or the same one will light up with a new task.

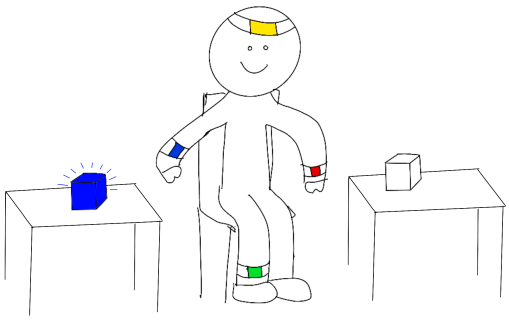


Figure 13: Hit the Cube with two ColorCubes.

7.2.2 Defuse the Bomb

Defuse the Bomb is a game that requires two ColorCubes, a minimum of two colors (ColorLabels), and a minimum of one player. One of the ColorCubes will play the role of a stationary *solution cube*, and the other will play the role of a portable *player cube*. The labels can be spread out and placed around the room, for instance, on an obstacle course or placed near the player, appropriately to their ability.

Physiotherapy Goal and Target Group

This game is primarily for players with some flexibility, movement, and speed. It can be used to train cardio, cognitive skills, agility, and other skills that can be trained using an obstacle course. *Defuse the Bomb* also has numerous customization options, which are explained further in the section about Customization.

Game Objective

The goal of *Defuse the Bomb* is to defuse a bomb before time runs out, by collecting and delivering colored light that matches the solution cube.

Gameplay

When the game starts, music starts playing along with a countdown until the bomb explodes begins, as illustrated in Figure 15. A solution cube stands at the base, next to the countdown, and lights up in a *solution color* (Figure 14a). The player has another cube, a player cube that is initially white (Figure 14b). The player carries the player cube to the ColorLabel that matches the current color of the solution cube (Figures 14c and 14d) and when the player cube touches the ColorLabel, it inherits the label's color (Figure 14e). Then the player must return to the base and touch the solution cube with their player cube (Figure 14g), delivering their colored light. The solution cube will play a victory sound if the color is correct, change into the color of the next task (Figure 14h), and the number of remaining tasks in the app will decrease by one. However, if the colors of the player cube and the solution cube do not match, a negative sound will be played as the two cubes touch, and the color of the solution cube and the number of remaining tasks will remain the same. The player cube will turn white, and the player will have to find the correct ColorLabel and try again. This goes on until the player has completed all the color tasks correctly and the player wins, or until the time runs out, the bomb explodes, and the player loses.

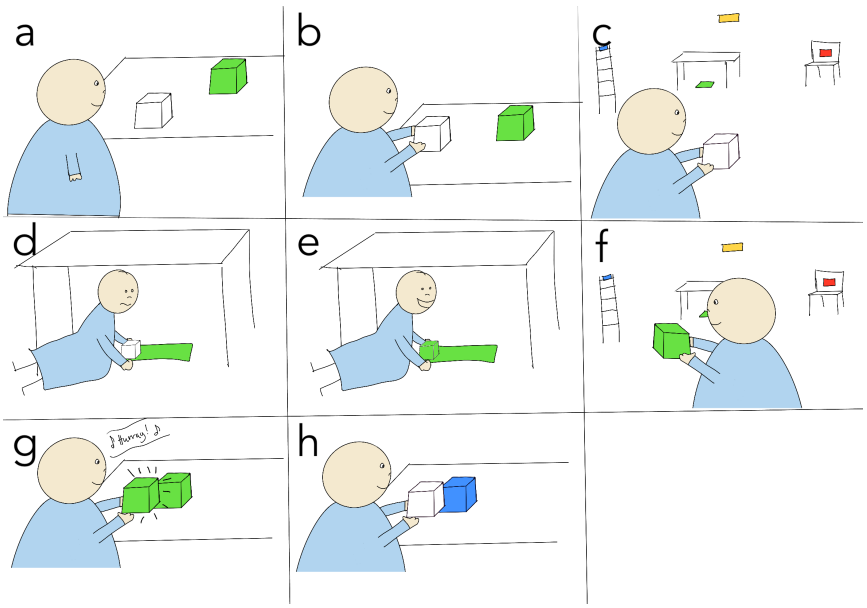


Figure 14: Defuse the Bomb

User Interface and Game Controls

One ColorCube, the solution cube, functions, similarly to *Hit the Cube*, as a task-provider that checks and verifies the player's action and color matching. Another ColorCube, the player cube, works as a controller that the player uses to gather colors from the ColorLabels and deliver them to the solution cube. Tasks are shown as a colored light on the solution cube, and the color collected from the ColorLabels is shown as colored light on the player cube.

An illustration of a bomb with a countdown and the number of remaining tasks is displayed in the ColorCube app while playing, as shown in Figure 15. If the time runs out, an animated explosion with sound effects will play in the app, and both cubes will flash red. Then the number of remaining tasks will be displayed along with an encouraging message. If the player completes all the tasks, a victory screen will be displayed, showing the remaining time.

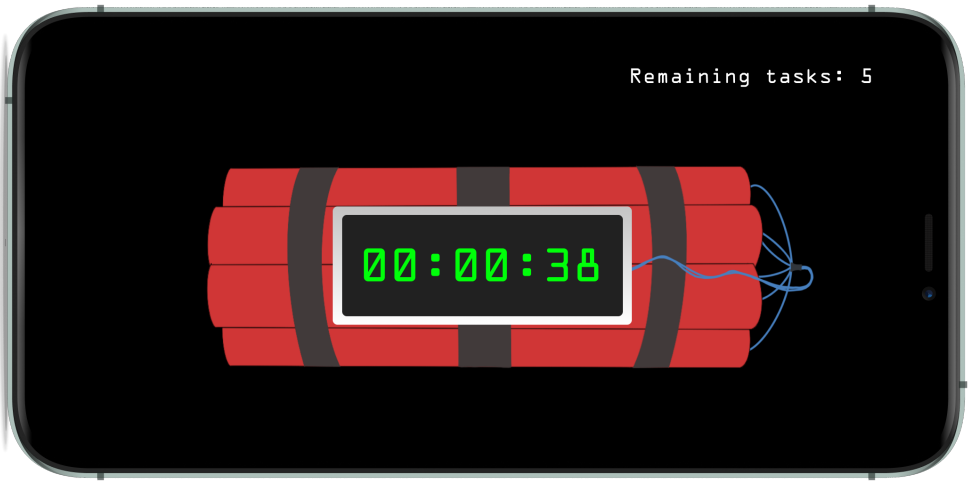


Figure 15: Example of how Defuse the Bomb could look in the ColorCube app.

Game Elements

Similarly to *Hit the Cube*, various game elements and theory was considered and implemented in *Defuse the Bomb*. First there is *feedback*, *challenge*, and *concentration* from the flow theory (Section 2.1.4). In *Defuse the Bomb*, both visual and auditory feedback is used, where the visual feedback takes the form of light and color and provides information about the task, correctness, and which color the player has obtained from the ColorLabel. The auditory feedback is given through a victory sound or an error sound to let the player know if their answer was correct or not. Challenge is implemented in the game through adjustable difficulty and randomness to match the players' abilities and prevent boredom. To keep the players' concentration and interest, the game requires focus and provides stimuli from different sources like light, color, music, and visual graphics.

In addition, one of the characteristics of enjoyment, *fantasy*, defined by Malone (1980) and forms of reward by H. Wang and Sun (2011) is included in the game. Fantasy is implemented through a ticking bomb and is meant to make the game more interesting and to increase motivation and engagement and rewards in form of an animation and victory sounds if the player manages to defuse the bomb. A summary of the game elements used in Defuse the Bomb, how they were applied, and their intended effect, can be found in Table 19.

Table 19: Game elements and theory used in *Defuse the Bomb*.

Game Element	Sub-Category	Application and Intended Effect
Feedback	Visual feedback	Light: The solution cube gives a task and changes color when a task is completed correctly. Color: The solution cube tells you where to go in the obstacle course by the color. Light: The player cube changes color when touching a color label. Guides where to go next in the obstacle course and gives feedback on performance.
	Auditory feedback	Victory sound: Returning to the solution cube with the correct color on the player cube. Error sound: Returning to the solution cube with the wrong color on the player cube. Player gets feedback on their performance, which can motivate them to perform well and correct errors.
Challenge	Adjustable difficulty	Adjusting difficulty to players' abilities will keep them from getting bored and prevent an impossible level.
	Randomness	What color the solution cube lights up in is random. Randomness can provoke curiosity and variation in the game so that every time the game is played, there are some variations.
Concentration	Grab and maintain focus	To quickly get to the correct color label, the player will have to stay concentrated and focus on remembering the solution cube. Such concentration can lead to immersion in the game and flow.
	Stimuli from different sources	Light and color from the cubes. Sound feedback: from the cubes. Music: from the app. Score: points and score in the app. Stimuli from different sources keeps the game more interesting.
Fantasy	Extrinsic	The game uses a fantasy about a bomb that is about to explode unless the player can defuse it in time. The purpose of the fantasy is to make the game more interesting, and create excitement and motivation for the task.
Reward	Animation	An animation is provided in the app if the player succeeds in defusing the bomb before time is up. This animation motivates the player to move quickly around the obstacle course to defuse the bomb in time and perform well.
	Victory sound	A victory sound is provided in the app together with the animation to motivate the player to win the game.

Customization

Defuse the Bomb can be adjusted to different types of players and to their abilities and needs in several ways. The obstacle course can be designed in numerous ways

to give the player appropriate exercises and challenges and the ColorLabels can be placed at different heights and distances. In addition, the number of ColorLabels affects the cognitive complexity of the game. The countdown time and the number of tasks can be adjusted for a suitable difficulty, and the game can be played in a multiplayer mode for social players. An overview of the customizable options is shown in Table 20.

Table 20: Customizable options in *Defuse the Bomb*.

Customizable	Effect
Different physical obstacles or obstacle courses	The physical environment where the ColorLabels are placed affects the difficulty of the game.
Placement of the ColorLabels	Affects the difficulty and can be adjusted according to patient needs. A ColorLabel placed on top of a ladder is harder to reach than one placed on the floor.
Number of ColorLabels	Affects cognitive complexity. Adjust the number of elements in the game.
Number of tasks	Controls difficulty when combined with a countdown timer. Can affect the game duration.
Countdown time	Controls the game's duration and can affect difficulty when combined with the number of color tasks.
Single- or multiplayer	Multiplayer creates a possibility to introduce an element of social interaction and cooperation.

Multiplayer Mode

Defuse the Bomb has two multiplayer options:
1) Color-Blending: To play *Defuse the Bomb* as a color-blending multiplayer game, three ColorCubes are needed; one set to be a solution cube, and the other two set to be player cubes. This mode is a cooperation mode, similar to the cooperation mode of *Hit the Cube*, where the players have to work together and blend colors to defuse the bomb. For instance, if the solution cube turns green, the two players have to run and gather one color each, blue and yellow, then run back and touch the solution cube simultaneously to create green.
2) Relay: The relay cooperation multiplayer mode requires two ColorCubes: one player cube and one solution cube. The game is played identically to the single-player version of *Defuse the Bomb*, except that after a player has delivered the correct color to the solution cube, they pass the player cube to the next player, who runs to gather the next color, like in a relay.

7.3 Summary

In this chapter, the ColorCube concept has been presented. ColorCube has a tangible interface that consists of ColorCubes that can glow in different colors and make sounds, and ColorLabels, wearable colored labels that can be fastened to different body parts and objects using a strap. Two ColorCube games, *Hit the Cube* and *Defuse the Bomb*, were explained with their therapeutic purpose, game objectives, gameplay, game controls, game elements, customization options, and different game modes.

Chapter 8

Evaluation

After creating the ColorCube concept, a functional prototype was made and was tested during eight separate evaluations. The goal of the evaluations was to answer the second research question:

RQ2: How do physiotherapists experience using concepts from gamification in the treatment of patients?

In this chapter, the ColorCube prototype will be introduced, followed by details on how the evaluation was conducted, before finally, results from the evaluation will be presented.

8.1 Prototype

This section describes the technology behind the ColorCube prototype, its functionality, and how it was used to create an illusion of a working game.

8.1.1 Prototype Description

In the description of the ColorCube concept (Section 7.1), four types of technology and their properties were listed (see Table 16). One of the technology types, the colored lights, was implemented in the prototype (Figure 16). The light could be switched on and off and had four different color options: red, blue, green, and yellow. The prototype could also play audio, but to simplify the workload of the researcher controlling the prototype, the sounds were controlled by the researcher

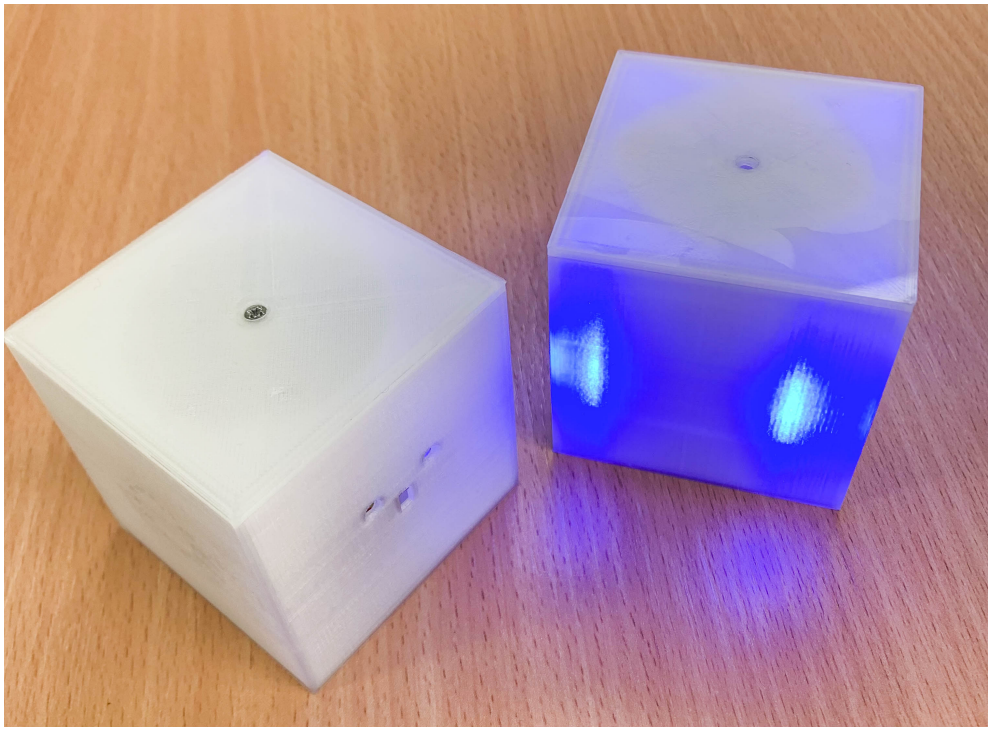


Figure 16: Prototype of the ColorCubes.

present with the users, through an external application instead.

The concept described sensor technology implemented in the ColorLabels, but for the prototype, the ColorLabels were elastic straps with labels made from colored EVA foam sheets and did not contain any technology. The communication between the ColorCubes and ColorLabels were simulated by one of the researchers by using a remote control.

The time registration and whether or not the answers were correct was also simulated by one of the researchers. A video with a 1.5-minute countdown animation and spy music was created to simulate an app with the music and visual graphics of Defuse the Bomb. Due to the graphics being a video that could not be individually adjusted, the number of remaining tasks (as shown in Figure 15) was not displayed but instead communicated verbally by the researcher.

8.1.2 Technology

The cube (Figure 16) was designed in FreeCAD and was printed on an Ultimaker S5 in transparent PLA. It measures 60x60x60 mm^3 and has a square post in the middle to mount electronics on. The lock was fastened with a screw that went

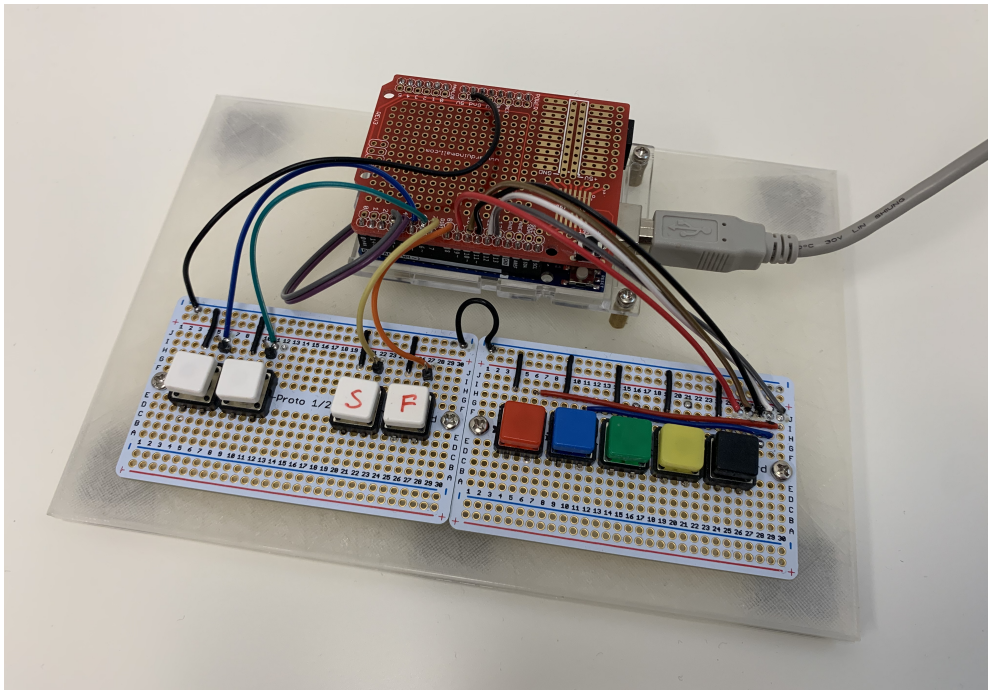


Figure 17: Prototype remote control.

down into a screw hole at the top of the post. Next, a device that fit Adafruit's Feather system was made, which could be threaded down on the post. An Adafruit Feather Huzzah ESP8266 was mounted on one side, and a Feather prototyping board on the other side.

Feather Huzzah ESP8266 had built-in WiFi and a battery charger and was connected to a 500mAh LiPo battery via an on/off switch. It was connected to four Neopixel LEDs attached to a ring so that there was an LED for each side of the cube when the lid was open. These were connected in series and could be addressed individually with unique colors, but in this case, all had the same color and light at the same time. These were used to avoid wire chaos in the cube.

The microcontroller (Feather Huzzah ESP8266) was programmed to connect to the university's Internet of Things (IoT) network and could only be used internally at the university. Furthermore, it was programmed to receive messages via MQTT on the following topic: / cube / 1 / color or / cube / 2 / color. The actual message (payload) was the numbers 0, 1, 2, 3, or 4. These corresponded to red, blue, green, and yellow.

An Arduino WiFi rev2 was used for the remote control, which was also connected to the university's IoT. Seven pushbuttons were connected to it: two cube selectors and five color selectors. The pressure switches were soldered to prototyping boards, and the components were mounted on a plate (see Figure 17).

An event-based library, *Eventually*, was used, which also took care of debouncing. It sent messages via MQTT about which color to put in which cube. All microcontrollers were programmed in C ++ with Arduino IDE.

8.2 Purpose and Preparation

To test the concept and the prototype, eight evaluations were conducted. This section presents the purpose of the evaluation, the methods used, the participants, the procedure and setup, and the tasks the participants were given.

8.2.1 Purpose

The purpose of the evaluation was to understand the physiotherapists' experience of using the ColorCube, observe how they interacted with it, and discover more about its potential. This purpose was divided into three primary goals for the evaluation:

- Gain insight into important design considerations.
- Evaluate ColorCube for use in physiotherapy.
- Explore ways to use the ColorCube.

8.2.2 Participants and Recruitment

A total number of nine physiotherapists (two male and seven female) participated in the evaluation. Four of them (Phy6, Phy7, Phy8, Phy9) had already participated in the brainstorming interviews, while the remaining were recruited by self-selection sampling through an online physiotherapy group on social media. Their role was to be a physiotherapist, set up and adjust variables in the games, and instruct the patient. One physiotherapist participated in each evaluation, except for one session, where two participated together.

In addition to the physiotherapists, five persons (two male and three female) participated as patients. There was one patient per evaluation and their role included playing the games with instructions from the physiotherapist and providing feedback on their experience. Two of the patients (P9, P10) had been treated by a physiotherapist earlier, while the remaining three (P6, P7, P8) were healthy persons recruited using convenience sampling. However, due to simplicity and their role in the evaluations, all five persons are referred to as patients throughout this thesis. Table 21 shows an overview of the physiotherapists and patients that participated in the evaluation.

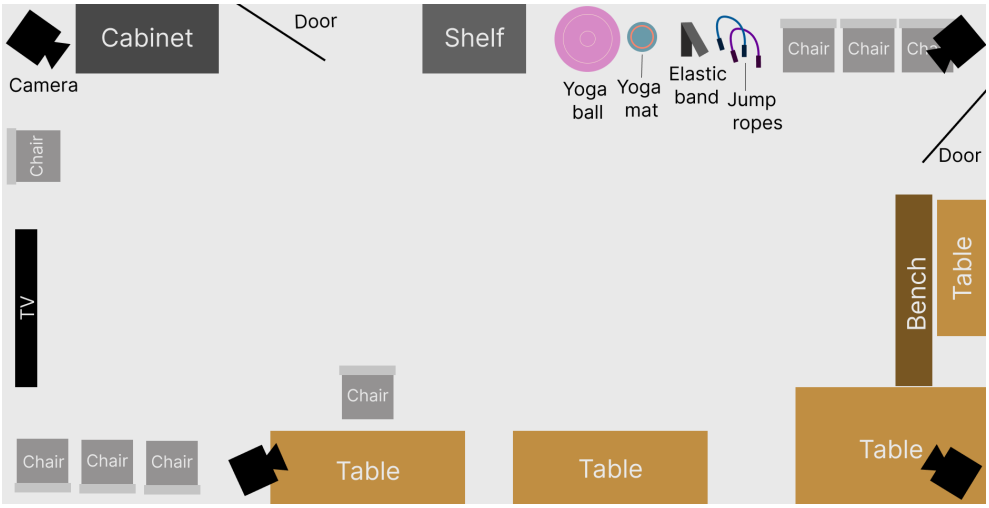


Figure 18: Lab setup for evaluation.

Table 21: Overview of the physiotherapists and patients participating in the evaluation.

Physiotherapist	Type/Specialization	Patient	Type of Patient	Type of Workshop
Physiotherapist 10 (Phy10)	Associate Professor	Patient 6 (P6)	Healthy Student	Physical
Physiotherapist 7 (Phy7) Physiotherapist 11 (Phy11)	Children's Physiotherapist Children's Physiotherapist	Patient 7 (P7)	Healthy Adult	Physical
Physiotherapist 12 (Phy12)	Children's Physiotherapist	Patient 8 (P8)	Healthy Student	Physical
Physiotherapist 13 (Phy13)	Children's Physiotherapist	Patient 9 (P9)	Physiotherapy Patient	Physical
Physiotherapist 14 (Phy14)	Human Movement Scientist	Patient 10 (P10)	Physiotherapy Patient	Physical
Physiotherapist 6 (Phy6)	Professor	N/A	N/A	Digital
Physiotherapist 8 (Phy8)	Physiotherapy Student	N/A	N/A	Digital
Physiotherapist 9 (Phy9)	Special Physiotherapist	N/A	N/A	Digital

8.2.3 Procedure and Setup

The evaluation was held in a lab at the university. The lab had audio and video recording options, sufficient space for the participants to move around, chairs and tables, a shelf, and some simple gym equipment (see Figure 18). The gym equipment was picked out based on insight gained in the preliminary study (Table 11).

There were two types of evaluations: digital and in-person. A total of three digital evaluations were held, where the physiotherapist participated in a video conference meeting over Zoom and five in-person evaluations where a physiotherapist and a patient participated physically. The digital evaluations were held to further

Figure 19: Physiotherapist instructing the patient on how to play *Hit the Cube* with two ColorCubes.

include physiotherapists who participated in the brainstorming interviews and who could not participate in person. The same procedure was used for both evaluation types, except that the physiotherapists who participated digitally had to instruct every action verbally instead of placing and moving things physically. In addition, a researcher took the role of the patient instead of a recruited participant in the digital evaluations.

8.2.4 Tasks

Two games were evaluated: Hit the Cube and Defuse the Bomb. Hit the Cube was first played with one ColorCube, then two ColorCubes. Due to limited time, the games' multiplayer modes were not prioritized. For each game, the researchers explained the game rules and conditions before letting the physiotherapist take over, decide the placement of the ColorCubes and ColorLabels and instruct the patient (Figure 19). Next, the game was played, and for each game, the patient and the physiotherapist were asked about their experience, what they liked and disliked, and if they had suggestions for improvement. To conclude the evaluation, a reflection session was held in the form of a semi-structured interview.

8.3 Data Collection and Analysis

The in-person evaluations were video recorded using the cameras and microphones in the lab. The digital evaluations were recorded using Zoom's built-in recording functionality. The researchers watched the videos, and relevant speech and observations were transcribed into a text document. The transcriptions were analyzed, categories were created using an inductive approach, and the data was sorted and grouped into categories in Miro (see Appendix A.2). The main results were derived from the categories and will be presented in the results section.

8.4 Results

This section will present the results from the evaluations. The results are grouped into five categories: *Physical Attributes, Context of Use, Game and Technology, Game Impact on Patients*, and *Ideas for Future Games*.

8.4.1 Physical Attributes

The first category contains feedback and observations about the physical design of the ColorCube and ColorLabels.

Size

Four physiotherapists (Phy7, Phy10, Phy11, Phy12) and four patients (P6, P7, P8, P9) expressed concerns about the cube being too big, especially for patients with small hands, like children. For example, one of the patients (P6) worried that children might have to use both hands to hold the cube because of its size, making it hard for them to play games like Defuse the Bomb, where a ColorCube must be carried while moving through an obstacle course.

> "*I just thought a bit about the size when it comes to children and such. Their hands are not as big, right? So, it's not like they can hold it with one hand. They would have to hold it with both hands. And it's a bit harder to hold something with both hands and get past... Because I sometimes managed to just lean on one hand to get up the obstacle course. That might be a good thing to think about.*"
>
> Patient 6

Physiotherapist 12 suggested smaller cubes for children and patients struggling with grip-functionality but expressed satisfaction with the current size for adult-sized hands with sufficient grip. The physiotherapist therefore suggested to have a variety of cube sizes to meet the needs of a diverse patient group.

> "For children's hands, it can be a little too big to hold, the cube. . . . And especially if you have reduced grip strength and... If you could have it in different sizes, for example. But it's not a problem for an adult to hold it. No, I can see that."
>
> Physiotherapist 12

Physiotherapist 10 speculated that the cubes could be too small in situations where patients must hit or touch the cube with limbs like feet or ankles and suggested increasing the size of the cube.

Shape

Several observations were made about the shape of the ColorCube during the evaluations. The cube shape allowed for many different placements of the cube and at different heights. Some physiotherapists chose to hold the cube during the games, while others left it stationary on a flat surface like the floor, a table, a chair, or a shelf. The colored light was visible from multiple sides and from above, and during Hit the Cube, it was observed that the patients did not just hit one side of the cube but used multiple sides while playing. Which side they used depended on the body part in use and where the ColorLabel was placed on that body part. Physiotherapist 10 reflected on the cube shape and how it enabled placing and stacking:

> "It's very convenient to put it down, really. I cannot quite see what other shape... A triangle may not be the best, hehe. [A cube is] easy to put down, easy to stack, simple, and... Yes. It would be stupid to have like a round one."
>
> Physiotherapist 10

Two physiotherapists (Phy8, Phy12) mentioned that the cubes should be comfortable to hold for the patients. For instance, physiotherapist 8 suggested having rounded corners to prevent patient injuries while playing:

> "Maybe the cube needs to have rounded corners so that it is not sharp and so that you won't injure yourself on it."
>
> Physiotherapist 8

Defuse the Bomb requires the patient to carry the cube through an obstacle course (Figure 20). Both participants and physiotherapists expressed that carrying the ColorCube through obstacles could be challenging. Therefore, four physiotherapists (Phy7, Phy10, Phy11, Phy13) and two patients (P7, P9) suggested creating a wearable version of the ColorCube, such as a bracelet. A wearable ColorCube would enable the patient to move around more freely, and overcome obstacles like wall bars, where the patient would have to use both hands to climb. Physiotherapist 10 pointed out how patients with CP might benefit from a wearable cube. Such patients might not be able to use both arms that well and that if their good arm is devoted to carrying the ColorCube, they will struggle to get through an obstacle course.

> "I wonder, like, if you have the opportunity to wear it or... Maybe you should have had like a bracelet with a cube, right, so that it is the bracelet that changes color, and then you go over there and... . . . Because then you actually get to use both arms, that is, if you, for instance, only have, say [CP] then, right? Children with CP who may have a side that does not work so well, and will hold it in their good arm. Then they will not get around, in a way. So then to have such a bracelet..."
>
> Physiotherapist 10

Material

The ColorCube prototype aided in revealing several important design considerations about the material.

Four of the physiotherapists (Phy6, Phy8, Phy9, Phy14) mentioned the importance of having a robust cube. Games and physical activity can lead to sudden movements, rough treatment, and the ColorCube falling and hitting hard surfaces. Physiotherapist 14 emphasized that to get the most out of the cube and the exercises, one should not need to worry about the cube breaking:

> "I also feel that [the cube] is easy to destroy, but I know it is a prototype, so, hehe. I kind of want... I have to be careful with it so that it does not fall to the ground. But the fact that it must be very robust, right? So that you don't... Like, you must be able to use it without being afraid that it will break."
>
> Physiotherapist 14

Four of the physiotherapists (Phy8, Phy11, Phy13, Phy14) suggested that the ColorCube could be waterproof to enable playing outdoors or in a swimming pool.

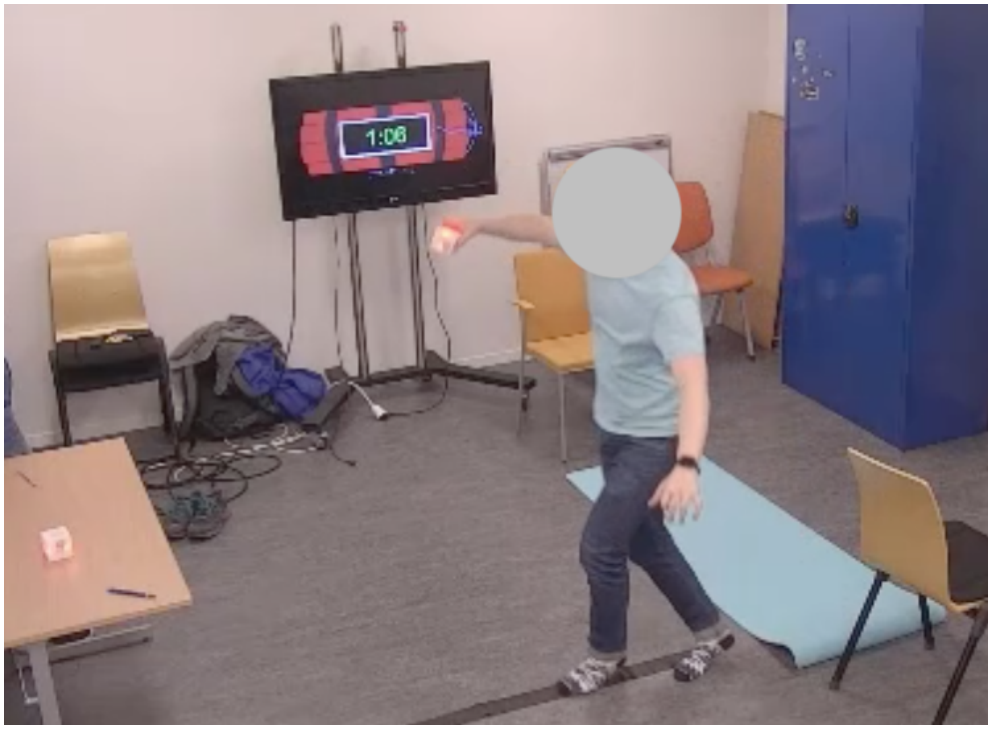


Figure 20: Patient playing Defuse the Bomb.

Physiotherapist 8 claimed that if it were portable and could be used in wet environments, it would be revolutionary:

> "So if this is, like, battery-powered and can be used outdoors or is also waterproof and can be used in the pool, then it is sort of a game-changer."
>
> Physiotherapist 8

Since the ColorCube potentially would be used by multiple patients and in an environment where infection prevention and control are important, two of the physiotherapists (Phy8, Phy9) mentioned that the equipment should be easy to disinfect. Physiotherapist 9 advised paying attention to this when choosing the material of the cubes and labels:

> "I also hope that the material on those color labels, that they are, like easy to disinfect and wash."
>
> Physiotherapist 9

A design consideration mentioned by five physiotherapists (Phy9, Phy11, Phy12, Phy13, Phy14) and one patient (P8) was that the cube should be made in such a

way that it does not slip on the surface it was placed. Physiotherapist 12 worried about the safety of the patients while playing because of the cubes' lack of friction on the surface:

> "Ideally, you might have a mat underneath here, so [the cubes] do not slip like that. Because it can be a bit scary when you work with children. At least, so that [the cubes] do not slide away."
>
> Physiotherapist 12

Physiotherapist 13 suggested using a suction cup to fasten the ColorCubes to the floor and avoid sliding:

> "We should have had something sticky underneath, so it stuck to the floor. A suction cup or something."
>
> Physiotherapist 13

Mounting

Seven of the physiotherapists (Phy6, Phy7, Phy8, Phy10, Phy11, Phy13, Phy14) and one patient (P9) expressed a wish to fasten the cubes not only to the floor but also to ceilings, ropes, walls, and other surfaces. Physiotherapists 7 and 11 discussed what they envisioned as the optimal solution: to be able to fasten the cubes on the wall or to the ceiling and easily remove them again both in the therapy room and if they brought the game with them to other locations, like a school:

> "And so it is, in a way, we have rooms that are pretty bare and without shelves. I imagine that if we were to use them on a wall, there would have to be something we could have had almost flat on the wall, so it would have been possible to attach them as needed and then just remove them again. I imagine in such a therapy room, then it is difficult to, in a way, mount such shelves to..."
>
> Physiotherapist 7

> "It should also be, for example, say if you are going to take it to a school, that you can take it down and just have an open wall and do exactly the same thing there."
>
> Physiotherapist 11

> "And if not a board then, perhaps kind of like a velcro cloth with velcro cubes, that you could just 'click' fasten them in different places and

> then easily fasten them and take them down from the wall. Dream scenario! So ways to hang them from the ceiling and ways to hang them on the wall. In addition to being portable."
>
> Physiotherapist 7

ColorLabels

In addition to suggest ways to improve the ColorCube, the physiotherapists gave some feedback on the physical attributes of the ColorLabels. Physiotherapist 9 appreciated that there were straps of different lengths because it opened up for many different ways of using them, and physiotherapist 6 especially liked that there were very small ColorLabels that could be worn on the patient's fingers.

> "Very nice that you have thought of small, slightly larger, large, such labels. It, in a way, gives a great latitude."
>
> Physiotherapist 9

> "Does that mean you can have a label on your finger? Brilliant!"
>
> Physiotherapist 6

Physiotherapist 7 suggested having straps that were even more customizable and adjustable:

> "Adjustable straps, in different sizes, instead of elastic which in a way has a given length. Then you have for both small children and a little bigger, and/or adults."
>
> Physiotherapist 7

Two of the physiotherapists (Phy7, Phy14) found the possibility of having two ColorLabels on one strap useful. Physiotherapist 7 suggested having two ColorLabels on one strap and, for instance, placing one label on each side of the head or upper body to allow for different types of rotation movements.

Four of the physiotherapists (Phy7, Phy11, Phy12, Phy13) instructed the patients to wear ColorLabels under their feet. To use the ColorLabels this way, they must be designed to withstand being stepped on. Some patients expressed that it was difficult to remember which color was placed under which foot, increasing the cognitive load of the task. Physiotherapists 12 suggested adding an indication of the color on the top of the patient's foot to reduce the cognitive load:

> "I also thought that for children, it can be difficult to remember where the green is and where the yellow is. So if there could be an option and get the color up [on the top of the foot] and . . . Because I think it might have been... It will not be as difficult."
>
> Physiotherapist 12

8.4.2 Context of Use

The second category suggests where, how and by whom the ColorCube can be used and presents the physiotherapists' reflections on its versatility and ease of use.

Patient Groups

Results from the evaluation indicated that a great variety of patients could use the cube, both in terms of age and disorder. For example, six physiotherapists (Phy7, Phy8, Phy10, Phy11, Phy12, Phy13) had experience working with children and identified children as an obvious patient group.

Seven physiotherapists (Phy6, Phy7, Phy8, Phy9, Phy10, Phy12, Phy14) imagined it in use for adults or the elderly too. Physiotherapist 6 pointed out how the ColorCube has a very flexible target group, and especially has potential for patients that need more motivation:

> "And I think that is the key to success with the ColorCube that it has such a flexible area of use. . . . There are so many patient groups that will be relevant to train in that way. Anyone who needs the motivation to do their exercises, as quick as possible. And that's most people."
>
> Physiotherapist 6

Stroke rehabilitation patients was a frequently mentioned group, brought up by four physiotherapists (Phy8, Phy9, Phy10, Phy13). Physiotherapist 8 gave a specific example of how the ColorCube could be useful in post-stroke rehabilitation by motivating patients to raise and lower their arms towards the cube.

Four of the physiotherapists (Phy10, Phy12, Phy13, Phy14) and three patients (P7, P8, P9) mentioned uses for the ColorCube outside of physiotherapy. Physiotherapist 10 suggested using it in training for top-level sports, while patient 8 and physiotherapist 12 discussed how it would work well for neurorehabilitation. Patient 8 saw potential in the cognitive challenge of remembering colors, and physiotherapist 12 pointed out how the games could help connect pathways between the brain and muscles and motivate patients to complete many repetitions.

> "And I, coming from the field of psychology, kind of see a lot of this neuro part of it as well. The thing about remembering what color was underneath and... Yeah, I think there are many areas of use. . . . "
>
> Patient 8

> Yes, because there is a connection between the brain and muscles, so I think there is a lot to be gained in neurorehabilitation and rehabilitation by having tasks where you have to think. Because then you work extra to connect pathways from the brain and out to the muscles. So I really believe in this, and it's... Yeah. I think you can get many more repetitions when you have something motivating. Because that's what you want, you want many, many repetitions."
>
> Physiotherapist 12

Other patient groups mentioned can be found in Table 22.

Table 22: Overview of areas of uses and examples given by the physiotherapists.

Context of Use	Type
Patient Groups	Children, elderly, athletes, CP, nevro-/rehabilitation, overweight, psychology, stroke, wheelchair.
Exercises and Skills	Balance, bending forward, cardio, cognitive, concentration, coordination, endurance, hands over head, heel raises, impulse control, knee lift, lunges, plank, reaction, simple shoulder rehab, speed, stand on one foot, strength training exercises, turn palm of hands, and combining several movements.
Physical and Social Context of Use	Clinic, home, outside, school physical education.

Physical and Social Context of Use

The evaluation was set up with a physiotherapist and a patient in a room that was designed to resemble a clinic. Therefore, the clinic was a naturally suggested context of use for the ColorCube. However, the participants also imagined other contexts where it could be used. For instance, four physiotherapists (Phy7, Phy10, Phy11, Phy13) suggested that the games could be used in cooperation with the school and a group of students. Physiotherapist 13 imagined that ColorCube could enable students, who are normally given separate tasks in physical education, to play with their classmates. The physiotherapist could facilitate it by making discrete, individual adjustments to the ColorCube to suit the patient's target skill training or ability. Such adjustments could for instance be to choose which parts of an obstacle course to send the patient to by selecting the color of the solution cube, to make them practice a specific skill.

> "Yes, and the fact that you can integrate it into a class. That you can, in a way, challenge the student discreetly, in a way, without there having to be a stigma on the student or students who may have an extra need for balance training or, yeah, miscellaneous. . . . It would have been an easy tool for the physiotherapist to collaborate with the P.E. teacher. Because I know that some find that challenging."
>
> Physiotherapist 13

Five of the physiotherapists (Phy7, Phy8, Phy11, Phy12, Phy14) suggested using the cube outside. Physiotherapist 11 pointed out that being able to play with the ColorCube outside could be an advantage for cardio training because it would facilitate playing with a larger distance between the ColorCubes:

> "Can you be outside with it? Almost orienteering. Then you have larger areas to play with. If, for example, you have children and young people with obesity problems and then want a type of a little more fun cardio, maybe then, then you can put them at a greater distance, so the focus can be to move in a little greater distances, quickly. Or hills, or, yeah."
>
> Physiotherapist 11

Patient 10 expressed how bringing the cube home would give extra motivation. Physiotherapists 8, 13, and 14 also suggested that the patients could bring ColorCube home.

> "It may even be something they can buy or borrow to take home and use at home too. . . . That, in a way, the user himself could use it at home with his siblings or his family."
>
> Physiotherapist 8

The ColorCube can be used in many different contexts, and one reasons is its portability. Five of the physiotherapists (Phy7, Phy8, Phy9, Phy10, Phy12) mentioned its portability as a benefit. For example, physiotherapist 10 mentioned that the equipment could easily be carried in a bag, physiotherapist 9 pictured that it would be easy to bring it to other locations, and physiotherapist 12 mentioned the advantage of convenient storage:

> "I like that you can make the tasks into a game without a lot of fancy technology. Very convenient to carry. Really, you just have to put it in a small bag with some of those straps and a couple of cubes, and then you can set it up in all sorts of variations, so I think it's quite fun with

> that kind of technology."
>
> Physiotherapist 10

> "Very simple, I envision that it is very easy for us to just be able to bring it to a patient room or have it lying in the gym."
>
> Physiotherapist 9

> "Yes, it's very nice, something that is easy to carry and does not take up too much space. Because you usually do not have much storage space either. Yeah. So it's ingenious, you know, with small things like that."
>
> Physiotherapist 12

Exercises and Skill Training

The physiotherapists had suggestions for exercises and skills that can be trained using ColorCube. These are all listed in Table 22. During the evaluation, it was observed how the physiotherapists quickly invented ways to use the ColorCube by incorporating it into existing exercises. Physiotherapist 9 imagined using it with a reaching exercise where patients are asked to reach for imaginary objects, to give the patients something more concrete to reach for and more feedback:

> "I mean, it creates color and dimension for something other than 'could you imagine picking the strawberry that hangs up there?' And if they here could actually take 'can you take the red mark and hit here?' sort of, or, yeah. So that too could have been a thing, that you had four marks lying in front of you and then you have to choose the right mark and touch the cube."
>
> Physiotherapist 9

Physiotherapist 6 suggested combining ColorCube with a classic exercise by instructing patients to stand up and sit down between each color task in *Hit the Cube*:

> "I can think of the classic, most boring exercise the physiotherapist does, but which is still absolutely necessary, which is to get up and sit down. And now you have made the cube so simple that it would have been natural to say that between each opportunity you should sit down and get up again."
>
> Physiotherapist 6

In addition to the skills listed in Table 22, all nine physiotherapists thought of ways of how it could be used to train several skills simultaneously, as exemplified by physiotherapist 13:

> "A lot is being tested at the same time. It's kind of both focus, coordination, balance, endurance . . ."
>
> Physiotherapist 13

Six of the physiotherapists (Phy8, Phy9, Phy11, Phy12, Phy13, Phy14) explicitly mentioned how Hit the Cube was an excellent game to train reaction. Physiotherapist 12 pointed out how ColorCube could be used to train the signals that run between the brain and the muscles:

> "They have to work with reaction, in a way, by thinking fast and reacting correctly. Because it can often be a bit difficult because then you get to like work with the response that goes from muscle to the brain and back again."
>
> Physiotherapist 12

Versatility and Customization

The various patient groups, exercises, and context of use, summed up in Table 22, suggest that ColorCube is very versatile. This part will present the physiotherapists thoughts and reflections about the versatility, and their ideas of additional ways to customize the cube.

ColorCube's versatility was demonstrated further when physiotherapists took ownership of the cube and adjusted the variables they were given. For example, physiotherapist 9 set up the labels for Hit the Cube with two cubes in a way that forced the patient to rotate the wrist to make the palm face upwards or downwards, as illustrated in Figure 21. The physiotherapist explained that this was because for a lot of patients, holding their hands one way is easier than the other, and that the ColorLabels could be used to motivate patients to challenge themselves:

> "The reason I told you to hit one way with one label and the other way with the other was to gain a higher range of movement in the arm by using them differently. Because turning the palm of the hand up is, for a lot of my patients, at least, hard to do. Many of them think... Yeah, it is easier to hold the hand [with the palms pointing downwards], in a way, and turning them upwards is more demanding. This was very fun."
>
> Physiotherapist 9

Figure 21: This placement of ColorLabels forces the patient to rotate the wrists.

Physiotherapist 13 added rules to the game to increase the difficulty and facilitate balance training by asking the patient to stand on one foot while carrying out the exercise. Later, the physiotherapist explained how this version of the exercise might not be suitable for another type of patient, and that the difficulty then could be adjusted by decreasing the number of colors used in the game:

> "Well, I wouldn't have added the same challenge to a ten-year-old child with disabilities, in a way. So then we would just have to test a little bit. But it is easy to remove a couple of colors or..."
>
> Physiotherapist 13

During *Hit the Cube*, physiotherapist 7 reflected on what to consider when choosing where to place the ColorCube, and that moving the cube could change the focus of the exercise:

> "If I were to use this in therapy now, I would have started by thinking, 'What area should we work on? Why?' So then I would connect that to what height I put the cube at, where I place it, and so on."
>
> Physiotherapist 7

Physiotherapist 6 saw the potential of deciding precisely what body parts to work on by using the ColorLabels:

> "The brilliant thing you have achieved is the fact that you 'force' or we can challenge the patients to use specific body parts. That is maybe

Figure 22: Different placements of the cube.

> what makes you really stand out and actually makes it more user-friendly. That you can put [the label] on the elbow, you can put it on the knee, you can put it on the forehead if you want to. That is not a bad idea."
>
> Physiotherapist 6

A wide range of patients and physical abilities demands ways to adjust the difficulty of the games to appropriately fit each patient. Both patients and physiotherapists found ways to adjust the difficulty of exercises during the evaluation. For example, physiotherapist 7 suggested that the difficulty could be adjusted by changing the number of ColorLabels used:

> "There are many colors to remember now, though. So if I were to start with this, then I would preferably have one at a time, or fewer colors first and then added on along the way. . ."
>
> Physiotherapist 7

Physiotherapist 12 demonstrated how the distance between the ColorCubes and the patient could affect the difficulty level of the games:

> "Because then it is possible to just stand here [places the cubes on the floor right in front of the feet with a small distance] and then you just tap. I think that will be challenging enough for many of my patients. But if you want it to be more challenging [moves the cubes further away from each other] then it is possible that [the patient] could somehow move more sideways, then."
>
> Physiotherapist 12

Figure 22 shows three different ways the cubes were placed while playing Hit the Cube in the evaluation sessions.

Physiotherapist 8 suggested adjusting external variables, like adding weights on the patient's arms, to increase the difficulty and physical effort needed to complete the tasks:

> "To make it harder for people. Maybe you could have gloves or weights on your hands to make it heavier, so you kind of get a little more physical exertion out of it too."
>
> Physiotherapist 8

Many of the physiotherapists had suggestions for adjustable variables that could be customized in a ColorCube app. For example, physiotherapist 7 explained that the diverse patient group requires tools and equipment to be adjustable to make spontaneous changes and customizations as needed:

> "We are almost dependent on [flexibility] because there are so many different problems. And then you may have to make changes on the spot as well. It didn't fit, what we envisioned, so then we'll have to change it. In those situations, it's very nice if it is very flexible and adjustable. That we have the opportunity to influence the variables."
>
> Physiotherapist 7

Physiotherapist 11 suggested having the possibility to control how many tasks there would be of a particular color. The physiotherapist could decide that the majority of the tasks would be red and mark a limb that creates the target movement with a red ColorLabel. However, since this is controlled by the physiotherapist in the app, the patient could still experience the colors as random:

> "So if you, as a physiotherapist, use [ColorCube] and can control it through an app or software or something, and then I really want her to challenge herself with the left knee, then I can enter for instance that it does eight times on the left knee, and only three on the right? Seems random [for the patient], but it won't really be."
>
> Physiotherapist 11

Several other variables that could be adjusted in the app was proposed by the participants and can be found in Table 23.

Table 23: Suggestions for customization.

Adjustable Variable	Details	Suggested by
Time	Countdown time	Phy7
	Timer on/off	Phy7, Phy10
	Speed (interval, color change)	Phy7, Phy11, Phy14
	Timing instead of speed	Phy14
Rounds	Number of tasks	Phy7, Phy11
Colors	Repetitions per color	Phy8, Phy11, Phy13
	Select colors	Phy7
	Assign specific colors to specific cubes	Patient9, Phy13, Phy14
Visuals and Graphics	Other options than a bomb	Phy11, Phy13
Sounds	Select music	Patient9, Phy11
	Sound on/off	Phy11

Setup and Ease of Use

The physiotherapists emphasized that it was important that the ColorCube was easy to use. Physiotherapist 6 appreciated how the ColorCube was simple and intuitive while still requiring the therapeutic knowledge and creativity of a physiotherapist:

> "But now you have done exactly that. You have created something that is very intuitive, and then it's me as a therapist who must consider how it should actually be used; what is relevant to my patient."
>
> Physiotherapist 6

Patient 8 also found the ColorCube easy to understand and use:

> "I think it was very intuitive and easy to understand, which I appreciated. Yeah, it was easy to understand how it worked."
>
> Patient 8

A factor mentioned by physiotherapists 9, 11, and 14 was the importance of a quick and easy set-up and ease of use. For example, physiotherapist 14 stressed that physiotherapists would refrain from using ColorCube if the set-up was too complicated or time-demanding:

> "As long as you do not have to spend a lot of time in the beginning, setting it up. That is, in a way, the most important barrier. If it's just

> 'plug and play', press two buttons, and you're good to go: perfect. If you have to spend ten to fifteen minutes to somehow plan out the exercise and find out how it will be and have to be careful not to ruin it, then it won't work. Then it won't be used. Because you do not want to waste time with the patient. It's a worst-case scenario."
>
> Physiotherapist 14

8.4.3 Game and Technology

This category presents feedback on the ColorCube games, the technology, and the game elements used.

Colored Light

One of the elements used in ColorCube to engage the player is colored light. Physiotherapist 12 thought that especially children would enjoy the colors:

> "Children like having something to do, and that it is to respond to colors and such, I think, I think could be catchy, really."
>
> Physiotherapist 12

In *Defuse the Bomb*, the player carries a colored light from a ColorLabel to the solution cube. Patient 10 and Physiotherapist 14 described that experience and how they appreciated the feedback the colored light provided. They especially appreciated the illusion of carrying the colored light inside of the ColorCube, and getting feedback on task completion:

> "I love that [the player cube] turns into the color you touch. And yeah, that you sort of carry the light with you to [the solution cube]."
>
> Patient 10

> "Yes, cool! You see that you have actually picked up something! You have completed the task. And that's also a pretty nice thing, that you see that you have reached the goal you set and you get a visual feedback as soon as you did it."
>
> Physiotherapist 14

One potential challenge with colored lights is the concern for patients with color blindness or reduced vision which was mentioned by three of the physiotherapists

(Phy7, Phy8, Phy14). Physiotherapist 8 suggested having an option where the cube plays the name of the colors out loud for such patients:

> "Can the cube also, for example, say what color it is? Maybe someone is a bit visually impaired or is color blind and does not recognize the colors that well."
>
> Physiotherapist 8

Audio

Several sounds were incorporated into the ColorCube games. In *Hit the Cube*, there were feedback sounds, a victory sound for correct color matching, and an error sound for incorrect matching. In *Defuse the Bomb*, spy-themed music was played as long as the countdown lasted.

Physiotherapist 9 expressed appreciation of the feedback the sounds in *Hit the Cube* provided because it made it easier to understand if a task was completed correctly or not:

> "Also, it's a bit rewarding. Like, if it's a pleasant sound, then it's pretty cool to just get a confirmation that you hit it, if you were in doubt about the color somehow."
>
> Physiotherapist 9

Physiotherapists 10, 12, and 13, as well as patient 8, expressed enjoyment over the spy music in *Defuse the Bomb*. Physiotherapist 13 said that the music was motivating and created a sense of urgency and time pressure:

> "I think the music was fun, but it was just that I got such a flashback to when you played like that bomb stuff on the computer when I was little, where you kind of should, that the bomb should not go off, then you get like a motivating time pressure, in a way."
>
> Physiotherapist 13

However, physiotherapists 7 and 11 claimed that not all patients would benefit from auditory feedback and music. They explained that overstimulation could be disadvantageous to sensitive patients and that some might be discouraged if they get a lot of negative feedback when making mistakes:

> "If you could manipulate sound, then we could have lots of such animal sounds, for example. Connected to different colors. But some

> [patients] are disturbed by sounds. That it becomes too much at once, and then there is a bit of overstimulation."
>
> Physiotherapist 7

> "Also, considering what we were talking about earlier about removing sound. It's not only that it becomes sensitive, but also removing the sound because now we had the sound of right and wrong, but maybe it's not always so important if they missed maybe, for some [patients]."
>
> Physiotherapist 11

Time

Physiotherapist 14 and patient 10 tried Hit the Cube with some knee rehabilitation exercises. The physiotherapist's greatest concern about the game was that the timer would negatively impact the movement quality (defined in Section 2.3.2) as the patient was more concerned about doing the movement quickly than correctly:

> "My point is that we must be careful so that using these do not decrease the movement quality because you are more focused on touching [the cube] than you are doing the movement properly."
>
> Physiotherapist 14

Physiotherapist 10 shared the concern about having a timer because it could negatively affect the movement quality but stated that it could be a valuable indication of performance for exercises focusing on quantity:

> "If it's about quality, then it's very foolish to have a timer. If it's about quantity, then time is a very good indication of one's own performance. So it's a bit like, having an option for both. As long as time is just an application additional to the cube, it doesn't really matter."
>
> Physiotherapist 10

To solve this problem, setting a specific time for each movement was suggested. That way, feedback can be given if a movement is completed too fast, and instead of hitting the cube as fast as possible, the goal would be to perform the movement within a set amount of time:

> "And if you perform a movement too fast, then you are informed about it. That now I know that you performed the movement poorly because you were too fast. You cannot have done it correctly in just 0.1

> seconds."
>
> Physiotherapist 14

Physiotherapist 7 was concerned about the timer having a negative impact on some patients' stress levels and suggested, therefore, an option to turn off the timer:

> "So being able to adjust, if, for example, the part about you having to do it quickly, then there are a lot of kids who may back out. Because it's common that those who struggle with the motoric skills or have difficulty with movement know it very well and tend to perhaps shy away. So if one then had the opportunity to disconnect this stress with time pressure or countdown, I think it would have embraced an even wider group."
>
> Physiotherapist 7

8.4.4 Game Impact on Patients

The fourth category presents reflections from both the physiotherapists and the patients regarding how using the ColorCube affects the patients. The reflections and feedback are grouped into three aspects: *Motivation, Progress,* and *Diversion*.

Motivation

Both physiotherapists (Phy6, Phy7, Phy9, Phy11, Phy12, Phy13) and patients (P8, P9, P10) believed that the ColorCube has potential to help with patients' motivation. For example, Physiotherapist 12 believed ColorCube could motivate the children and young people at their clinic:

> "I think it was a bit exciting. I see the benefit of being able to use it in my own practice. I do. And I think it is something that could have motivated the children and young people we follow."
>
> Physiotherapist 12

Patient 9 imagined that ColorCube could positively change patients' attitudes towards going to the physiotherapist by turning the physiotherapy sessions into something fun, shifting the focus away from the negative aspects of their condition:

> "Because there are many, who may be a bit like that... If you're in a bad mood because you have a condition, it's a bit like 'okay, now I'm going to the physiotherapist again, and we'll just do the same exercises again', and then, in a way, to have such a motivating factor to it, like being joyful about it. . . . I think, if it had been like that to go to a physiotherapist, then it would have been like, 'Yes! I'm going to the physiotherapist!' instead of more like, 'today there is a physiotherapist appointment again. It's good for me, but yeah...' So, it's going to be... It's this motivational factor that, in a way, is fun, and you look forward to it more if you know you can do something like [using ColorCube]."
>
> Patient 9

Physiotherapist 7 observed how the exercises were turned into fun and games when using the ColorCube and claimed that creating playful experiences was a common goal for children's physiotherapists:

> "It will be play-based and not exercising. That's what it is... That's what we try to achieve otherwise too, that you turn many things into playing. When it's a game, it's much more fun for everyone."
>
> Physiotherapist 7

Patients 6 and 8 experienced how the games triggered their competitive instincts and patient 8 explained how the timer activated it:

> "I get very motivated by the fact that it has a timer. So I notice that I really want to do it as fast as possible. Even though I now don't gain anything from doing it quickly, I still feel that it makes me... Yes. The competitive instinct is very much set in motion."
>
> Patient 8

Patients 8 and 9 experienced that ColorCube added a goal and purpose to the exercises beyond the goal of training, and that it motivated them to make a greater effort in completing the exercises:

> "I very much agree with the last part [that the colors motivate] as I sort of... It's my experience of it, that it sort of motivates me to do [the exercises]. That I feel like I have a goal for the activity I do, and that I get a little push from the timer and... You want to achieve it."
>
> Patient 8

> "It challenges me, in a way, to push myself further. That I'm much more aware that now I'm going to... Now I have a goal, and that's playing this game, instead of now I have a goal and it's going to be training for my own sake. So, in a way, to have a goal with the physical activity makes it, in a way, much more fun. I would almost compare it to Pokemon Go. It was incredibly much more fun to walk when you had Pokemon Go than to go out just to have a walk. So it is, in a way... One kind of gets the same feeling with the use of this cube, that I can... Yeah. It gives... It makes more sense to me to do the exercises."
>
> Patient 9

Progress

When working towards a goal over a longer period of time, seeing progress is very important for motivation. Physiotherapist 9 reflected on how the games could be used together with a tablet or computer to register scores and times so that patients could receive concrete and measurable feedback about their progress:

> "So if you are going to have more functionality and you are going to do registration and score and such, then you may have to connect to a computer or a tablet or something to simply be able to register. So, in any case, my experience is that everything we can manage to register with time or number of hits or whatever you manage, it creates motivation in patients and joy. More than if it's just like, 'Yeah, I think you managed to hit this and that.' So if you can manage to either, that you keep it as it is now and maybe have a form that you can easily cross off or that you make it yourself, or that you actually get your own registration, preferably with a graph or something like that, then I think it will somehow make it even better for the patients in the context of exercise. And children, too, are a bit focused on scores and, 'How many did I get?' and 'How many did I hit?' and 'How fast did it go?'"
>
> Physiotherapist 9

Physiotherapist 9 also mentioned how the ColorCube games could encourage patients to compete against themselves and make progress:

> "The visuals and the fact that you have actually set up a bomb that has a countdown, it means that you add a little extra stress and time pressure, which can... I think can feel very motivating for many patients and especially if you don't complete the task, then 'okay, approximately how much did you have left'. Yes. So especially to try to beat

> yourself then, do it better every time. So great. Fun!"
>
> Physiotherapist 9

Receiving feedback on personal progression encouraged patient 9 to repeat the exercise in attempts to improve the score. Being able to measure and compare results was pointed out as an advantage:

> "I feel like you get a tool to be able to... What should I say? Make things measurable too. If you have like 'Okay, these exercises are suitable for this patient. Okay, here we'll do some exercises, and then we'll see if the time can improve or the reaction can improve and see if there is something like... And gives a bit like progression...' Yes, that it is measurable and gives... I feel, at least, that I am motivated to do the exercise several times to improve."
>
> Patient 9

Diversion

The physiotherapists saw the potential of the ColorCube games to be used as a diversion from pain, fear, and the fact that one is exercising and feeling tired. Physiotherapists 10 and 11 reflected on how the ColorCube could be beneficial to move the patients' focus away from their pain by creating a positive diversion:

> "So it is a very positive thing to somehow create that activity. It is, like I said, not necessarily always about doing exactly one type of exercise, right? But just creating that activity, and just being able to move without necessarily thinking so much about what you are doing. If you have pain in a knee, or in the back, then you often become like, you become very cautious about what you do, so you will be a bit careful. But once it's a bit like [a game], you forget it."
>
> Physiotherapist 10

> "I like what [Physiotherapist 7] said, that in a way, [the game] takes the attention away from the specific task and that it makes the patient think only of these colors and not so much exactly what you are doing. So it can work well for people that refuse to move, in a way. That they avoid moving in specific ways to avoid pain, for instance. That one forgets to think about such things."
>
> Physiotherapist 11

Physiotherapist 9 suggested using ColorCube to divert stroke patients from their fear of bending forward:

> "We have a lot of stroke patients who are afraid to bend forward. Many people are very afraid to lean forward just to tie their shoelaces. So it could have been relevant to have an elevated table or a bench in front where you would, for example, use both hands to hit with and maybe lean forward with your head. So it could be a nice exercise like that to train the abdomen and back, and sitting posture, but also sitting balance and challenging the fear of leaning forward and falling."
>
> Physiotherapist 9

Patient 7 experienced how the focus had shifted from the exertion to the engagement of the game:

> "I thought it was fun! That it was more like playing. I did not think about the fact that it was exercising, in a way, or that I was doing anything in particular. I was more just focusing on colors and having fun."
>
> Patient 7

8.4.5 Ideas for Future Games

One of the goals of the evaluation was to discover new ways to use the ColorCube. In this final category, game ideas for ColorCube suggested by the physiotherapists will be presented.

Multiplayer Games

Four of the physiotherapists (Phy6, Phy10, Phy13, Phy14) and one patient (P8) suggested having a multiplayer mode. The other physiotherapists were asked about the games' potential for a multiplayer mode. Physiotherapist 12 brainstormed around having both a competitive version of Defuse the Bomb, where the goal was to complete more tasks than your competitor, and a collaborative version where the players work together to complete as many tasks as possible in total:

> "You could both have that you have a collaborative task, or you could have a competitive task. That it is about trying to collect the most, for example, or cooperating where it is about gathering as many as possible of something. Or that you have to go high and low and a little around to collect points or colors, yeah. And for competition, each [player] could have their own color, for example."
>
> Physiotherapist 12

Send the Sequence (Multiplayer)

Physiotherapist 8 suggested using two cubes to communicate between two players by sending light signals to each other:

> "But maybe it could be something like that the two cubes acted as a walkie-talkie or something. That they sent light signals from each other to each other. So that one could, in a way, have cooperation between children or adults if they are in different rooms or with greater distance to each other."
>
> Physiotherapist 8

Defuse the Bomb - Sequence Version (Single Player)

Physiotherapist 8 also suggested an alternative version of *Defuse the Bomb* where the solution cube would give the player a color sequence to repeat instead of just a single color. Then the player would have to find and touch ColorLabels in the correct order to match the sequence:

> "So maybe if that cube... If it was like detonating the bomb with the cube flashing in a sequence, you also had to touch something with the other cube, the labels, or other lights that flashed. Then you kind of had to remember that sequence. It's cool to have light because then you could, you could have been given a sequence, and then you had to run forward and touch them with the cube, and then, if it was wrong, then all of the cubes could light up in red at the same time and make a beeping sound."
>
> -Physiotherapist 8

Rulers of the Obstacle Course (Multiplayer)

Physiotherapist 6 suggested a game with two teams with a designated color. Every team member wears ColorLabels in their team color, and the players must use their ColorLabels to change the color of the ColorCubes that are located in an obstacle course. They have won if the team manages to change all the ColorCubes in the obstacle course into their team color.

> "So you have exactly the same obstacle courses as you did now, but two different teams, and then it's, for instance, about trying to make all the cubes glow red while the other team tries to make all of them

> glow blue. Then you can say that when I have taken my blue label and made [the ColorCube] blue, the blue color is locked for ten seconds so that during those ten seconds, the red team does not have the opportunity to go and make it red. They have to remember which one I touched ten seconds ago, and then they have to go to make it red. So it's just another application with exactly the same setup."
>
> Physiotherapist 6

8.5 Summary and Key Takeaways

The goal of the evaluation was to evaluate the ColorCube concept for use in physiotherapy, discover important design considerations and potential for improvement, and explore different ways to use it. This section will summarize the main results from the evaluation and present what the researchers consider the key takeaways. Table 24 shows a summary of these.

Physical Attributes

The participants suggested several improvements to the ColorCube's physical attributes. First, for the size of the cube, it might be too large to hold, especially for patients with small hands, like children, while the cube might be too small to hit for some patients, especially when using their feet. Therefore different cube sizes could be explored to find what will fit a variety of patients and uses. The cube shape was observed to be advantageous, but the edges were sharp, and it was challenging for some patients to carry it through the obstacle course. Therefore, the cube could benefit from rounded corners and edges, and options for a wearable version could be explored. Physiotherapy games can lead to rough treatment of the cube, so it must be robust and durable, especially if it is to be used outside. Adding a side of anti-slip material, so the cube does not slide during play and endanger the patients should also be tested. Further, to enable ColorCube to be used by different patients and in a clinical environment, the equipment must be easy to disinfect. Finally, physiotherapists saw the potential for the ColorCube to be mounted on walls, floors, and ceilings, so mounting possibilities should be explored.

Different sized ColorLabel straps enabled attaching the labels to different limbs, like on hands and under the feet, and some physiotherapists used two ColorLabels on one strap to enable specific movements. Therefore, the ColorLabel straps should be adjustable in size, have the possibility of having two labels on one strap, and the labels should withstand being stepped on without breaking.

Context of Use

The ColorCube has the potential to be used by many different types of patients and in different contexts like clinics, schools, outside, and at home. ColorCube's portability enables it to be used in many different contexts and it can be used to train various skills and be incorporated into existing exercises. This potential could be further investigated by evaluating the ColorCube with different patient groups and contexts.

The physiotherapists appreciated that the ColorCube was versatile, because it enables it to be used with various patients, contexts, exercises, and settings. Adjustable variables will give the physiotherapists ways to customize the games to each patient and the target exercise. Therefore, physiotherapists should have the option to adjust settings and variables in the game, for instance through an app. However, a balance between the number of options and the simplicity must be preserved so that the complexity does not get in the way of the ease of use. Finally, the set-up time must be minimal or the game will not be used, because of the therapists limited time with their patients.

Game and Technology

The lights created enjoyment, but the colors could be an issue for patients with color-blindness or reduced vision. The ColorCube should be tested with color-blind or visually impaired people to see if this is an issue and if an auditory option is necessary or the colors need to be altered. The participants appreciated the auditory feedback, but physiotherapists pointed out that it could lead to over-stimulation for sensitive patients. Therefore, there should be a way to turn on and off the auditory feedback. Finally, time pressure had a motivating effect on patients and could be beneficial for movement *quantity* but could negatively affect the movement *quality*. The use of other game elements than time pressure could therefore be explored.

Game Effects on Patients

ColorCube seemed to increase motivation and competitive instincts and showed potential of improving the patients' experience of going to the physiotherapist. It is therefore important that the ColorCube keeps its fun and engaging elements. In addition, the participants saw the potential of creating measurable data with the ColorCube games, which could enable viewing and tracking patient performance and progress, as well as diverting patients from tiredness, fear, and pain. This potential could be further investigated by evaluating the games with patients that struggle with such challenges.

Game Ideas

Some of the ideas for future games proposed by the physiotherapists were competitive and collaborative versions of *Defuse the Bomb*, and a version where the task

is a sequence of colors instead of just a single color. Moreover, there was a suggestion of a competitive team-based game with ColorCubes placed in an obstacle course and of a game where the ColorCubes are used to communicate between two players.

Table 24: Summary of the evaluation.

Category	Sub-Category	Findings	Takeaways
Physical Attributes	Size	Large ColorCubes can be hard to hold; small cubes can be hard to target and hit.	Explore cubes of different sizes.
	Shape	The cube shape worked well but had sharp edges. Difficult to carry a cube through an obstacle course.	Keep the cube shape but round off corners and edges. Explore possibilities for wearable ColorCubes.
	Material	The ColorCube should withstand rough play and weather and be easy to disinfect. The prototype slipped on surfaces during play.	Use robust, waterproof material with a surface that is easy to disinfect and a side with anti-slip material.
	Mounting	Physiotherapists saw the potential for the ColorCube to be used mounted on walls, floors, and ceilings.	Explore ways for mounting.
	ColorLabels	Different sized ColorLabel straps enable attaching them to different limbs, like under the feet, and two ColorLabels were used on one strap to enable certain movements.	Keep the ColorLabel straps adjustable in size and the possibility of having two labels on one strap. ColorLabels should withstand being stepped on.
Context of Use	Patient Groups	Potential to be used by many different types of patients, as well as uses outside of physiotherapy.	Test ColorCube with the envisioned patient groups.
	Physical and Social Context of Use	Potential contexts of use: Clinic, schools, outside, home. The ColorCube is very portable.	Keep the game/equipment very portable and test in different contexts.
	Exercises and Skill Training	Can be used to train many different skills and can be incorporated into existing exercises.	Test ColorCube to train different skills and with different exercises.
	Versatility and Customization	That the ColorCube is versatile enables many uses. Adjustable variables give the physiotherapist ways to customize the games to the target exercise, the patient, and their needs.	The game should be customizable to fit different types of patients and needs. This can be done through adjustable settings and variables.
	Setup and Ease of Use	Physiotherapists found ColorCube to be intuitive and simple. Time required for setup should be minimal.	Keep the game simple with an easy and quick setup.
Game and Technology	Colored Light	The lights created enjoyment, but the colors can be an issue for patients with color-blindness or reduced vision.	Test the ColorCube with people with color-blindness and reduced vision and adjust the colors if necessary.
	Audio	Auditory feedback was appreciated but can result in overstimulation for sensitive patients.	Create an option to turn off auditory feedback.
	Time	Time pressure motivates and is suitable for quantity movement but can negatively affect the quality of movement.	Explore the use of other game elements than time pressure.
Game Effects on Patients	Motivation	ColorCube increased motivation, competitive instinct, and possibly the experience of going to the physiotherapist.	Keep the games fun and engaging.
	Progress	Potential to create measurable data to track progress which can motivate the patient.	Create the possibility of viewing and tracking patient performance and progress.
	Diversion	Diverts from tiredness, fear, and pain.	Test with patients that struggle with motivation, fear, and pain.

Chapter 9

Discussion

This chapter will discuss the results from the evaluation. For each topic discussed, one recommendation for how a tangible interactive game for use in physical therapy should be designed will be presented and then be compared to earlier research. First, Section 9.1 discusses the importance of versatility. Then how time elements can negatively affect the movement quality is examined in Section 9.2, followed by some positive aspects of diversion in Section 9.3. Next, the importance of being able to adjust the difficulty to suit each patient is discussed in Section 9.4. In Section 9.5, some issues on game setup and time use are presented before Section 9.6 describes some essential factors to consider when designing the physical attributes of the game interface. The final recommendation is presented in Section 9.7, which considers the methodological approaches for designing a game for physiotherapy with a recommendation to involve both physiotherapists and patients in the design process.

9.1 Versatility

During the interviews with the physiotherapists in the Preliminary Study, it was discovered that there is a wide range of patients with individual needs, and one of the physiotherapists' tasks is to find exercises and adjust them to fit and engage each individual. Even within one area of specialization, such as stroke rehabilitation, the exercises vary from patient to patient and the patients' needs at the beginning of the treatment can be quite different from the needs at the end. Therefore, it is crucial to give the physiotherapists ways to adjust and customize the games to each patient.

When designing the ColorCube, one of the goals was to make it flexible enough to be used with a wide variety of movements and by many types of patients. A

unique part of this solution is the ColorLabels which can be attached to different body parts and in that way facilitate a big range of movements. Additionally, the portability of the cubes contributes to the versatility since they can be placed at different heights and distances. ColorCube's simplicity gives the physiotherapist freedom to add rules to how a movement should be performed and incorporate it into existing exercises. Observations during the evaluations suggest that the physiotherapists who are already used to adjusting and adapting tools and exercises for their patients, can do likewise with the ColorCube. The flexibility of the ColorCube was considered an important advantage by the physiotherapists who participated in the evaluations.

Despite the advantages of a versatile solution like this, a trade-off might be that the ColorCube is not designed to perfectly fit one exercise or one type of patient. Prioritizing versatility could result in a less optimal solution for specific patients, but acquiring custom-designed equipment for each of the many patient types and groups, would require great costs and efforts. A versatile solution would widen the range of patients who could benefit from it. Therefore, we recommend designing physiotherapy games and game equipment that can engage a multitude of body parts, exercises and patients.

Recommendation 1: Design for versatility
There is a great variety of patients and needs in physiotherapy. Therefore, games should be designed for a variety of body parts and movements to accommodate these different needs.

This recommendation is in line with a study by Chandra et al. (2012) where the physiotherapists pointed out the wide range of patient problems and that patients usually are very different from each other. Because of this difference, patients' needs will vary greatly. To accommodate such variety, a versatile solution will be needed, but this recommendation differs from the common approach. All games analyzed in the SLR specified a user group (see Section 3.5.1), focusing on specific body parts or movements to perform during the game. However such games can become very specific which might limit the range of use of the game.

9.2 Movement Quality

Time pressure is a game element frequently used to engage players. It can activate players' competitive instincts and motivate them to focus on and complete a task faster. For instance, Kawrykow et al. (2012) used a timer to "increase the entertaining value" (p. 3) of their puzzle game. However, according to Vanden Abeele et al. (2010), time pressure can be disadvantageous for patients who need to practice

performing slow and controlled motions, like patients with spasticity. The study suggests that time pressure can result in unintended movements because of lack of focus on the actual task. Paraskevopoulos et al. (2014) also expressed a concern that encouraging the patient to speed up could lead to injury. Similarly, during one of the evaluation sessions, a physiotherapist pointed out how the time pressure element in *Hit the Cube* caused the patient to focus on completing the movements quickly, rather than thoroughly (Section 8.4.3).

On the other hand, one physiotherapist claimed that for various groups of patients, like children struggling with obesity, quantity of movements and physical activity can be just as important as the quality. Therefore, having a way to motivate physical activity in general, could also be beneficial. To summarize, observations from the physiotherapists in the evaluation suggest that the competitive time element used in the ColorCube games, positively affected patients' engagement, but negatively affected the quality of specific movements.

Movement quality, as explained in Section 2.3.2, centers around characteristics or attributes of movement, rather than a movement trajectory. For certain characteristics or attributes of movement to occur, slower movements may be required. Therefore, to facilitate movement quality, some of the ColorCube games should be designed without time pressure. However, similarly to *learning games*, where players' motivation is dependent on an appropriate balance between fun and learning (Breuer and Bente, 2010), exergames must have a balance between fun and therapeutic goals. Therefore, it might be advantageous to explore the use of other game design elements instead of time pressure, like puzzles, combos or achievements, to preserve the engagement of the game.

Recommendation 2: Facilitate movement quality
Stressful game elements like time pressure can negatively affect the movement quality. Therefore, some games should be designed with less stressful game elements to facilitate thorough and slow movements and the quality needed in many exercises.

This recommendation is similar to one presented by Nawaz et al. (2014), stating that "The primary focus within game play experience should be on movement quality without too much distraction" (p. 6). A difference between the two recommendations is that the one by Nawaz et al. recommends prioritizing movement quality, while this thesis' recommendation focuses on having the *possibility* to focus on movement quality, since the importance of it can vary for different patients and exercises.

9.3 Positive Aspects of Diversion

Despite the concerns on how lack of focus on the given task can negatively effect the movement quality (Section 9.2), diversion could also be an advantage. Some patients struggle with avoidance, and refrain from making certain movements because they believe it will worsen their condition or increase pain. If the avoidance of physical movement remains persistent over time, it can result in negative physical and psychological consequences (Vlaeyen et al., 1995). During the evaluation, physiotherapists mentioned that they believed ColorCube could divert patients from their pain and from fear of for instance bending forward, and pointed it out as a positive effect (see Section 8.4.4).

When a player is immersed in a game, their focus tends to shift away from their surroundings and worries (Sweetser and Wyeth, 2005). Immersion can therefore be an important factor in creating a positive diversion. Patients who participated in the evaluation seemed immersed in the games and said that they forgot that they were tired because they focused on the game and having fun instead of the fact that they were exercising (see Section 8.4.4). This could be advantageous for patients in need of long-lasting and tiresome exercises, especially for those who lack motivation or for children who do not understand the importance of undergoing treatment.

Potential conflicts can arise when trying to design both for movement quality and diversion since they might require opposite measures. A designer should therefore aim to find the appropriate balance, based on the main purpose of the game. Nevertheless, we recommend designing games with at least some degree of positive diversion, to divert patients from things that could otherwise get in the way of the treatment like exhaustion, pain or fear.

Recommendation 3: Design for positive diversion
Factors like tiredness, pain, and anxiety can make patients avoid movements necessary for the treatment. Therefore, games should be designed to make patients experience immersion so that they are diverted from such negative factors.

That a positive diversion can reduce the focus on pain and anxiety in patients correlates with findings from research on *electronic gaming as pain distraction* by Jameson et al. (2011). The study indicates that people's experience of pain and anxiety can be reduced with active distraction and that people were more inclined to participate in a painful activity again while playing electronic games. Participants in a study by Hagen et al. (2016) expressed that when playing the exergame, they did not think about the fact that they were tired until the game

ended, similarly to the implications in this thesis.

9.4 Degree of Difficulty

To achieve the positive diversion discussed in Section 9.3, an appropriate level of challenge is crucial. Challenge is often recognized as the most essential game element in good game design because if a game is too easy, the player will get bored and if it is too difficult, the player will get discouraged (Sweetser and Wyeth, 2005). According to the Dual Flow model (described in Section 2.1.7) the intensity level is also important to achieve flow in ExerGames. The correct intensity level is crucial to obtain the desired health effects. ColorCube was designed with several ways to adjust both the challenge and the intensity. Physiotherapists who participated in the evaluation recognized some of these, like adjusting the number of ColorCubes and colors in play, the placement of the ColorCubes and ColorLabels, the number of tasks, and manipulation of external variables like adding weights, the design of the obstacle course or setting rules for the patient's movements. By adjusting these factors, the physiotherapists can customize ColorCube to appropriately fit their patient's skill and fitness level and help them with their motivation.

The physiotherapist is responsible for adjusting both the challenge and intensity level of the ColorCube games. This can be seen as a disadvantage if the physiotherapist is, for instance, more concerned about the effectiveness of the game rather than of the attractiveness. On the other hand, these are aspects that many physiotherapists are already used to adapting when composing exercises for a patient. Observations from the evaluations indicated that the physiotherapists quickly saw how to use the adjustable factors to custom-tailor the game and its difficulty level for their patients. They could also think of other ways to adjust for other types of patients (see Section 8.4.2).

Recommendation 4: Design for adjustable difficulty
The gameplay skills and physical abilities of patients can vary greatly. Therefore, the games should be designed with adjustable difficulty so that the physiotherapists can customize the game to appropriately fit each patient.

A similar recommendation can be found in a study done by Kattimerib (2017) at an elderly service home. They recommended providing game calibration and customization to suit the patients' physical abilities. Another tangible interactive technology, called ExerTiles, was designed and developed by Subramanian et al. (2020). The possibility to adjust the ExerTiles' placement and the distance between the tiles, which can be used to customize difficulty, resembles what can

be done with the ColorCube. They discussed the advantage of tailoring tangible interactive technology to individual needs and similarly observed how the physiotherapists came up with their own exercises and challenges to add to the parameters provided by the design.

Recommendation 4 can also be compared to a study done by Henschke et al. (2012), who discuss the importance of adding new elements of difficulty to keep the game compelling and meaningful. They suggest adding time constraints or introducing variations like obstacles or goals, but did not mention anything about letting the physiotherapist control these settings. However, Annema et al. (2013) highlighted how the therapists value the possibility of adjusting the difficulty before starting the game but also during gameplay, which supports the recommendation of this thesis.

9.5 Game Setup

The physiotherapists who participated in the user evaluation emphasized the importance of having many ways to customize games and modes based on their premises and needs. On the other hand, they pointed out that it was essential that the game was plug-and-play and did not require much setup time. They claimed that time demanding setups could result in the game not being used. This is due to the limited time the physiotherapists have with each patient, which should not be wasted.

Having a generous amount of customizable factors and parameters can provide freedom but can also result in more complicated systems and longer setup time, so there needs to be a balance between simplicity and freedom. A way to solve this could be to have predefined games and modes with only a few adjustable variables, like the number of tasks and time. Then, for more advanced users or situations where the physiotherapists have more time, there can be a mode with options to adjust more detailed settings like assigning specific colors to specific cubes and how many tasks will be a specific color. However, regardless of the mode, the game's setup should an as quick and easy as possible.

Recommendation 5: Ensure a quick and easy setup
The physiotherapists have limited time with the patients. Therefore, the setup of the game should be intuitive and require as little time as possible.

This recommendation can be compared to a study by Elnady et al. (2018) where all the physiotherapists that participated were concerned about the setup time.

The study indicated that the setup should take ten minutes or less, while physiotherapists participating in the ColorCube evaluation insisted that ten minutes was too much and that it should be closer to two minutes. Annema et al. (2013) also support keeping the setup time to a minimum due to the short therapy sessions and highlighted the importance of an option for skipping other time-consuming parts such as on-screen instructions and cut scenes. In addition to setup time, an *easy* setup is important, especially since technical knowledge among physiotherapists can vary. Research by Gerling et al. (2012) presented the design guideline *simple setup routine*, and argued that if older adults or nursing staff were to setup and play the games, it must be easy enough so that they can do it by themselves, without much technical competence. However, this design guideline focused more on the technical competence and ease of use, while recommendation 5 focuses on minimizing the time spent on the setup so it does not waste the time with the patient.

9.6 Physical Attributes

A physical attribute is "a spatial or sensory aspect of a technological outcome. Physical attributes describe how the outcome looks and feels." (Te Kete Ipurangi, New Zealand Ministry of Education, n.d.). They play an important role in tangible game interfaces, and the physiotherapists suggested several ways to improve the physical attributes of ColorCube. Physiotherapy games will at times require rough play. For instance, *Hit the Cube* requires the player to hit or tap the ColorCube, which can result in the patient accidentally stepping on the cube, and in *Defuse the Bomb* the player needs to carry the cube through an obstacle course, which can cause them to drop it on the floor. This physical impact on the cube is a natural consequence of play, and the cube needs to be durable enough to withstand it without breaking. The physiotherapists pointed out that if the equipment was experienced as fragile, the patients would feel like they had to be very careful which could inhibit the patients' movements.

A request frequently mentioned by the physiotherapists was to have a way to mount and fasten the ColorCube. Different mounting options could widen the range of uses for the game, since it provides more options for cube positions and placements. During the evaluation, another benefit of mounting options was discovered. The cube tended to slip away because of the lack of friction when standing on a smooth surface which made it difficult for patients to hit it. Some of the physiotherapists worried that a slipping cube would be unfortunate for their patients' safety as it for instance could make them fall. Therefore, we recommend to design durable equipment that is safe for the patients to use.

Recommendation 6: Design durable and safe tangible interfaces
Patients should be able to focus on the game tasks and not worry about their safety or breaking the equipment. Therefore, tangible interfaces for games used in physiotherapy must be durable and safe.

The recommendation about safety is in accordance with a design consideration presented by Subramanian et al. (2020) and findings by Pyae et al. (2015). Both studies stressed ensuring the safety of patients, especially considering fall prevention. Subramanian et al. (2020) recommended making sure that the equipment is "sufficiently fastened to the floor during stepping exercises to avoid trips and accidental falls" (p. 237). The recommendation of durability is in line with a requirement highlighted by Campos and Pessanha (2011) about using resistant and robust material when designing tangible interfaces, suited for getting handled by children.

9.7 Involvement of Physiotherapists and Patients in the Design Process

A methodological finding was the benefit of including both patients and physiotherapists in multiple phases of the design process. In addition to the common recommendation of involving users (ISO 9241-210, 2010), the involvement of both physiotherapists *and* patients was important to create a balance between therapeutic goals and enjoyment in games.

The involvement of physiotherapists lead to insights into physiotherapists' field of work, routines and what they view as important in a game for use in physiotherapy. Additionally, coming up with game ideas, evaluating the prototype and giving feedback about the solution's relevance, potential and therapeutic utility, resulted in interesting findings. Further, the involvement of patients was important as their challenges, needs and experience of using ColorCube could differ from the physiotherapists' assumptions. The involvement of patients especially contributed to maintain the motivational focus of the game, making sure the therapeutic goals did not overshadow and vitiate the engaging aspect. Therefore, we recommend actively involving both patients and physiotherapists in the process of designing and evaluating games for use in physiotherapy.

Recommendation 7: Involve both physiotherapists and patients in the design process
Patients and physiotherapists have different roles, perspectives, and preferences, but are both target users of the game. Therefore it is important to involve both physiotherapists and patients in the design process to identify and meet both user groups' needs, and to find a balance between engagement and therapy goals.

The importance of involving physiotherapists throughout the design process is in line with the findings from a study by Almeida, Nunes et al. (2020). They claim that such involvement is essential to the acceptance of a solution and to create something that is appropriate and useful for physioterapeutic treatment. Recommendation 7 adds the importance of including both types of users, specifically to ensure the balance between the engagement needed for patients' motivation and the therapy goals needed to achieve the desired health effects.

Chapter 10

Limitations

Through this research project, we discovered a number of important design considerations for tangible interactive games, from which a set of design recommendations were derived. However, we acknowledge that our work has certain limitations worth mentioning. In the following, what we consider the three main methodological considerations are briefly discussed.

The first limitation concerns the external reliability. LeCompte and Goetz (1982) states that "External reliability addresses the issue of whether independent researchers would discover the same phenomena or generate the same constructs in the same or similar settings" (p. 32). The solution was evaluated with a limited number of physiotherapists and an even lower number of actual physiotherapy patients. Even though the participants in this study had similar experiences and were in agreement of a number of design considerations and factors, it is not guaranteed that other physiotherapists and patients would share their views. Moreover, the majority of the physiotherapists were used to working with children and may have a different perspective on games than physiotherapists working with adults or elderly patients. However, the researchers used two other methods to increase the reliability of the results by conducting an SLR and interviews before creating a prototype and testing it. Such a method triangulation strengthens the reliability of the study.

The second limitation concerns the generalizability of the game concept. Generalizability is about whether the results are generelizable, meaning the same results can be obtained in a different situation or context (Oates, 2006). Due to limited time, a wizard of oz prototype was developed instead of a fully functional prototype. However, the prototype was designed to function well with the tasks in the evaluation and the participants were made to believe that the prototype was operating on its own. Additionally, since the main purpose of the prototype was to be a starting point for reflections around the concept's potential and important

design considerations, a wizard of oz prototype was considered sufficient.

The third limitation also concerns the generalizability. The game was tested during an evaluation workshop in a laboratory and not in therapy sessions at a clinic, which was necessary to use and operate the prototype properly. To compensate, the laboratory room was designed to resemblance a physiotherapy room, and a patient participated together with each physiotherapist so that the context would be as realistic as possible. Future research efforts could develop a more functional prototype that allows for evaluation in real physiotherapy sessions with patients over time.

Chapter 11

Summary and Conclusion

This thesis aimed to explore the potential of using tangible interactive games in physiotherapy and discover important design considerations for such games. To reach this goal, we conducted a structured literature review and followed a user-centered process where physiotherapists and patients were involved in initial data collection, ideation, and the design and evaluation of a game concept called ColorCube. ColorCube is an interactive, tangible tool with accompanying games designed to be a part of the physiotherapists' "toolbox" and motivate physiotherapy patients undergoing treatment.

This thesis was motivated by two research questions which will now be presented together with a summary of the main findings.

The first research question, *RQ1: What can we learn from existing research literature concerning the design of game-based solutions for physiotherapy?*, consists of three sub-questions that were answered through findings from the SLR:

RQ1.1: What types of interactive, game-based design solutions are developed for use in physiotherapy?

To answer this research question, we looked at what type of technology and game elements have commonly been used in existing games for physical therapy. The review revealed that most of them used VR glasses or a conventional screen. Furthermore, all the games were single-player, and over half of them used points to reward the players. These findings revealed a gap in research on the use of non-screen based tangible interactive games.

RQ1.2: What are the purposes of the design solutions?

This second sub-question was answered by looking at whom the games were designed for and their primary purpose. All games in the SLR had a defined domain for the game, which was either a specific disorder like CP or a specific body part, such as upper limbs or the neck. The majority of the studies' purpose was to increase the motivation and enjoyment of physiotherapy exercises due to the wide and known problem of patients not completing the exercises they are given (Campbell et al., 2001). However, some also aimed to assist the therapist or guide or correct the patient's movements. These findings revealed the potential to explore games without a specific target patient group, which was later supported by findings from the preliminary study.

RQ1.3: What are the methodological approaches for designing and evaluating the solutions?

The final sub-question aimed to discover common approaches for designing, testing, and evaluating games for use in physiotherapy. There were great variations in methodological approaches, but all studies included users in at least one step of the process by, for instance, interviewing physiotherapists before designing the game or including patients in a final evaluation. Most of the studies used a qualitative approach, but the design process was often vaguely explained with varying degrees of detail.

Findings from the SLR and the interviews were used to develop the ColorCube concept, which later was evaluated to answer the following research question:

RQ2: How do physiotherapists experience using concepts from gamification in the treatment of patients?

The physiotherapists who participated in the user-centered evaluations expressed positive attitudes toward the concept. The possibility to use the game with a wide variety of patients and exercises was especially pointed out as an advantage. However, they emphasized that a game designed for use in physiotherapy must be customizable, and easy to use and set up. Most of them appreciated the engaging element of the game, but some were skeptical of the use of time pressure in the games due to the negative effect it could have on the movement quality.

Based on the findings from this study, we suggested seven design recommendations for the design of tangible interactive games for use in physiotherapy:

- Design for versatility

- Facilitate movement quality
- Design for positive diversion
- Design for adjustable difficulty
- Ensure a quick and easy setup
- Design durable and safe tangible interfaces
- Involve both physiotherapists and patients in the design process

In conclusion, this research shows that there is a great potential for using tangible interactive games in physiotherapy and that such games could become a part of the physiotherapists' "toolbox" to increase the patients' motivation.

Finally, we see possibilities for further research. First, there is potential to improve the physical attributes of the ColorCube and evaluate a more robust prototype with rounded corners, anti-slip material, and different mounting possibilities. Second, multiplayer games and games that use other game mechanics and elements than time pressure could be explored. Third, an app that controls the ColorCube could be investigated to explore customizable options and evaluate the ease of use for the physiotherapists. Such an app could also contain elements of feedback that can help the physiotherapists and patients monitor development and progress. Finally, the ColorCube could be evaluated with real physiotherapy patients, preferably over a period of time, so that the lasting effects and use of the product in actual physiotherapy sessions can be examined.

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Appendix A

Appendix

A.1 Interview Guides

A.1.1 Interview Guide for Interview with Physiotherapist

INTERVJUGUIDE FYSIOTERAPEUT
Takk + samtykke

Hvilken type fysioterapeut er du?
Hvilke typer pasienter behandler du?
Hva gjør du på en vanlig dag på jobb?
Er det noen utfordringer som ofte dukker opp i behandling av pasienter?
Har du noen tanker om hvordan disse utfordringene kan løses?
Hvordan er pasienters holdning til behandling?
Må pasienter ofte gjennomføre øvelser på egenhånd?
Opplever du at pasienter gjennomfører øvelsene de blir anbefalt?
Bruker du noen verktøy eller hjelpemidler i behandling av pasientene dine? (ball, balansepute osv.)?
Kan vi få se disse hjelpemidlene?
Er det noen av disse du liker ekstra godt? Hvorfor?
Er det noen av disse hjelpemidlene du kunne sett for deg kan videreutvikles eller blitt bedre?
Er det noen hjelpemidler du kunne ønske du hadde som du ikke har?

Takk igjen for tid og hjelp!

A.1.2 Interview Guide for Interview with Patient

INTERVJUGUIDE PASIENT
Mål:

- Finne smertepunkter i pasienters opplevelse av fysioterapi.
- Finne ut mer om pasienters motivasjon for å gjennomføre øvelser på egen hånd.
- Finne ut hva pasienter tenker om bruk av spill i fysioterapi
- Finne ut hva pasienter tenker om sosiale øvelser/multiplayer

Generelt:
Hva går du til fysioterapeut for?
Hvor lenge har du gått til fysioterapeut?
Hva bruker du å gjøre når du er hos fysioterapeuten?
Får du oppgaver som du skal gjøre på egen hånd mellom timene?
Hva er eksempler på slike oppgaver?
Hvordan oppleves det å skulle gjøre oppgaver på egen hånd?
Hvordan er motivasjonen din for å gjennomføre oppgavene?
Bruker du noen apparater/hjelpemiddel/utstyr enten hos fysioterapeuten eller hjemme? Hvilke?
Har du en favorittøvelse? Hvorfor er den din favoritt?
Hvilken øvelse liker du dårligst? Hvorfor?
Hva er det beste med å gå til fysioterapeut?
Hva er det mest utfordrende med å gå til fysioterapeut?
Er det noe du savner i fysioterapitimene?
Har du forslag til noe som kunne vært gjort annerledes eller bedre?

Om spill:
Hva tenker du om å gjøre øvelser sammen med en annen person? (multiplayer?)
Hva tror du du hadde syntes om å ha interaktive eller spillbaserte øvelser?
Tror du det hadde påvirket motivasjonen din?

A.2 Miro: Data from Evaluation

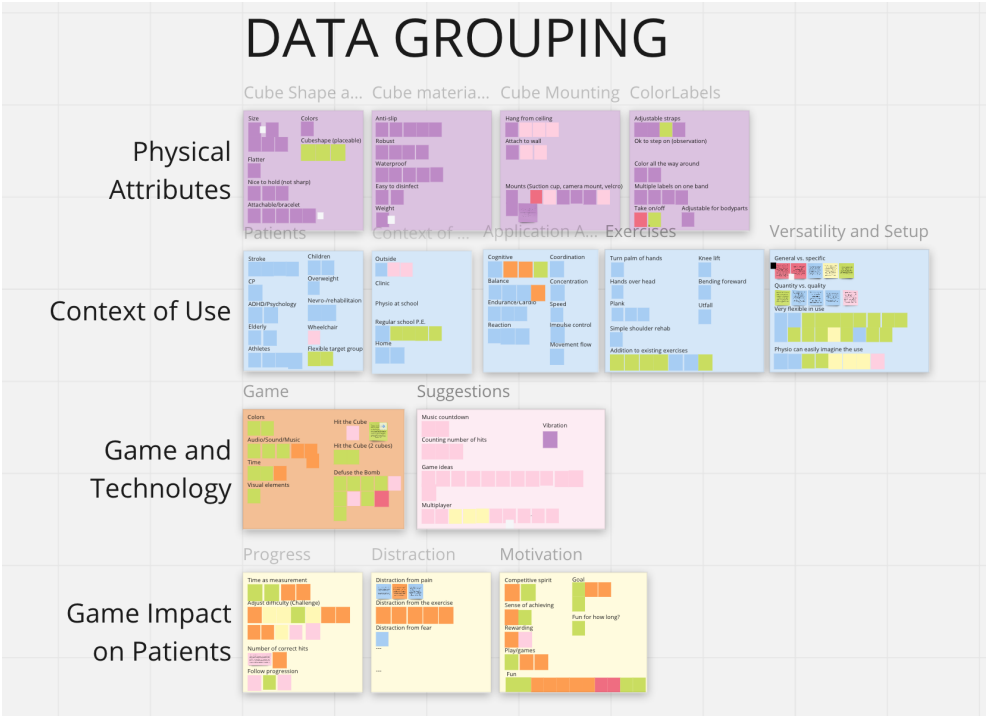

Figure 23: Data from evaluation.

A.3 Additional Games

A.3.1 React and Act

In this game, only 1 ColorCube and no ColorLabels are needed.

Physiotherapy Goal/Target Group

The physiotherapy goal of this game is to train reaction and speed. The game also brings a cognitive aspect, training memory skills.

Objectives/Goals

The goal of this game is to complete the correct task given by the cube until a total of 20 tasks are reached.

Gameplay

The cube is placed somewhere in front of the player so he can clearly see the cube. Different colors indicate what to do with the cube. If it lights up in blue, the player has to hit the cube. If it is orange, the player has to wait and not do anything. If the cube turns yellow, the player has to lift the cube and place it back. When the player has completed the task, the cube will provide a victory sound if it was the correct movement and award points. If the wrong movement is done, the cube will provide an error sound, and no points will be awarded.

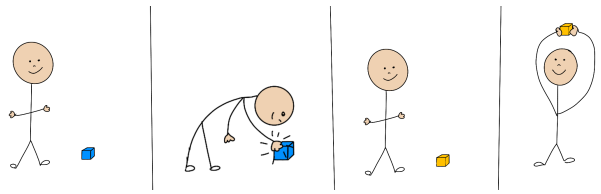

Figure 24: *React and Act*.

User Interface/Game Controls

The app always shows the game's current status, how many tasks are completed (for instance, 6/20), and a timer counting upwards. A total score, in the end, will

be a mix of time spent in total and how many of the completed tasks were correct.

Game Elements

The game element found in this game is *reward* given as points. Points are calculated by the number of correct tasks completed by the player and the total time. The score is meant to motivate the player to perform well and fast.

Customization

There are two ways to customize this game. One is to adjust the number of colors or possible actions given to the player, and the other is to set the number of tasks for one gameplay. Table 25 shows the effect of adjusting these variables.

Table 25: Customizable options in *React and Act*.

Customizable	Effect
Number of colors (actions)	Increasing the number of available actions, will make the game more challenging on the cognitive level, as the player will have to think more about what task is corresponding to which color.
Number of tasks for one gameplay.	Players with a higher endurance may have several tasks during one game, while others might need less tasks.

Multiplayer Mode

This game can also be played in multiplayer mode as a competition. Still, only one ColorCube is needed, and the goal is to be the first one to carry out the command of the ColorCube. The first one to complete the task gains points.

A.3.2 Tap to the Rhythm

Tap to the Rhythm uses 2 ColorCubes and one or more color labels. When playing with two cubes, they should be placed somewhere the player can reach them, and color labels should be placed on the body parts.

Physiotherapy Goal/Target Group

Tap to the Rhythm is suitable for all patients who need to practice flow in their movements. It is also a good game for doing movements where it is important to do them in a set tempo and not just as quick as possible, which is the goal of "Hit the Cube".

Objectives/Goals

Tap to the Rhythm is a single-player game where the goal is to get as many points as possible by tapping the ColorCubes with the correct body part and in time with the music.

Gameplay

The player sits or stands with two cubes that they can reach. A song is selected and played, and the cubes will light up in different colors to the song's beat. The cube must be hit/tapped before the light disappears or changes and must be hit with a body part with a color label that matches the color of the light. The player will get more points if they hit the cube in time with the beat. That is more important than being fast. Hitting the cube with the wrong colored label or too slow will give 0 points and negative auditory feedback. Well-timed hits will trigger positive auditory feedback. The points will be displayed in the app. The two ColorCubes can light up simultaneously, or just one at a time, with one single color, or with multiple colors.

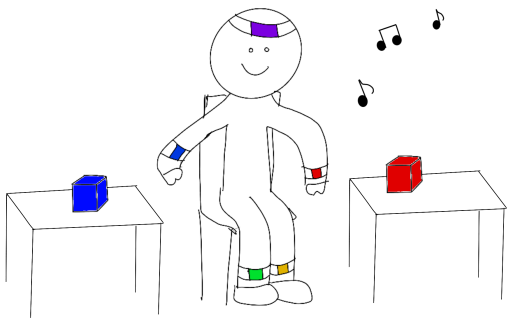

Figure 25: *Tap to the Rhythm*.

User Interface/Game Controls

The user interface consists of two ColorCubes and a number of ColorLabels that the player wears, decided by the physiotherapist. The app displays how much is left of the song and shows how many correct hits and missed hits the player has. When not playing the game, statistics and a leaderboard for each song can be found in the app.

Use of Game Theory and Elements

Table 26 shows an overview of the Game Elements and its effects used in Tap to the Rhythm.

Table 26: Game elements and theory used in *Tap to the Rhythm*.

Game element	Sub-category	Application and effect
Feedback	Visual feedback	Light: Gives task, turns off when hit. Color: Tells the player which body part to use Guides movements and gives feedback on performance.
	Auditory feedback	Victory sound: great timing, bonus points Error sound: too late or matched the wrong colors. Player gets feedback on their performance, motivating them to perform well and correct errors.
Challenge	Adjustable difficulty	Adjusting difficulty to players' abilities will keep them from getting bored and prevent an impossible level.
	Randomness	Which Cube that lights up and its color is random, which can provoke curiosity and variation in the game, so that every time the game is played, there are some variations.
Concentration	Grab and maintain focus	The player will have to stay concentrated and focus on the cubes throughout the song to react in time. Such concentration can lead to immersion in the game and flow. Trying to hit the cube on the beat can also increase focus.
	Stimuli from different sources	Light and color: from the cubes Sound: Feedback from the cubes Music: Throughout the game Score: points and score in the app Stimuli from different sources keep the game more interesting.
Music	Personal taste/genre	Playing to a song that you enjoy can improve the experience and add joy through music.
Reward	Points	Points for each correct hit and a bonus for timing the hit to the beat. These points are meant to motivate the player to hit the cubes and perform well.
	High score	A competitive element that can motivate the player to return to the game.
	Unlocking	Unlock new songs by completing other songs.

Customization

This game has many customization options. An overview can be found in Table 27.

Table 27: Customizable options in *Tap to the Rhythm*.

Customizable	Effect
Placement of the color cubes	Affects difficulty and targeted movements, by placing them high or low, in near proximity or farther away, in front of the patient or on the sides.
Placement of the color labels	Affects the difficulty and can be adjusted according to patient needs. A label can be placed on arms, feet, the head or other body parts.
Position of the player	The game can be played sitting, standing, on one leg, etc. according to the patient's needs and training goals.
Number of color labels & light colors	Affects cognitive complexity. Adjust number of elements in the game.
Number of cubes	Affects difficulty and complexity.
Duration of the song	Shorter songs might require less stamina and concentration span.
Tempo of the song	Affects the difficulty and reaction demands.
Timing sensitivity	Adjust how sensitive the cube is for timing and accuracy in relation to the rhythm, to match the patient's level. An alternative is to turn off the rhythm bonus so that the player gets the same number of points per hit, as long as they hit the cube before the light turns off or changes, regardless of timing to the music.

A.3.3 Run For It

Run For It is a game that requires three cubes that can be placed around the room, on the floor, at different heights, or close to each other. The physiotherapist can decide the number of color labels.

Physiotherapy Goal/Target Group

This game has the potential to be used with players who need cardio exercise and or reaction and coordination training, but the game can also be customized for other uses.

Objectives/Goals

The game goal is to hit the cube with the correct color label as fast as possible and complete all the tasks in the least amount of time.

Gameplay

Three ColorCubes are placed appropriately according to the target training of the player but should be placed so that the player can see all three cubes. One cube will light up, and the player has to get to that cube and hit it as fast as possible with the matching ColorLabel. As soon as the player hits the cube, one of the other cubes will light up. Then the player will have to get to that cube and hit it. This is repeated until the player has reached the number of tasks set by the physiotherapist before the game started. When all tasks have been completed, the player will receive a completion time and a score calculated based on the number of tasks and the time spent.

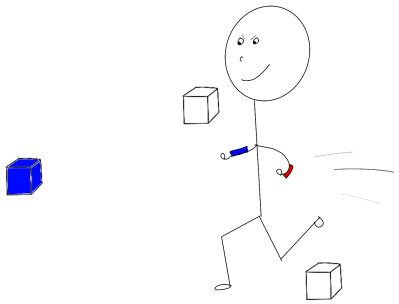

Figure 26: *Run For It*.

User Interface/Game Controls

The user interface consists of three Cubes used to give a task, one at a time. The player wears ColorLabels, which he uses to gain points by touching the cube with a label. A timer is displayed in the app, and when the game is over, the final time and score will be shown in the app. A high score list can also be found in the app outside of gameplay.

Game Elements

Table 28 shows an overview of the game elements and theory used in the game.

Table 28: Game elements and theory used in *Run For It*.

Game element	Sub-category	Application and effect
Feedback	Visual feedback	Light: Gives task, turns off when hit Color: Tells you which body part to use, and where to run to. Guides movements and gives feedback on performance.
	Auditory feedback	Victory sound: Hitting the cube with the correct label. Error sound: Hitting the cube with the wrong label. Player gets feedback on their performance, motivating them to perform well and correct errors.
Challenge	Adjustable difficulty	Adjusting difficulty to players' abilities will keep them from getting bored and prevent an impossible level.
	Randomness	What color and which cube lights up is random. Randomness can provoke curiosity and variation in the game so that every time the game is played, there are some variations.
Concentration	Grab and maintain focus	The player will have to stay concentrated and focus on the cubes to react quickly, by observing all cubes at the same time. Such concentration can lead to immersion in the game and flow.
	Stimuli from different sources	Light and color: from the cubes Sound: Feedback from the cubes Score: points and score in the app Stimuli from different sources keep the game more interesting.
Reward	Points	Points for each correct hit, and a bonus for not using a lot of time. These points are meant to motivate the player to hit the cube(s) and perform well.
	High score	A competitive element that can motivate the player to return to the game.

Customization

This game can be customized to fit a wide range of players and needs. An overview can be found in Table 29. 29.

Table 29: Customizable options in *Run For It*.

Customizable	Effect
Placement of the color cubes	Affects difficulty and targeted movements, by placing them in different heights, in near proximity or farther away, in front of the patient or to the sides.
Placement of the color labels	Affects the difficulty and can be adjusted according to patient needs. A label can be placed on arms, feet, the head or other body parts.
Position of the player	The game can be played sitting, standing, on one leg, with weights, etc. according to the patient's needs and training goals.
Number of color labels & light colors	Affects cognitive and coordinative complexity. Adjust number of elements in the game.
Number of cubes	Affects difficulty and complexity.
Number of tasks	The number of tasks affects the duration of the game.

A.4 Evaluation Workshop Guide

Introduser oss selv og masterprosjektet (15 min)

- Master informatikk på NTNU, bruk av spillteknologi i fysioterapi.
- Hatt intervju med pasienter og fysioterapeuter.
- Hatt idémyldringsintervju og laget et konsept basert på dataen vi har samlet inn.
- Laget en prototype som vi nå vil prøve ut og utførske.
- Mål:
    - Få innsikt i viktige designbetraktninger.
    - Evaluere ColorCube for bruk i fysioterapi.
    - Utforske måter å bruke ColorCube på.
- Ønsker at du er ærlig: konstruktive tilbakemeldinger er veldig nyttige for oss.
- Tenk gjerne høyt underveis: Si hva du tenker, forklar hva du gjør, hva du vurderer, eventuelt ikke forstår, ville gjort annerledes osv.
- Vi kommer nok ikke til å svare på så mye underveis, men du kan gjerne stille spørsmål, så kan vi svare på dem mot slutten av workshoppen.

Fyll ut samtykkeskjema (5 min)

- Peke på videokamera og mikrofoner i taket.
- Spørre om opptak.
- La de signere.

Presenter konseptet ColorCube (5 min)

- Wizard går inn i bakrommet.
- Vis kuben.
- Forklar egenskaper.
    - Den kan lyse.
    - Den kan gi lyd.
    - Den kan merke når en merkelapp rører kuben.

Hit the Cube (Merkelapper på pasienten, 1 kube (20 min)

- Presenter reglene i Hit the Cube:
    - 12 oppgaver.
    - Rør kuben med riktig merkelapp så fort som mulig.

    - Merkelappene kan være plassert på for eksempel hender, føtter eller på hodet.
- La fysioterapeuten plassere kuben og merkelappene.
- Spørsmål?
- Prøv spillet.
- Diskuter opplevelsen av Hit the Cube (og bruk av kuben generelt).

Hit the Cube (Merkelapper på pasienten, 2 kuber (20 min)

- Presenter reglene i Hit the Cube:
    - Samme som det forrige men med to kuber.
- La fysioterapeuten plassere kuben og merkelappene.
- Spørsmål?
- Prøv spillet.
- Diskuter opplevelsen av Hit the Cube (og bruk av kuben generelt).

Diffuse the Bomb (Merkelapper rundt i rommet) (30 min)

- Presenter reglene i Diffuse the Bomb:
    - To kuber: solution cube og answer cube
    - Målet er å få answer cube til å bli samme farge som solution cube, ved å gå gjennom en hinderløype frem til riktig merkelapp.
    - Man har tid på seg, og bomben vil "eksplodere" om man ikke rekker å gjøre den om til alle X fargene før tiden renner ut.
- La fysioterapeuten lage hinderløypa.
- Spørsmål?
- Prøv spillet
- La fysioterapeuten plassere merkelappene på en annen måte, og spill igjen.
- Diskuter opplevelsen av Diffuse the Bomb (og bruk av kuben generelt).

Refleksjon (20 min)

- Hvordan var opplevelsen rundt å bruke ColorCube?
    - Hva likte du?
    - Hva likte du ikke?
    - Hvordan kunne den blitt bedre?
- Andre måter å bruke ColorCube på? (Show and tell).
- Evaluering av workshoppen. Hvordan var det å delta?

Stine Johanne W. Løhren, Maria Osen

Tangible Interactive Games for Use in Physiotherapy

NTNU
Norwegian University of Science and Technology