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DOCTORAL DISSERTATION

The Design of Physical Rehabilitation Games: The Physical Ambient Abstract Minimalist Game Style

Doctoral dissertation submitted to obtain the degree of doctor of Audiovisual and Visual Arts, to be defended by

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Abstract

Physical neurorehabilitation is essential for a large number of individuals who have suffered a stroke or cope with multiple sclerosis (MS). Stroke and MS often result in physical impairment and disability which can lead to a loss of an independent lifestyle. Through neurorehabilitation therapy, people may regain or retain their physical ability and thereby maximize their quality of life.

Building on insights from previous research, we believe digital games can provide a positive contribution to physical neurorehabilitation therapy. On the one hand, the physical exercises performed during rehabilitation therapy are considered hard and repetitive, resulting in a demotivating rehabilitation experience. On the other hand, many digital games offer a pleasurable experience even when players continuously perform the same tasks. It has been suggested that rehabilitation therapy may be translated into a digital game, transforming the negative rehabilitation experience into a pleasurable gaming experience and increasing the intensity and length of time spent on the rehabilitation.

The translation of neurorehabilitation therapy into a digital game presents a number of challenges. One challenge is the integration of physical exercises into the mechanics and dynamics of a challenging game. Digital games are difficult to design even without the rehabilitation context, and constructively adding specific physical exercises makes this even harder. A second challenge is digitally presenting the exercises in a manner that takes into consideration the physical, cognitive and visual impairments of persons who have had a stroke or persons with MS. The physical, cognitive and visual skills needed to play an off-the-shelf game are often high, and may potentially cause difficulties for a target audience that does not fully possess these skills.

In this dissertation we present the creative design process of the physical abstract minimalist rehabilitation game style in order to address the above two challenges. This game style is constructed using a design research approach in which the exploration of design possibilities takes a central role. As such, a range of game elements are investigated through the development of four novel game prototypes. In the first prototype, the role of game mechanics as an essential connector between the game and the rehabilitation world is explored, along with the risk of including game genre conventions that unintentionally introduce barriers for those with physical, cognitive, and visual disabilities. For the second prototype, it is experimentally explored how the artistic processes of abstraction and minimization can help avoid the inclusion of such game genre conventions. In the third prototype, the second prototype is transformed into a more usable and playable game by emphasizing, among others, graphical, compositional and expositional game features. Finally, the fourth prototype explores how the style of the third prototype might be transformed into a tactile game that is integrated in the rehabilitation space in which the physical exercises are actually performed. The development of these prototypes is supported by play sessions with rehabilitation therapist as well as qualitative player and play experience tests.

Researchers and designers working in the field of physical rehabilitation games can apply this game style and its features in their own rehabilitation games. The value of the work lies not only in the explication of the design process and rationale, but also in the resulting prototypes themselves. Designed game objects offer information that stretches beyond the written language, communicating in form, color, and game play. This offers researchers and designers the opportunity to directly perceive how they may implement, extent or alter the presented style. In this manner, we believe, the following dissertation presents one possibility of how a digital game world can be constructed for rehabilitation games starting from physical exercises and game mechanics while taking into consideration a number of physical, cognitive, and visual disabilities.

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Some months ago, I set out on a backpacking adventure through South-East Asia. Of the many lessons I learned during my journey, there is one I especially hold dear: no matter how spectacular the scenery and the cities, it is the people you meet along the way that truly matter. I feel that this is also true for my journey towards my PhD.

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Chapter 1

Introduction

1.1 Motivation

In the 1950s, the first digital games began to materialize. Since that time digital games have steadily grown into a highly popular and profitable entertainment medium. Today, children and adults of all ages play such games as they typically provide an enjoyable experience. However, digital games are not only played for entertainment purposes; they also serve more practical and functional purposes. Over the last decade researchers have progressively addressed the usage of digital games for learning or training purposes in a wide variety of areas. For example, military, governmental, educational, corporate and healthcare institutions have all considered the use of digital games to teach or train the public or their own personnel [1]. The main rationale for this is that learning and training are often considered as tedious, and the enjoyable features of digital games may make these activities more motivating. One such activity, the topic of this dissertation, is the physical rehabilitation of people who have suffered from a cerebrovascular accident (CVA/stroke) or individuals with Multiple Sclerosis(MS). Specifically, a closer investigation is performed on the creative design of physical rehabilitation games for these individuals.

1.2 What are stroke and multiple sclerosis?

1.2.1 Etiology

Stroke is one of the most common and severe diseases in society today. It presents itself when a specific area in the brain ceases to receive blood and is damaged as a consequence [2]. Because blood carries essential oxygen and nutrients, a stroke causes brain cells to die off. Those brain cells are vital in our daily lives; without them we are not able to act or think. Even the most simple of tasks becomes impossible to perform [3]. In general, there are two manners in which a stroke happens: when the blood flow is blocked in an artery (ischemic stroke) or when blood escapes from a ruptured artery (Hemorrhagic Stroke) [4, 5, 6]. Depending on this, as well as on the affected brain area and the severity of the stroke, people experience a wide range of disabilities and may even pass away as a consequence.

Although MS and stroke have different clinical origins, they do share similarities in their consequences for the affected individuals. While the etiology of MS is not agreed upon, it is generally considered as a disease of the central nervous system [7] resulting from a combination of genetic and environmental factors [8]. MS damages the myelin or the insulating material surrounding the nerves in the central nervous system – existing out of the brain and the spinal cord –, and disrupts the nerves' communication in and to the brain and body [9]. Comparable to stroke, the specific consequences for individuals with MS vary significantly depending on where and how the nerves are damaged. Nevertheless, four general types of MS are commonly identified: relapsing-remitting MS, secondary-progressive MS, primary-progressive MS, and progressive-relapsing MS [10]. These types mainly differ in the occurrences of attacks that worsen neurological functioning (relapses) followed by periods of recovery (e.g. high in relapsing-remitting MS) versus the steady progression of the disease with fewer relapses (e.g. primary-progressive MS).

1.2.2 Impact on individuals and society

Each year, approximately 192.000 people die as a consequence of stroke in the European Union (EU), making it the second single most common cause of death in the EU [11, 12]. With nearly 140.000 deaths each year, stroke is the fourth single leading cause of death in the United States (US) [13]. Worldwide, the disease amounted to 6.7 million deaths in 2012, making it the second leading cause of death in the world [14]. Though MS does not commonly result in death directly, it is estimated that globally 2.3 million people are diagnosed with it, amounting to 108 cases per 100 000 in the EU, and 140 per 100 000 in the US [15].

Stroke and MS negatively impact an individual's life [16, 17, 18]. A prominent example of this is their loss of independence [19, 20]. Before a stroke and the onset of MS, individuals are able to perform activities of daily living themselves, yet afterwards they often need to rely on family or professional caregivers to do these for them. For instance, their mobility might be severely reduced and they may no longer be able to visit friends and family independently. This, in turn, leads to personal problems such as social isolation, an important contributor to the detriment of the well-being of the individuals [21, 22]. Another consequence is that these individuals often struggle with their new identity. They are not able to do the same activities they could before, and it is unclear for them how this situation might develop in the future, leading to a severe lack of self-esteem [19]. It is not uncommon, then, that depression is prevalent among stroke survivors and individuals with MS [23, 24].

However, stroke and MS also lead to a range of issues for the family who act as a caregiver [25, 26, 27]. Taking care of individuals with stroke or MS and helping them in their daily lives may cause a significant amount of anxiety and stress [28, 29, 30]. Simultaneously, caregivers also have to deal with their own emotional issues. For instance, they may feel emotionally distanced from the individuals as a result of their personality changes, or they feel the need for time for themselves and taking care of tasks unrelated to the stroke [31, 32]. The severity of this can eventually result in shifts of the social roles within a family [33]. Finally, stroke and MS also affects society on a whole as it weighs heavily on healthcare systems (cfr. [34]).

1.2.3 Physical, cognitive and visual disabilities

Stroke and MS are a major cause of disability [35, 36, 24]. As a result, stroke survivors and individuals with MS are often unable to perform activities of daily living such as driving a car, picking up a drinking glass, or dressing themselves. Underlying these disabilities are the physical, cognitive and visual impairments caused by damage to the central nervous system. Common physical impairments include a reduced dexterity (e.g. reduced strength, coordination, range of motion, etc.), muscle weakness, spasticity [37, 38], and balance problems [39, 40]. The cognitive functions affected by stroke as well as MS include worsened memory and slower processing speed [41, 42, 43] and language problems [44, 42, 43], in addition to visual impairments such as low vision or perceptual difficulties [45, 42, 43]. Often, these impairments appear instantaneously after a stroke and can affect a patient for a period of up to 10 years [46] if not longer. In MS, the onset of the impairments depends on the type of MS and may form gradually and recurrently flare up throughout the entire life-span of individuals with MS. Of course, while both stroke and MS bring about these impairments, the specificity of these impairments may vary between both groups. For example, 26% of stroke survivors experience visual neglect [47] and are unable to process part of their visual field even though visual stimuli are present, which is not common in individuals with MS. However, impairments may vary so greatly that even a comparison within one group is problematic (cfr.[48]).

1.2.4 Upper-limb rehabilitation

In many cases of stroke and MS, the physical consequences manifest themselves in the upper limbs. As a result, functional tasks such as lifting objects or reaching for, grasping, and holding objects may prove difficult. In order to (partially) recover these skills or prevent them from worsening, stroke survivors and individuals with MS require physical neurorehabilitation therapy. While different approaches to such therapy exist, it is generally agreed upon that individuals need to perform physical exercises high in repetition and with a certain intensity in order to rehabilitate [49]. Preferably, these exercises are task-oriented and directed towards the training of activities patients want and need to use in their daily lives [50, 51]. If these activities are too difficult, they may be divided into different sub-tasks and emphasize one or more components of the movement such as strength, coordination and speed.

Common rehabilitation approaches include Constraint Induced Movement Therapy (CIMT), robot-aided therapy, and resistance training. In CIMT, the most functional upper-limb is restricted and individuals are required to only use and train their less functional limb. This has been shown effective for upper-limb rehabilitation in a range of studies [52]. In robot-aided therapy, robotic hardware assists individuals during their exercises by, for example, supporting the motions of their limb. While some studies have shown positives effects of robot-aided therapy in itself [53], Prange, et. al, [54] conclude it is mainly valuable as an extension of non-robot-aided therapy. Finally, during resistance training, individuals perform physical exercises with a relatively high load in order to produce fatigue and thereby improve muscle force development [55], which has shown to increase functional ability in a number of cases [56]. Regardless of which therapy is applied, it is essential that it focuses on relevant parameters (e.g. range of motion, strength, endurance, accuracy, etc.) and meets the specific needs and abilities of each individual patient.

1.3 Digital games as a motivator for upper-limb rehabilitation

Motivation is considered an important determinant of the rehabilitation outcome [57], as motivation stimulates a patient's active involvement in the therapy and encourages longer therapy sessions. Yet, patients may experience difficulties in becoming and staying motivated because of the high intensity and repetitiveness of the physical therapy. Similarly, patients may further be demotivated when they struggle with affective issues such as depression [16] and self-insecurity [19]. Between stroke and MS, the specific nature and progression of the diseases may also affect motivation. For example, recovery in stroke survivors may progress faster in the first weeks and months of the rehabilitation process (potentially stimulating high motivation), but slow down after 6 months [58]. In MS, the outlook of recurrent flares in which patients lose a certain amount of rehabilitation progress may especially negatively impact motivation. Furthermore, the higher chances of fatigue [59] in persons with MS may demotivate them more than stroke survivors. Regardless of these difficult situations for both groups, it is thus essential for individuals to stay motivated in order to achieve a positive recovery.

To improve the motivation of patients, researchers advocate the use of digital games during rehabilitation therapy (cfr. [60, 61]). Digital games are a popular medium played by millions of people. What specifically attracts people to digital games is difficult to state, yet, it is clear that these games offer players an engaging experience, often aligned with the concept of flow, indicating that players forget the time and the world around them [62, 63, 64, 65]. Researchers suggest that this same experience can motivate patients to rehabilitate longer and with more interest. However, regular entertainment games are not necessarily usable in a rehabilitation context. For instance, hardware may not be adapted to disabilities [66] or the progression of the game is too fast [67] and need to be slowed down.

1.4 Problem statement

In physical rehabilitation games, the requirements of an entertainment product and a program for physical training are combined in one artefact. While the experience of the player is of central importance in these games, an improved quality of rehabilitation is the main criterion against which their value is judged. Thus far, most physical rehabilitation games have been developed from the perspective of rehabilitation science, and have had only a limited focus on the game design perspective [68, 69]. For example, some studies emphasize the creation of novel input devices for patient with disabilities (cfr. [70][71][72]) or investigate the efficiency digital rehabilitation games [73], which indicates that the researchers main focus resides in therapy concerns. As they do not address specific game play elements, it has been argued that the quality of the aesthetics has threatened the effectiveness and the degree of adaptation of existing games for physical rehabilitation [74]. This argument reflects a recurrent concern in the development of educational games, where authors have warned against the 'academisation' of the design process [75].

Within digital game design, a wide variety of game layers (e.g. experience, storytelling, etc.) and game elements (e.g. mechanics, virtual objects, etc.) exist that influence one another (cfr. Chapter 3). Preferably, these layers and elements need to influence one another in such a manner that a coherent game experience emerges for players (cfr. [76]). This means that from a game design perspective, not only are the individual layers and elements important, but also how they are tied together as a whole. Of course, by integrating non-game elements from rehabilitation therapy, this coherence might be affected as these elements are, in a first instance, external to the game world. Thus, rehabilitation game designers have to consider how the inclusion of rehabilitation therapy characteristics could be integrated into the whole of a digital game. In this dissertation, two of such characteristics are addressed: the integration of physical exercises and taking into account patient disabilities.

1.4.1 Integrating physical exercises

Physical exercises are a key part of neurorehabilitation therapy and should therefore be included in rehabilitation games. However, rehabilitation game designers have to ensure that predefined rehabilitation exercises are integrated in the game's concept. For example, if a simple horizontal arm motion from left to right is required for the rehabilitation therapy, the game needs to communicate, register and interpret these exercises. Of course, these exercises need to be consistent with other game elements in order to form a coherent whole and provide a logical game experience.

1.4.2 Taking into account patient disabilities

Digital games are physically and cognitively complex to play as they often require an enormous amount of skill to operate. People who lack such skill as a result of their impairments might therefore not be able to play a game [66] or the game is too fast and needs to be slowed down [67]. For example, if individuals suffer from low vision they might not be able to respond to what happens in the game world on a display screen. Or, as another example, when players' memory is affected they may not be able to remember what happened in previous play sessions. Finally, if patients experience difficulties controlling their arms and hands, it may be problematic for them to physically control and play digital games. Thus, these issues need to be taken into account in the game concept without threatening its coherent and logical game experience.

1.4.3 Game style

A coherent game experience can be captured in the concept of game style. Game style refers to how the individual elements in a game world are – in their totality - presented to players on a visual, acoustic, and gamic level. Although different games are constructed according to different game styles, the game elements within each style support one another in a coherent and logical manner. For example, the game Tetris [77] has a small 2D virtual world presented through a single shot camera, where abstract shapes gradually fall down so that players need to put them together within a set amount of time. In contrast, the large 3D world of Grand Theft Auto: Vice City [78] is filled with realistic characters in which players walk and drive around and complete challenges in their own pace. While both games contain different game elements, in both cases they are arranged in a coherent and logical manner to form a unique game style. We believe that constructing a game style could aid in the development of coherent rehabilitation game even when external physical exercises and patient disabilities are introduced.

However, in existing research, style is rarely explicitly or even implicitly taken into account. Most of the available research on designing rehabilitation games integrates existing game concepts and takes over the style associated with that concept. For example, Burke, et al. [79] and King, et al. [71] use whack-a-mole as the blueprint for their games, while Andrade, et al.[70] and Decker, et al. [80] use Pong, and Shah, et al. [81] use Marble Maze. The style of these games is rarely considered in the research. There are some examples where custom games are built. Sometimes these contribute to the formulation of individual elements of style.The most promising example, we believe, is the work of Vanden Abeele, et al. [82] who define the notion of "slow fun" for rehabilitation games, suggesting that the entirety of a rehabilitation game should provide challenges that do not involve fast movement of the body, similar to the work of Pitaru [67] outside of the context of rehabilitation. We believe that a further exploration of this line of thought, with a more explicit and holistic focus on the notion of a game style, will provide valuable insights to the field of rehabilitation games.

1.5 Contributions and research questions

The main contribution of this research is the novel physical ambient abstract minimalist game style. This game style is developed to emphasize the integration of physical rehabilitation exercises within digital games while taking into account patient impairments. In particular, the style stresses how an existing game world (e.g. commercial game) can be (de)constructed in order to accommodate physical, visual, and memory impairments, yet keep its core game mechanics connected to simple physical exercises.

We developed this style starting from the concept of abstract minimalism found in art and adapted this to the area of digital rehabilitation games. Throughout this dissertation, the design process of the developed style is elaborated on, starting from a digital game world and gradually transforming to a tactile world that reflects the physicality of the rehabilitation exercises. This contribution provides an overall direction to researchers whose purpose is to design physical rehabilitation games that holistically connect a game world to rehabilitation exercises and patient impairments.

This contribution is obtained by following a design and art research philosophy as further discussed in chapter two. In order to guide the research, one main research question is presented, together with four sub questions:

RQ: What rehabilitation game style can be designed in order to integrate rehabilitation therapy and digital games, while emphasizing the inclusion of physical rehabilitation exercises and while taking into account patient disabilities?

1. **How can game elements contribute to the creative design of physical rehabilitation games?** Digital games often contain a wide variety of elements that each contribute to the overall game experience in different manners. In Chapter 3, we present an overview of such game elements, and discuss their use in entertainment games and their potential application in a rehabilitation context. This overview provides a theoretical ground for the design of a rehabilitation game style.

2. **Which game elements can be identified to guide the practical formation of a game style that integrates digital games and rehabilitation therapy?** There are a wide range of potential game elements that can be taken into account in the development of such a game style. It is therefore necessary to select one or a few of these elements, which will serve as an initial guidance. Rooted in the selection of two rehabilitation therapy characteristics (i.e. integrating physical rehabilitation exercises and taking into account the patient disabilities) **game mechanics** and **the avoidance of unforeseen genre conventions** are suggested as relevant elements (cfr. Chapter 4). First, game mechanics simultaneously represent a link between virtual game actions and real world rehabilitation exercises, thereby stimulating the integration of the real in the virtual world. Second, unforeseen genre conventions may result in the unintentional inclusion of entertainment game elements that may conflict with patient disabilities, caution for these is elements is thus advised.

3. **Which digital game elements and qualities can serve as stylistic features in a physical rehabilitation game style?** As a game style consists of a number of stylistic features that describe the manner in which a collection of game elements are combined, it is necessary to first explore which elements or qualities can be included and how they can contribute to the overall style. Grounded in the results related to RQ2, we developed the novel game Collider. This game is displayed in Figure 1.1 which portrays two of the three suggested style qualities relevant for physical rehabilitation games : (1) **abstract minimalist qualities** that reduce the amount of game objects and their pictorial qualities (cfr. Chapter 5) and(2) **ambient qualities** such as color and light that visually and interactively create an aesthetic experience while guiding patients through the virtual world (cfr. Chapter 6). Additional **physical qualities** such as the material qualities of the game's hardware are suggested (cfr. Chapter 7) to bring together the virtual world and the physical world in which the rehabilita-

tion exercises are performed. These qualities direct researchers and designers to specific formations of game elements that support the integration of digital games and rehabilitation therapy.

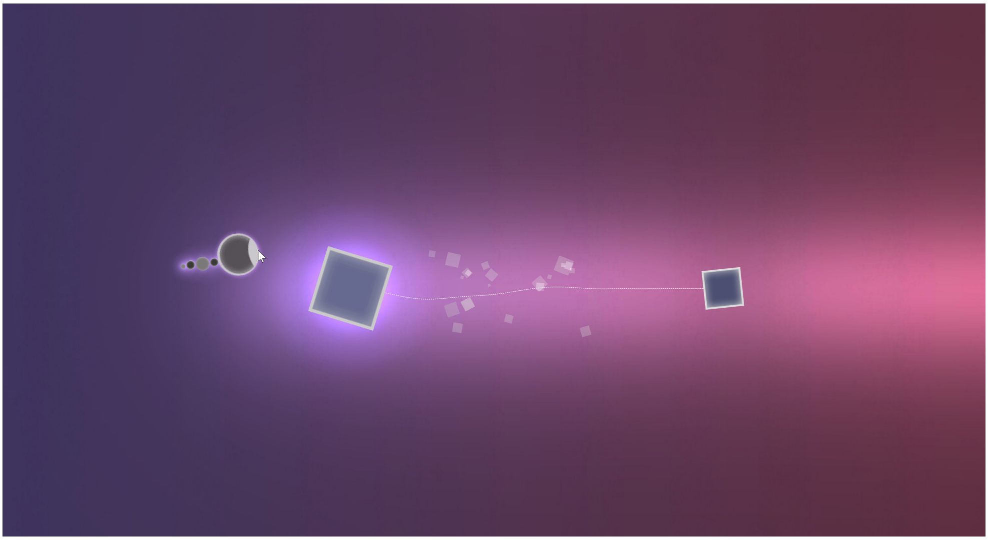

Figure 1.1: The ambient abstract minimalist game ‘Collider’.

4. **How can these game elements be shaped into a single rehabilitation game style?** Because a game style refers to the totality of the stylistic elements, it is important to synthesize all elements into a single whole. Built on the results related to SQ3, we created the novel rehabilitation game Shapes displayed in Figure 1.2. This figure shows three physical objects can playfully be connected when their side-segments light up the same color. The objects are designed in such a way that they contain abstract minimalist, ambient and physical qualities, resulting in the physical ambient abstract minimalist style. Shapes is specifically designed to inspire and inform researchers and designers by presenting an example case of this style.

1.6 Outline of the dissertation

The research questions are elaborated on according to the following outline of this dissertation. In Table 1.1, a schematic overview is provided of the method design and evaluation used in each chapter, and the included participants when players tests were performed.

Figure 1.2: The physical ambient abstract minimalist game 'Shapes'.

			Participants			
	Design	Evaluation	N	Type	Inclusion Criteria	Exclusion Criteria
Chapter 2	Methodological Overview		-	-	-	-
Chapter 3	Literature Review		-	-	-	-
Chapter 4	Design Prototyping	Reflection	-	-	-	-
Chapter 5	Experimental Game Design	Playtests	4	T.	-	-
Chapter 6	Explorative Game Design	User experience and playability tests	7	MS/ CVA	Diagnosis of MS/CVA	Severe physical or cognitive disabilities that may prevent the play of a digital game
		Experimental study	6	MS/CVA	Diagnosis of MS/CVA with a specific level of cognitive ability	Severe physical or cognitive disabilities that may prevent the play of a digital game
Chapter 7	Explorative Game Design	User experience and playability tests	4	CVA	Diagnosis of CVA	Severe physical or cognitive disabilities that may prevent the play of a digital game
Chapter 8	Conclusions	-	-	-	-	-

Table 1.1: Overview of the different chapters and design/evaluation used. T = therapists.

Chapter 2: Methodological perspective

In Chapter 2, the methodological perspective maintained in the current project – that of design research - is described in accordance to the methods used in the field of art and design. First, three design concepts are presented: Schön's seeing-moving-seeing, Cross' designerly ways of knowing, and Frayling's research for and through design. These three concepts form the groundwork of current day design research. Second, a demarcation of the particular characteristics of design research is provided by presenting it according to a constructivist philosophy. Finally, a pragmatic framework is presented on how these concepts and characteristics have been applied in the current dissertation.

Chapter 3: The game design perspective in current rehabilitation game research

In Chapter 3, a content analysis of a wide range of publications on rehabilitation game research is presented. The results of this analysis describe the degree to which these publications have implemented a game design perspective compared to a rehabilitation perspective. Specifically, it is examined how certain game design elements are being applied in rehabilitation research. Additionally, an inventory is made of the game elements that are important to game designers, and how these contribute to the overall play experience of a digital game.

Chapter 4: deep content in rehabilitation games - on game mechanics and game conventions

In Chapter 4, the exploratory game prototype Flowers is presented. This prototype was developed in order to define game elements that provide an initial direction to the creation of a rehabilitation game style. To begin with, the concept of 'deep content' - originating from general educational games - is introduced to shift the focus from creating fun games to creating well-integrated games. Then, the activities of including rehabilitation exercises and taking into account patient disabilities are outlined as important concerns for the creation of a rehabilitation game style. The elements discovered during the design of the prototype (game mechanics and the avoidance of unforeseen genre conventions) are then discussed.

Chapter 5: Exploring the concept of abstract minimalism in relation to physical rehabilitation games

In Chapter 5, the design of an experimental game prototype is elaborated on. This game prototype was created with the aim of including game mechanics while avoiding unforeseen genre conventions. The experimental game will be discussed in relation to an abstract minimalist style. Additionally, the design rationale behind this process is debated, and the results of play tests with four rehabilitation patients are outlined. These results indicated that further adjustments needed to be made in terms of the prototypes' play and user experience, as well as its adjustability to an actual rehabilitation therapy.

Chapter 6: Improving the abstract minimalist design style in terms of usability and play experience

In Chapter 6, the abstract minimalist design style is expanded on in relation to its usability and play features, as well as its adjustability to an actual rehabilitation therapy. In order to do this, the game Collider is created which further develops the abstract minimalist style of 5 by adding a number of game design elements. This resulted in the creation of the ambient abstract minimalist style. By using a range of expositional and compositional techniques, involving color gradients, lighting and fine graphical details, Collider not only guides patients through an elaborate virtual world, but also offers them a specific aesthetic look and feel. Additionally, the use of simple yet engaging challenges has almost entirely removed the need for an explicit user interface or score system. Collider was play tested with a small sample of patients, which yielded promising results in terms of play experience and usability.

Chapter 7: Combining the virtual world with the physical world in rehabilitation games.

In Chapter 7, the ambient abstract minimalist style is further extended to include game elements relating to the physical world in which the rehabilitation exercises take place. First, an exploratory design experiment using interdisciplinary design teams is presented in which physical game elements are revealed as potentially relevant for a rehabilitation game style. Second, observations of a therapy session in an actual rehabilitation center are presented. These indicate that physical space is also central in such a session. In a final step, the identified physical game elements are combined with the previously defined virtual elements into a single game. This game is then contextualized according to a play test with four patients following neurorehabilitation therapy.

Chapter 8: Conclusions, contributions, and future work

In Chapter 8, the main contributions of the dissertation are summarized and reflected upon. Finally, the research questions introduced in Section 1.5 are answered and directions for future research are described.

Chapter 2

Methodological Perspective: Design Research

2.1 Introduction

In this dissertation, we aim to explore and expand the creative design possibilities for physical rehabilitation games from the perspective of the game designer. As a first step in making this attempt, we need to clarify our methodological position. The current project applies the methods used in the field of art and design, which are relatively new in academic research at the time of writing, both on a local [83] and an international level [84]. For this reason, our position as researchers requires a detailed clarification. In the following section we describe the main research strategies used in this project as well as the research goals.

Specifically, we first introduce three concepts (seeing-moving-seeing, designerly ways of knowing, and research through design) that are central to understanding the philosophy of design research, because this is the main philosophy that will be taken[1]. Following this, we relate these concepts to the general history design research and describe the overall methodological framework that will be used. Finally, we describe the specific steps that will be taken within this framework in order to address the research questions.

[1]There is no international consensus on the name of design research, as it can be referred to as design research [85], practice-based research [86, 87], design through research [88], practice-led design research [89], etc. For practical use, we apply the term design research. Furthermore, within this dissertation little distinction is made between design and art research. We hold that the distinction is less relevant here, as within this chapter we define in detail which artefacts are part of the current research, and which are not, regardless if one considers these as design or as art.

2.2 Design research: three essential concepts

Cross [85] argues that design research considers the artificial world as its subject, not the natural world. The artificial world is not given to us by nature, but is created by the efforts of men and women who design objects such as cars, books, tables, houses, computers and so forth. These objects, henceforth referred to as artefacts and designed objects, contribute to society by addressing a specific issue or possibility. For instance, artefacts such as cars allow for fast and reliable transportation, and books carry information across time and space without the need for oral transcription. People may also derive pleasure or other enjoyable experiences from these objects in the form of self-expression [90], social contact (e.g. video chat through a computer), or entertainment (e.g. computer games). According to Friedman [91] the artificial world is a valuable subject for academic research as it widely affects the operation and progression of society. Therefore, an increase and expansion of our knowledge regarding the artificial world can enable us to steer society towards a positive or, rather, more informed future.

In its most general sense, design is the creation of the artificial world. Logically a more accurate description is needed if we wish to define a research framework based on the specific characteristics of design. In this dissertation, design is understood as the deliberate act of reshaping materials [92, 93] with the main objective of creating artefacts [94, 95, 96, 97] that embody new possibilities [98, 99, 100] and contribute to the evolution of society [91]. Throughout this chapter, this definition is explored and concretized. In the following subsections, three essential concepts that form the basis of current day design research will be introduced to clarify the terms 'reshaping materials' and 'artefacts'. Afterwards, these terms will be adapted to further explain the definition in order to outline our methodological framework.

2.2.1 Schön: seeing-moving-seeing

Schön, a social scientist, greatly contributed tot the field of design research through his theory of the reflective practitioner [101]. In this theory, he describes how practitioners (broadly categorized as urban planners, designers, psychologists, etc.) not only gain knowledge through analytic and formal learning, but more importantly by reflecting on their own practice. In the case of design, Schön [92] highlights that in order to reflect, designers create artefacts during the practice of designing [102], and this occurs through a repetitive pattern of seeing-moving-seeing as displayed in Figure 2.1. Each segment of this pattern reflects a fundamental action required to make progress through the design process. Schön provides a simple and practical example case in which this pattern is used. He describes a situation where an architectural design student under supervision of her teacher is presented with a specific design scenario. The design goal in the scenario is to create a teaching space with use of six classroom units. As a first step, seeing in the box on the left in Figure 2.1, the student sees or inspects the design scenario and the materials (classroom units) at hand. This inspection not only concerns the visual registration of information, but, more importantly, the active construction of meanings relating to the scenario and the materials. The student identifies a (subjective) problem in the design scenario: the units are too small for the purpose of teaching. In an attempt to solve this problem, she continues to the second step, that of moving displayed in the between the two boxes of seeing, and changes or, rather, reshapes the classroom units. In the example, the student rearranges the classroom units into attached spaces, aiming to create a larger total space. The student, thirdly, reflects on the changes made again by seeing, the box on the right in Figure 2.1. If the new arrangement does not address the problem as expected, the second and third steps are repeated until a satisfied design solution has been reached. As Schön acknowledges, this example does not contain the complexities of actual design scenarios. Nevertheless it provides a solid basis for comprehending the basic process underlying the creation of an artefact. This process is what Schön [92] referred to as a "reflective conversation with the materials of a design situation." This concept is especially important within design research as it reveals how the act of reshaping design materials yields knowledge.

While the example relates to the design discipline of architecture, the pattern can be applied to a wide variety of disciplines, including (but not limited to) product design, interaction design, graphical design, ... In fact, Schön often applies to the non-discipline specific term 'the practitioner' [101] or, in other words, the person who designs an object or artefact in practice. The general methods defined in design research may be similar across different disciplines, yet the materials and the type of artefact depend on each specific discipline. In the example, the materials and the artefact related to a living space, a subject of architecture. In graphical design, these might involve pen, paper and a drawing. In fashion design, these might include textiles, thread and needles. In the current project, the main materials used will be, as pointed out further on, game mechanics [63] and digital code [103] to create games as artefacts.

To summarize, Schön distinguished three phases that define a design process. In the first, seeing, the design materials and scenario are analyzed in order to formulate a design problem. In the second phase, moving, the materials are reshaped in order to practically convey or explore a design solution. Finally, in the last phase of seeing, the design solution is reflected upon in relation to the materials and the original design problem, potentially leading to the reiteration of the second and third phase if the problem is not satisfied.

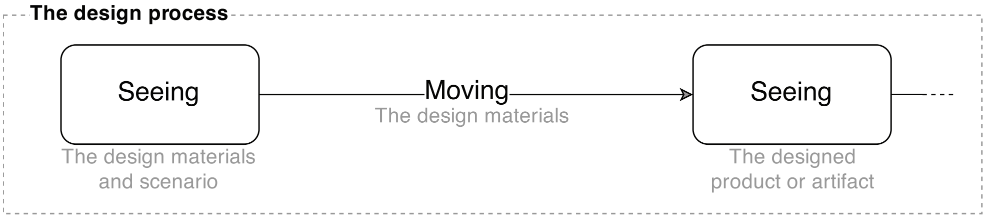

Figure 2.1: The seeing-moving-seeing pattern according to Schön [92].

2.2.2 Cross: designerly ways of knowing

Similar to Schön, Cross's [94, 95] view of design starts with the observation that designers create artefacts. While the ideas of Schön and Cross mostly complement one another, Cross additionally asserts that designers apply specific types of knowledge to interact with the design scenario and materials. He terms these as designerly ways of knowing [94, 95] or types of knowing that "rest on the manipulation of non-verbal codes in the material culture" [94, p. 10]. Contrary to traditional knowledge created in the sciences [97], design knowledge does not necessarily or predominantly reside in the written or spoken word. Cross argues that design knowledge is contained within the practical process of designing and within the designed object itself. This is depicted in Figure 2.2 where knowing the design process flows from the entire seeing-moving-seeing structure, and knowing the designed object from the phases of seeing. This is especially important for design research as, by doing this, Cross created a discussion within the academic community on the academic value and validity of design knowledge.

Whereas the written and spoken word rely on the symbolic meaning of words to represent reality, the design process and design objects operate as symbols in their own right. For example, a design scenario might require a graphical designer to draw a real life person. Ideally, designers already know through practice how to draw the correct proportions of the human body, how the drawn lines should flow in order to outline the person's body, or how shading adds depth. By actually drawing the person, designers capture this knowledge within the drawing, within its colors, shapes, textures, etc. [94] Other graphical designers are able, by looking at and observing the drawing, to use this knowledge to improve their own drawings.

The choices designers make when reshaping the materials in a design scenario are reflected within the resulting artefact. On the one hand, this may reveal knowledge about the design process (e.g. which drawing techniques are used) and, on the other hand, about the results of that process (e.g. what effect or understanding does the drawing provides its viewers).

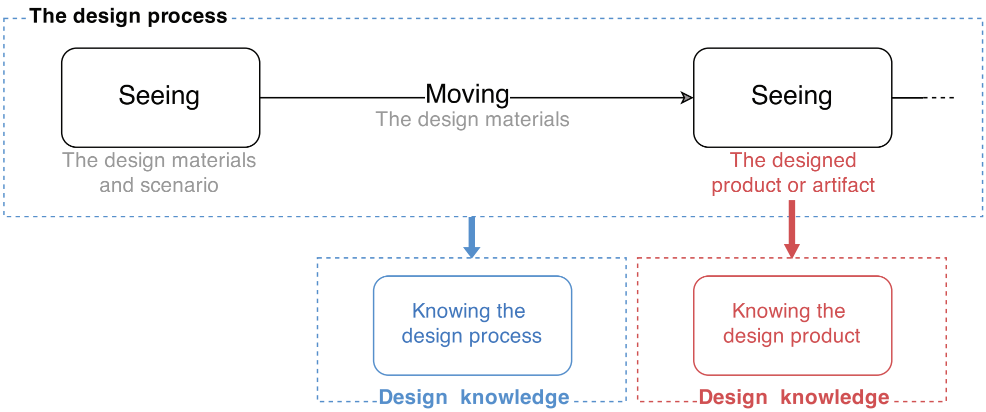

Figure 2.2: Two types of design knowledge described by Cross [94, 95] in relation to Schön's [92] seeing-moving-seeing pattern.

2.2.3 Frayling: research into, through, and for design

While Schön and Cross both contributed to the transformation of design into an area of research, it was Frayling who initially provided a specific terminology to describe design as research. Frayling [96] devised three types of design research: research into design, research through design, and research for design. Crucial is that by devising types, Frayling reveals that the act of design can be considered a general method in academic research. The categorization of Frayling is considered as ambiguous by a number of researchers [88]. Therefore, we follow Jonas' [104, 105] interpretation of these categories as it operationalizes Frayling's categories more. According to Jonas, research into design is the study of design as a phenomenon, for instance from a cultural, political or historical perspective [96]. It is the least applicable type of research in the current project as it is not concerned with the creation of artefacts itself. The two other types relate to Cross' [95, 94] divisions of design knowledge as is illustrated in Figure 2.3.

As seen in Figure 2.3, research for design produces knowledge relating to the the design process. This includes, for instance, material research, development work (e.g. the appropriation of technology for novel purposes), and action research in which a diary is kept of the design process [96]. It is important to note that the results of such research are usually communicated to a broader community using verbal or written documentation (see also [89]). Thus, this type of research makes explicit the knowing about a process, in order to avoid that the community needs to search for information in the artefact, thereby avoiding any ambiguity. In the current project, this type of knowledge is presented within the current written dissertation.

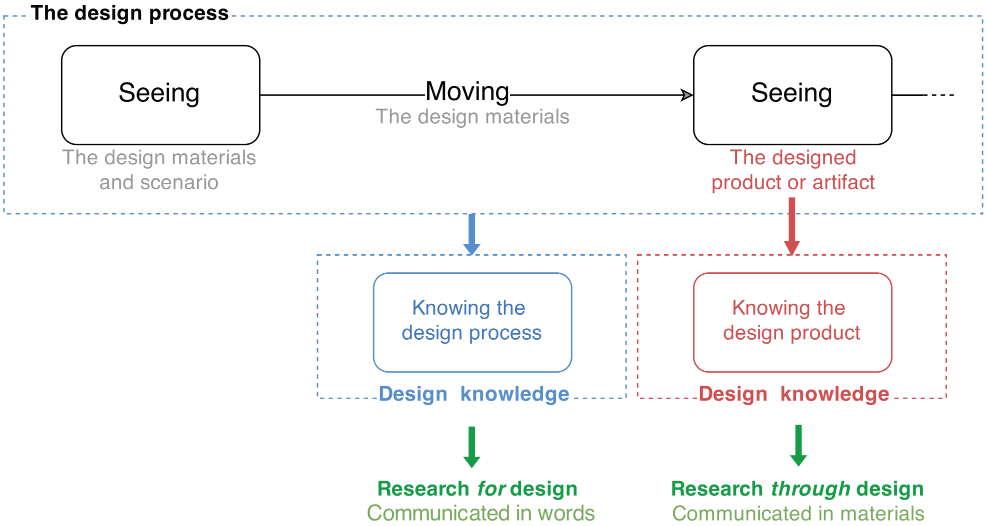

Figure 2.3: Two types of design research described by Frayling in relation to Schön's [92] seeing-moving-seeing pattern and Cross' [94, 95] two types of design knowledge.

On the other hand, research through design addresses the designed product itself, as the subject and container of knowledge (cfr. Figure 2.3). As Frayling states: "the thinking is, so to speak, embodied in the artefact" [96, p. 5]. This type of research cannot be communicated in words, as its results are located within the configuration of the materials [106, 107]. The artefact itself needs to be seen, heard, or used in order to be fully understood. A painting, for example, can be described in words, but it is only when its size, its texture, its colors, etc. are present in real-life that its effects become apparent. This type of research, as suggested by Cross [94], aids other designers to understand, select and apply certain materials in relation to their own projects. In the current project, this type of research is presented as a series of game prototypes developed throughout the project.

2.3 Design research and forms of knowledge

In the previous section, we have argued that designing an artefact results in at least two types of knowledge: research for design, and research through design. Within the chosen philosophy of design research it is vital to provide a demarcation of the specific characteristics of these types of knowledge [108, 109]. In this section, we elaborate on how these two types of knowledge relate to such characteristics. In addition, we will clarify the novelty of design knowledge in a research context. For a comprehensive overview we refer to the works of Bayazit [110] and Margolin [111].

2.3.1 Design research from a historical perspective

The rise of design research is characterized by an identity struggle between being an independent field of research and being a direct extension of established scientific research. Cross [112, 94] as well as Frankel and Racine [84] trace this struggle back to the 1960s, a period when design researchers aimed to define their field as a serious academic discipline. In order to do this, they incorporated practices and strategies from the academic sciences, and then dominant ontological paradigms such as positivist thought and values from modern art movements such as De Stijl [84, 112, 94]. As a result, design was viewed as a systematic and rational endeavor, which could lead to predictable design outcomes. Yet, in the 1970s this approach raised significant criticism [84, 112, 94], as it opposed several core values of the design practice [113, 114]. The critics argued that design, and in extension design research, deals with real-world problems that are too complex to have predictable results [110]. They therefore held that design research should regard this complexity as its starting point, rather than avoiding it [115, 116, 112].

Despite this criticism, the issues of rationality and predictability remain pertinent in design research today, though the field has gradually developed further. The influential peer reviewed journal Design Studies and popular conferences such as The Design Research Conference underscore this. Yet, in practical work, such as PhD-theses, it remained [86, 117] and still remains ambiguous [99] which methods should be used to perform design research, both on a student/supervisor as well as on an institutional level. According to Sevaldson [118], this can be traced back to a misunderstanding of what academic research is. He states that academic thinking is not governed by one established view or value system, and argues that design research should rather focus its attention on views sharing a common philosophy with it such as, to illustrate, Ethnography.

2.3.2 Design research as constructivist research

Following Sevaldson [118], the current research will be performed according to a constructivist philosophy, which is an important movement in the social sciences [119] and in design research (cfr. [120]). According to the constructivist philosophy "[r]ealities are apprehendable in the form of multiple, intangible mental constructions [which] depend for their form and content on the individual persons or groups holding the constructions" [121, p. 111]. While positivist research attempts to study the world independently of human thought and intervention, constructivist research acknowledges these as important contributors to reality itself. Constructivism holds that people constantly (re)interpret the world and, as a result, reshape the meanings of and the perspectives on how that world works [122]. Important within this consideration is that there can exist multiple realities, as individuals and groups of people can interpret the world differently through their interactions with it. The goal of research within this paradigm is not to seek out a single objective 'true' reality, but to create a deeper and more informed understanding of how these diverse realities come about and work together [121]. Applied to our description of design (see Section 2.2), the artificial world can be considered as a prime example of a multifaceted reality that is constructed by people or groups.

In relation to knowledge, positivist research describes a (fragment of) reality by means of a proposition, along with evidence-based arguments that prove to what degree this proposition is true or not [123]. For instance, the proposition that cars may have a harmful effect on the environment could be supported or discredited by studying, providing evidence, and discussing, the air quality in relation to exhaust fumes. Important to consider is that these propositions represent an objective reality, and therefore need to be communicated through a medium that is able to reflect that reality, such as the written word [123]. The aim of design research is not to reflect reality as such, but rather to generate, or construct, a (part of) particular reality through the act of designing [106, 124]. Thus, following the constructivist philosophy, it is vital to create a deeper and more informed understanding of that particular reality or, in terms of Schön [92], Cross [95, 94], and Frayling [96], of the design process and its resulting artefact.

2.4 A four-part framework for design research

In the previous section, design research has been described as adhering to a constructivist philosophy, aiming to create a deeper and more informed understanding of the design process and the designed object. In the following section, we describe how this understanding can be created in practice. We present a pragmatic framework that reflects the working process used within the current project. The three concepts of Schön, Cross and Frayling introduced in Section 2.2 are used as the leading thread for the description this framework. The structure of seeing-moving-seeing serves as its foundation, and is complemented with recent insights on design research. As such, each stage of the structure will be explained in practical terms to present a concrete picture of how design research works. We believe it is necessary to provide such a framework, as it will allow us to adequately address the needs of the current research [125, 126], while being rooted within the larger whole of design research. The framework is defined according to four phases: situating, exploring, synthesis, and

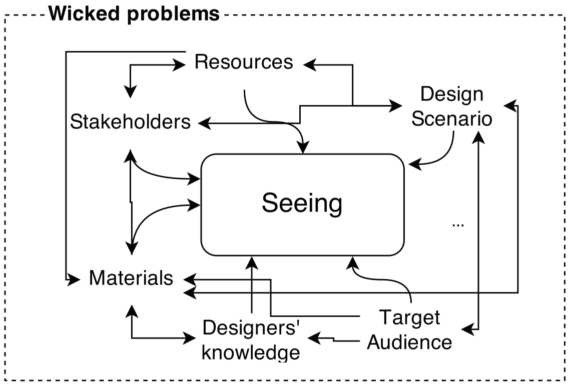

Figure 2.4: An example representation of wicked problems [127, 115, 128] in which many variables influence the act of seeing as well one another.

communication.

2.4.1 Situating

According to Schön [92], the pattern of seeing-moving-seeing is easy to understand in theory, but is difficult to apply in practice. The reason for this is that design deals with 'wicked problems [127, 115, 128]. Wicked problems are in essence complex problems that possess a number of characteristics that make them particularly challenging to solve. Some of those characteristics are, for example, their wide variety of potential solutions, the ambiguity of the methods with which to solve them, and their dependence on multiple other problems [127, 115]. This is the result of the real world context in which a wide range of design variables, such as stakeholders, target audiences, resources, and the designer's knowledge are located. These variables conflict with one another as they all have different constrictions and propose different types of solutions (see Figure 2.4). Farell & Hooker [129] posit that such complexity is not specific to design research, and that such problems are also found in other domains of academic science. However, we argue, with Schön, that wicked problems are different in the context of design research because their complexity in itself is used as input in the research process, as a means to create novel artefacts, rather than being simplified before forming a solution, as is often the case in other domains.

However, the general notion of complexity is vague as it fails to denote a concrete concept. Stolterman [98, p. 57] therefore presents the term "design complexity", or the complexity designers face when they deal with wicked problems. While this term shifts the notion of complexity to the area of design, it remains unclear how it can applied in practice. Recognizing this, Westerlund [130, p. 1] (see also see

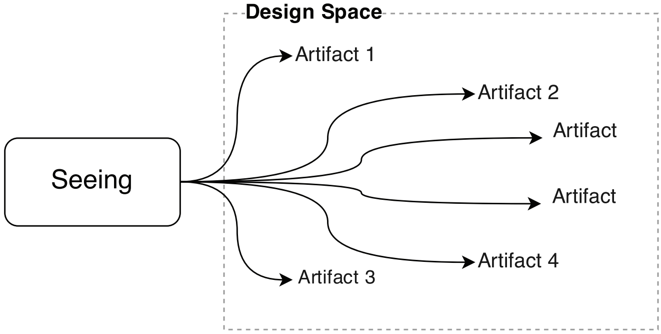

Figure 2.5: An example representation of the design space in which all possible artefacts to a specific design scenario are located.

also Goel, & Pirolli [128]) emphasizes the practical consequences of this complexity for designers, and introduces the term 'design space' as exemplified in Figure 2.5). The design space is a conceptual space that contains all possible design artefacts that can be related to a given design scenario, even those that will never be created [131]. These possible artefacts are directly related to the variables of the design scenario, because these variables determine which artefacts can be created. Thus, instead of targeting the complexity of a problem situation, the design space addresses the formulation of concrete solutions. Consequently, the notion of the design space encourages designers to act upon, rather than to analyze the variety of variables.

It is important to understand that the size and depth of the design space is, in theory, boundless [98, 131]. The more variables contained in a design scenario, the more artefacts that can be created. It is therefore virtually impossible to identify all the potential solutions at the start of a design process. Hence, Schön [92] defines seeing as a process – in contrast to an instant – of 'problem framing'. Schön comprehends the act of design not as proposing a solution (or hypothesis), but rather as discovering a solution. This is done by gradually defining the boundaries and the design variables to work with throughout the process (cfr. [94]|). Thus, in the pattern of seeing-moving-seeing, the first phase of seeing implies that designers explore design variables that reveal initial design elements that are relevant to the potential design solutions or artefacts. In the next section, we elaborate on what this exploring entails in practice.

2.4.2 Exploring

Schön [92] asserts that the seeing-moving-seeing pattern permits designers to "recognize more in the consequences of their moves than they have expected or described

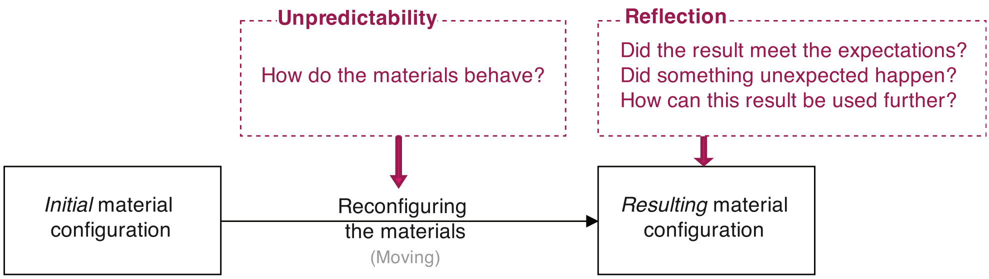

Figure 2.6: Reflection and unpredictability in the design process.

ahead of time." Schön refers to the fact that the created artefact allows designers to gain knowledge they did not have before it was created. This is done through the act of reflection [101] or, in other words, by looking back on the design result in relation to the initial configuration. As is seen in Figure 2.6, this reflection is on the designed artefact, which may contain materials that behaved in an unpredictable manner. Reflection is vital in design research because the material configuration is, to a degree, unpredictable [101]. The act of moving involves creativity and thus may contain unexpected outcomes [117], and reflection allows designers to see this unexpectedness and respond accordingly in subsequent phases [132].

To aid designers in this process of exploration, prototypes can be used. Lim, et al. [133, p. 7:2] define prototypes as "the means by which designers organically and evolutionarily learn, discover, generate, and refine designs." Prototypes can be considered as low fidelity artifacts used to explore specific parts of the design space while leaving other parts (perhaps momentarily) aside. Lim et al. [133]argue that prototypes are often regarded as means to evaluate designs in a resource-efficient manner, but more importantly, to stimulate the generation of design solutions. Likewise, Edelson [134] holds that through prototyping, designers can discover opportunities and problems not thought of before. Thus, in design research, prototypes serve as a material catalyst for inspiration during the exploration process.

The act of exploration can thus be considered as a manner to move towards a future which could not have been envisioned in advance. This emphasis on the future is a critical aspect of design research [98]. Designers do not direct their attention towards the now, but towards the construction of new futures [128]. However, they do not know what they can or should create before they have actually created it. Therefore, through the act of design, and building upon what exists today, designers explore parts of the future in the now. This exploration does not necessarily result in a specific future, but presents concrete alternatives, and as such it can contribute to a more preferred one [135, 99].

The exploration of a design space is not easy because of the design complexity and the insights and creativity required of the designers [126]. These elements submerge designers in the now and inhibit them from working towards new futures. Consequently, designers need to actively explore what is possible and desirable to create (cfr. [136]). As Schön [92, p. 11] observes, the designer constructs solutions and simultaneously "invents the moves by which he/she attempts to find [those] solutions". Often times, this is not a process whereby one linearly moves from point A to point B, but rather whereby one moves repetitively forward and backward again, exploring different pathways in a design space [137]. In this fashion, designers gradually discover the requirements, opportunities and limitations of a particular project [138], and direct both the problem and the solution towards one another [139].

2.4.3 Synthesis

The process of design exploration, naturally, has to evolve towards a design solution. In the current project we created a final design solution by looking back on the entire exploratory process towards the end of the project. As the exploratory process is often a non-linear process [137], affected by unforeseen opportunities and limitations [117], it can be relevant, at the end of the trajectory, to bring the gained insights together in order to provide a focused contribution to the design problem. In the current project it was important not to combine all solutions encountered throughout the exploration phase, but to synthesize them [140, 141, 142]. The synthesis was effectuated by integrating aspects of different prototypes that were considered valuable solutions to the problem statement, into a single final artefact, thereby capturing knowledge inside the artefact. In this way, our modus operandi resonates with Jonas' [114] definition of the phase of synthesis, which he defines as a solidification of the future states found in the exploration.

2.4.4 Communication

The previous phases address how designers move through a design project towards a synthesized solution. In the last phase the designers are concerned with disseminating their results and with communicating the relevance of a study in relation to academic research [114]. While the dissemination of design results in a scientific communication is regarded as problematic due to the physical nature of the material artifact (cfr. [97, 140, 142]), it remains a key issue how to verbally communicate design knowledge (which resides within a material artefact), and to define standards of validity and reliability relating to that knowledge. Within our current scientific environment, knowledge is predominately used to evaluate the world as it is in order to make predictions and control that world [121, 119]. As it is impossible to know that world exactly as it is, academic knowledge needs to possess reliability and validity [143, 144]. Because design research deals not with what is, but with what could be (see Subsection 2.4.2), the benchmarks of reliability and validity have to be defined in a different way [88].

Following Barone & Eisner [100], we state that the aim of design research is not to predict, but, instead, to deliver uncertainty. By constructing future possibilities, created through the exploration of a design space, one can peer into a certain possible future and reflect on it. One can determine if certain lines of that future are worthwhile to pursue or not, and thereby encourage doubt about our way of proceeding in case we had not looked into it [107]. In other words, it is impossible to control how the future will be by evaluating how it is now, but we can actively explore the now in order to make us aware of what is possible in the future through the effort of the designer. In this sense, like academic research, design research results in a more informed and sophisticated knowledge structure than existed previously, thereby making it relevant in a constructivist philosophy [121].

In the current study we aim to challenge and broaden the perspective that has thus far been taken in the design of rehabilitation games. New forms of rehabilitation games can arise from an exploration through the practice of game design. These new forms can inform us about our current approaches and, if contextualized properly, encourage reflections on those approaches. This is, we argue, especially relevant as the field of rehabilitation game design is still relatively young, and an exploration of possibilities should be done to guide future research.

2.5 Adaptation to the current research project

In the previous section, we described the methodological perspective of design research according to a general framework based on Schön's seeing-moving-seeing model, Cross's Designerly Ways of Knowing, and Frayling's definition of research through and for design. In the following section, we expand on how this method was applied within the current project. This allows us to specifically adapt the framework of design research to the specific characteristics of game design, as suggested by Kuittinen & Holopainen [145] and Kelly, et al. [146]. Throughout the following chapters, each step within the framework is addressed in more detail.

2.5.1 Situating

Following the above four-part framework, the first step in this research project was to situate ourselves in the complexity of the field of rehabilitation games. In the current project, this complexity is two-folded. On the one hand, the area of rehabilitation therapy provides requirements and limitations that need to be considered in order to create a design solution. On the other hand, the area of game design, in the same sense, provides such requirements and limitations. When this project was initiated, it was unclear which variables of rehabilitation and games could be relevant for a rehabilitation game style. The relatively small size of the rehabilitation games field contributed to this, because few examples of design-research were available (for a detailed discussion we refer to the literature overview presented in Chapter 3). Consequently, it was important to define initial characteristics of rehabilitation game research and game research in general, with which an eventual solution could be created.

We situated ourselves within this design scenario in two ways: (1) we examined both parts of the design scenario theoretically, and (2) we examined the parts of rehabilitation and games practically. In the first case, we performed a literature review and analysis of previous research in the domain of games for rehabilitation, as presented in Chapter 3. Our intention was to describe a key focus in the available literature and identify any gaps that could be used as a starting point for this research. Overall, the literature overview indicated that thus far there has been little emphasis on the game design elements that have been expressed by game design theorists such as Schell [63].

Based upon the literature analysis, we decided to focus our attention on the process of game development in a designerly way. As such it had to be established how to practically approach this. Games include many different design layers (technology, visuals, narrative, gamic elements, etc.) and these can be combined in a wide range of manners and styles (compare for instance Quake Live [147] with Limbo [148] and B.U.T.T.O.N. [149]). In the context of rehabilitation games, the requirements of rehabilitation add an additional layer on top of these basics of game design. Therefore, we needed to investigate if and how this extra layer could be connected to other layers to position us within the larger whole of game design. In order to accomplish this we designed a first prototype of a game for stroke rehabilitation to practically explore these layers. We initially devised three game concepts that incorporated simple rehabilitation movements in a playful manner. One of these was selected for further development based on its predicted future usefulness (e.g. fun, practical, etc.).

During this concept's design process, we observed that game mechanics are essential ingredients to elaborate both interesting video game play and engaging rehabilitation therapy. In the former case, mechanics facilitate interactivity and in the latter case, mechanics provide stimuli for physical movement, both key components of each respective area. Consequently, game mechanics provided the foundation for integrating rehabilitation exercises into video games. At the same time we noted that the resulting prototype contained game elements that opposed rehabilitation concerns. For example, an item inventory system was used that contained many different, small elements, which were difficult to select and potentially complicated to process by patients who had to focus most of their attention to the exercise of basic motor skills. This system was unknowingly inherited from the non-rehabilitation context of the game by which the initial concept was inspired (i.e. the RollerCoaster Tycoon series [150]) . Both considerations became the starting point of the following exploration phase, wherein we aimed to integrate rehabilitation exercises within the design of the game mechanics, and to avoid unwanted inheritances within the game context. As is discussed in Subsection 2.4.1, this starting point should be regarded as one of many possible starting points, yet, a necessary one.

2.5.2 Exploring

2.5.2.1 First Design Experiment

The goal of the exploratory phase was to explore the design space and to practically define potential elements that could relevant for a rehabilitation game style. Reflecting on the results of the previous phase, we intended to create an initial rehabilitation game style that encouraged simple rehabilitation movements, yet, also included only a minimal amount of game elements from non-rehabilitation games. In order to accomplish this, we abstracted and minimalized an existing game towards only a few of its game mechanics, thereby leaving out a majority of elements that did not contribute to the physical and tactical game experience. To start, we applied the idea of a first person shooter genre where the core game mechanics stimulate a tactile aesthetic or, in other words, create pleasure through the act of moving. This type of pleasure, we believed, could potentially support intrinsic motivation if transferred to a physical rehabilitation therapy context. Our game of reference was Quake Live [147] because of its prominent tactile aesthetic [151] and the author has significant experience in playing it. We needed to take into account that this tactile aesthetic – containing fast-paced action and energetic hand-eye coordination – was likely to conflict with the abilities of rehabilitation patients.

This design experiment resulted in an abstracted minimalistic prototype of Quake Live [147] which incorporated the basic movement of moving horizontally from left to right, with a minimal amount of game elements (for a detailed description we refer to Chapter 5). To align this prototype with rehabilitation therapy, we play tested it with one rehabilitation therapist, adjusted it, and then play tested it a second time with four therapists. The overall concept of abstract minimalism was received fairly positively, although several concerns were expressed in terms of value for rehabilitation. Similar concerns were raised during a following internal review of the game.

Overall, the abstract minimalist experiment allowed us to remove unnecessary elements from the game, and showed us we needed to focus our attention more strongly on the requirements of rehabilitation therapy. Furthermore, we noticed that the game was difficult to understand and play or as a result of the experimental design process. While this was counter-intuitive to our initial purpose, the process did allow us to experiment with new game forms that would inspire further research. By aligning ourselves with the philosophy of experimental game design, we created the freedom to construct a dedicated game world for a rehabilitation therapy, rather than merely combining existing game elements with rehabilitation exercises. In the next experiment, then, we focused our attention on the integration of rehabilitation therapy and the game play experience.

2.5.2.2 Second Design Experiment

In the second experiment, we planned to refine the rehabilitation game style in order to improve its usability, play experience, and relevance to the rehabilitation therapy. As such, we sought inspiration in the previous prototype and based ourselves on abstract minimalist entertainment games to, step by step, improve its design. The resulting design resembles the previous prototype, but differs from it in that it allows the player more freedom to navigate through the structure of the game world (cfr. [152, 153]). Overall, the player can move in every direction, while the types of movement and parameters (e.g. length, speed, trajectory, pausing) can also differ depending on the specific level. This facilitated the inclusion of rehabilitation exercises as well as rendered the play experience more open and free. Furthermore, we added structure to the game world by applying physics and end goals in each level, which increased the game's understandability. To aid in this, we also added aesthetic features reflected in that structure.

This prototype was tested with potential players. We set up a play test with eight patients in the MS & Rehabilitation Center in Overpelt, Belgium (see Chapter 6). In a first play session, we observed the patients playing the game without any interruption. Afterwards, they were questioned about the play session. After the interview was finished they were asked to play once more, and in these play sessions the game was paused several times during which we asked more questions. The results showed that one player was not able to conceptually play the game, and the physical strain of one person prevented him from enjoying the game. Otherwise, however, the game showed promising features, such as the simplicity of its design, its visuals, and its play experience. The relevance towards the rehabilitation therapy was not tested, though rehabilitation therapists were included in the design process of the game to ensure this relevance.

2.5.3 Synthesis

The design experiments described above mainly focused on the virtual world and the elements inside that world. However, rehabilitation exercises are performed in the physical world itself as the virtual world only provides feedback and a motivating layer on top of those exercises. In an attempt to explore this gap between where the exercises are physically performed and where feedback is given, a novel tactile game artefact named Shapes was developed. Specifically, during this phase of synthesis, three elements relating to the physical world (spatial configuration of display screens, physical materials, virtual feedback in real world objects) were identified as potentially relevant additions to the virtual world as physical rehabilitation proceeds in the physical world. In a final step, then, the ambient abstract minimalist styles developed in earlier prototypes was combined with these physical world elements. This resulted in the creation of the game Shapes.

2.5.4 Communication

Finally, the results of the entire research project were summarized and communicated according to the view laid out in Subsection 2.4.4.

Chapter 3

The Game Design Perspective in Current Rehabilitation Game Research

3.1 Introduction

This chapter aims to quantitatively assess the validity of the claim that games for physical rehabilitation are too often developed from a rehabilitation-centered perspective only, and that these applications do not sufficiently comply with the promise of immersion, motivation or fun typically ascribed to the medium of digital games. With this assessment, we position ourselves in the general literature on rehabilitation games and can, consequently, identify specific features relevant to the development of a rehabilitation game style. In order to make this assessment, a clear understanding is needed of what it means that a game has been developed from a rehabilitation-centered point of view and conversely, that a game has been developed from a game designer's point of view. Although the distinction between both orientations lies at the heart of the current debate, few authors have attempted to conceptualize the game developer's perspective in the context of games for physical rehabilitation.

A content analysis was performed of a wide selection of contemporary games for physical rehabilitation, aiming to quantify the degree to which rehabilitation-centered and game designer concerns have been taken into account during the development process. Additionally, this study provides a qualitative exploration of how an integrated approach could improve immersion, motivation and fun in games for physical rehabilitation. An inventory is made of the different elements that are relevant to the game designer and their relationship to the overall play experience. Each component of the analysis scheme is complemented with an in-depth description of how it can be used in the future development of physical serious games.

3.2 The rehabilitation perspective vs. the game designer's perspective

This section provides a literature overview focusing on two lines of research. First, important recent research addressing the translation of (real-life) physical therapy and rehabilitation to a virtual reality or game context is described. Second, an introduction is provided to the field of digital game design theory.

3.2.1 Games for physical rehabilitation

In recent years, research in the area of games for physical rehabilitation has increased tremendously. Ample studies have described rehabilitation games as meaningful additions to existing (offline) rehabilitation models [154, 155, 73]. A wide range of games for physical rehabilitation have been developed, making use of dedicated gaming devices such as the Nintendo Wii [80] or Virtual Reality devices such as data gloves [156, 157] and other movement trackers [158, 159]. For example, Curtis et al. [160] created an interactive rehabilitation application containing four games, and Broeren et al. [155] integrated a dozen games within a virtual reality rehabilitation system.

Research has indicated that the use of virtual environments can be beneficial to the efficiency and outcome of a rehabilitation session. Betker et al. [73] observed significant increases in practice volume and attention span, as well as substantial improvements in dynamic balance control with patients who are engaged in digital game-aided therapy. An additional benefit of games for physical rehabilitation is that they can be used outside of the hospital and be transferred to the home context, which can be augmented with a direct connection between the patient and the medical supervisor (telerehabilitation). Telerehabilitation is being facilitated by the use of games and virtual reality applications, as it "increases the accessibility of rehabilitation, and has the potential to become inexpensive with large scale production" [156, p. 28].

However, while virtual environments offer significant advantages, problems can arise when using readily available systems in a rehabilitation context. For example, the use of off-the-shelf commercial games in a therapy context is often considered problematic in terms of accessibility, usability and play experience due to visual, auditory, physical or cognitive complications [161]. Grammenos et al. [162] make a noble, but as of yet unattainable plea for the development of universally accessible games, or games that can be played regardless of the physical and cognitive capacities or disabilities of the player. Another problematic issue is the practicality of commercial available input devices or 'consoles', through which a player communicates with a digital game. For instance, stroke patients expressed particular frustrations while using the Sony PlayStation 2 EyeToy device [66]. A final concern of using commercial games, results from the fact that they are not developed with the explicit goal to improve rehabilitation, and therefore do not comply with the specific needs in physical therapy sessions [163].

Custom hardware systems constitute a highly important aspect in the development of physical serious games, because it allows to transfer the physical movements required for rehabilitation into a virtual environment, and to combine this with a human-computer interface that is immersive, motivating or fun. Different tools have been created that enable patients to interact with and manipulate objects in virtual space. Andrade et al. [70] developed a robotic system that encourages motivating and attractive activities for distal radius fracture rehabilitation. King et al. [71] developed two devices that facilitate bilateral arm training with recovering stroke patients. Furthermore, Fukamoto [72] constructed a custom input device to control a digital game using muscle-based electrical impulses. Others have opted for a cost-effective solution and used a Wii game console controller as a rehabilitation device [80, 164].

A number of researchers have emphasized that the design of a good game should be considered as equally important to the use of custom hardware or therapy requirements. Notelaers et al. [158] suggest that design aspects such as clear movement feedback are essential ingredients of a good game for Multiple Sclerosis patients. Burke et al. [79] and Goude et al. [165] formulate a series of general game design principles and design patterns, and apply these to the development of custom-made games for rehabilitation. Annema et al. [166] implement several design principles, including an easy start-up and configuration, in order to aid the therapist and ensure a motivating therapy session. Alankus et al. [167] highlight the relevance of audio and visuals. Similarly, Vanden Abeele et al. [82] encourage researchers to integrate the principles of 'slow fun' (i.e. no time-dynamics) in digital games for rehabilitation for spasticity. Finally, Dimovska et al. [168] use a procedural content generation system and propagate this as a viable way to personalize rehabilitation sessions.

3.2.2 Game design theory

Designing a game entails conceptualizing, modeling and implementing the rules and mechanics that constitute a game and define the player's experience. Usually, a game is developed by means of a layered approach: different layers are implemented that each account for a specific aspect of the gameplay and that in combination define an overall or integrated experience. Several authors have provided different and often overlapping definitions of the layers a digital game typically consists of, and of the elements that are relevant to the game designer [62, 169, 170, 63]. The layers defined by these authors can be considered as the 'tools' a game designer disposes of, and the resulting game design theories are often regarded as toolboxes for the game designer.

Salen and Zimmerman [62, p. 33] assert that "the goal of successful game design is the creation of meaningful play." Meaningful play arises when a player's actions produce an outcome that is significant on two levels: (1) immediately after an action has been finished, and (2) further on in the course of the game as it affects the future choices the player has to make. In the digital game Tetris [77], for example, positioning a block is considered meaningful because (1) it effectuates the instant clearing of a line and (2) it simultaneously affects the player's future possibilities for positioning new blocks. Salen and Zimmerman [62, p. 67] also put forward the construct of the space of possibility, defined as the "space of all possible meanings which can emerge from a game design". Every action a player is able to undertake and, accordingly, every type of meaning that can be generated during gameplay is represented in this fictional space. The main task of the game designer, then, is to define a game's space of possibility by setting up rules, and as a result, to provide the player with a meaningful experience. Finally, the game designer has to take into account the culture in which the game is designed and played. Culture, according to Salen en Zimmerman, refers to anything that influences the play experience from 'outside' the game, which includes, but is not limited to the thematic, behavioral, and symbolic customs or traditions of a certain community. Salen and Zimmerman [62, p. 5] define three main layers of game design:

1. Play: The experience of the player while playing;
2. Rules: The parts of a game which enable (meaningful) play;
3. Culture: The outside influences on (the design of) a game.

According to Rouse [169], designing a good game entails adhering as strongly as possible to the expectations of the player. A player desires to be challenged, to be immersed or to live a particular experience, and it is the game designer's task to provide the ingredients of this experience. In the first place this brings along the responsibility of providing an input/output system that is both intuitive and transparent. The game's feedback system should provide the player with the vital information needed to master the digital game. This information can take the form of, for example, a reward system or visual feedback. Rouse [169, p. 131] points out that some game designers fail to consider these factors, which is "a mistake you must avoid if you want your games to be any fun to play". Furthermore, Rouse discusses the integration of storytelling as an element that can significantly enhance the digital game experience. Also, the inclusion of social play against or with other real-life players will allow for new types of play. Finally, a game consists of (virtual) physical spaces and objects that can be manipulated by the player in order to make progress. According to Rouse [169] the combination of these elements defines the structure and quality of a game design:

1. Input/output: Communication between the player and the game;
2. Storytelling: A narrative that can enhance the play experience;
3. Social interactions: Interactions between multiple real-life players;
4. Level design: The game space encouraging the player to undertake action;
5. Items/character:s Objects the player can use throughout the game.

Crawford [170] offers an insight into one of the most fundamental elements of games: the construction of challenge. The fun derived from playing a game does not so much reside in the act of winning, but rather in overcoming a challenge. Crawford identifies different types of challenge, of which some require the player to engage in processes of spatial reasoning or pattern recognition, while others are based on social reasoning. While the main task of the game designer is to create compelling challenges, Crawford highlights the additional importance of storytelling. A backstory may provide the player with a context in which the game events can be framed or understood. Cut scenes or short videos, on the other hand, can be used in order to mark moments of progress or to advance through the story. Finally, graphics and sounds can be implemented to provide a more enjoyable game experience. Crawford presents at least four layers:

1. Play: Learning in an enclosed, safe and fun environment;
2. Challenge: Something the player has to overcome;
3. Interactivity: Two-way communication between multiple agents (including a computer);
4. Storytelling: A narrative which can enhance the play experience;

Schell [63, p. 130] defines a vast number of layers of game content, of which several directly relate to the task of the game designer. One of the most important layers is that of the game mechanics, described as "the interactions and relationships that remain when all of the aesthetics, technology, and story are stripped away." While no concrete definition is given, game mechanics is used as an overall term encompassing the following aspects: space, objects, actions, rules, skills and chance. In order for the player to have access to all these elements, the game designer additionally has to build an interface, facilitating the communication between the player and the game. Another important aspect of digital games is the (imaginary) world in which the player finds herself. This world is distinct from the real world, as it contains its own characters, spaces, look and feel, and is governed by rules that are distinct from the rules that apply to real life. From this world a story emerges, which the player has to explore. Schell [63] finally mentions that social interactions in games can be encouraged by having multiple players work together or against one another. The combination of these aspects affects how the game is psychologically experienced by the player. The game designer's task, then, is to create a particular experience by integrating these elements in a consistent whole. Shell suggests dividing the game design process in at least six layers:

1. Game mechanics: Interactions and relationships;
2. Interface: Connection between the player and the game;
3. World: Characters, spaces, environments, maps, general look and feel;
4. Storytelling: Sequences of events;
5. Social interactions: Interactions between multiple real-life players;
6. Experience: The experience of playing a digital game.

3.3 Research Questions

Two research perspectives have been tackled in the literature overview. While the first line of research highlights the benefits of playing physical serious games, including positive rehabilitation outcomes, an enhanced patient motivation and an increased exercise time, the second line emphasizes the importance of elements related to the creation of 'good gameplay' (e.g. challenge, audiovisual design or meaningful play). The opposition of both perspectives will be used to operationalize 'the rehabilitation-centered view' and the 'game design view' on the development of games for physical rehabilitation. The 'game design view' will be expanded further to investigate immersion, motivation or fun in digital games. Three research questions are addressed:

1. To what degree have researchers and practitioners used insights in the process, outcome and efficiency of physical therapy and rehabilitation as a source of inspiration in the design of games for physical rehabilitation?
2. To what degree have researchers and practitioners integrated the game design principles provided by Salen and Zimmerman [62], Rouse [169], Crawford

[170], and Schell [63] in the development process of games for physical rehabilitation?

3. To what degree can an enhanced focus on design aspects result in games that are more motivating, immersive or fun?

3.4 Method

A document analysis has been performed on twenty-one publications concerning games for physical rehabilitation. The ACM digital library and the ISI Web of Knowledge were used to select relevant publications (keywords= ‘game’, ‘game design’, ‘physical’, ‘rehabilitation’). Due to the novelty of the field only a relatively small amount of publications was found (N=21) . To perform the analysis, a scheme was developed based on the main areas of attention from the rehabilitation-centered perspective and the various layers of game content that constitute the game designer’s perspective. The scheme contained 24 questions that were rated on a Likert scale ranging from 1 to 10 (1 = “weakly”, 4 = “moderately”, 7 = “strongly”, 10 = “very strongly”). The rating was performed by two coders, who, as a consequence of their past and present involvement in various applied gaming projects, are strongly familiar with the theory and practice of game design. The first coder (also the first author of this chapter) has a degree in media design, and has in the past been involved in the development of several instructional design projects, including the development of an augmented reality game to be used in biology classes and the development of a physical tool for fine-tuning writing skills. The second coder has a degree in media studies and in applied computer science, and has intensively studied the culture and psychology surrounding contemporary games. He currently teaches game theory in a game design program, and is involved in several courses on the design and development of innovative game mechanics.

Table 3.1 provides a detailed description of all variables included in the coding scheme. The section of therapy-related variables included questions regarding the use of a dedicated input device (var03), of a dedicated in-game feedback system (var05) or of specific mission statements (var12), aiming to provide the player with an efficient or motivating rehabilitation experience. In addition, questions regarding the use of specific learning theories (var06) and the one-on-one translation of existing rehabilitation exercises into a virtual environment (var15) were used as indicators of the importance of therapy-related concerns in the game development process. With respect to the importance of the game designer’s point of view, a wide range of game content areas were identified, ranging from input devices (var04), graphics (var07), audio (var08) and challenge (var09), to narrative elements (var 10, var 11) and ludic elements such as freedom of choice (var 14, var 20, var 21, var 23), meaningful play (var 16, var 17) and conflict (var 24).

Because the research questions relate to the design philosophy applied by the development team of the projects included in the sample, the coders were instructed to rate the design process and the design decisions that were made, rather than the resulting games. In order to rate these aspects, the published papers were considered the main units of analysis. As a consequence, the results of the analysis cannot be considered as aesthetic, critical or evaluative assessments of the contents of the selected games. In case some variables could not be sufficiently rated based upon the selected documents, the raters were instructed to consult additional information through different channels: online information on the practices of the research group, unpublished design documents and online information about the games and therapy sessions. Still, we are aware that not all information regarding the design and development process can be reflected from the resulting game and the other sources of information that were mentioned. In order to avoid any type of rater-induced bias, a comprehensive coder manual was developed, aiming to provide both raters with specific instructions. For example, in the case of var04 (the importance of input devices as tools to improve the game design), the coder manual contained the following guidelines:

> "A score of '1' should be administered in case no explicit mention is made of the immersive, motivational or fun characteristics of the input device. A score of 1 or 2 should be administered in case a device is used that has already proven immersive, playful or fun in existing virtual reality or gaming applications (e.g. a Nintendo Wii game), without further motivation of the choice for this device. In case the choice for a specific device is based upon insights in the field of digital game design, a score of 4-7 is administered, dependent of how extensively this motivation is elaborated upon. In case the input device marks an important part of the game missions or actions, or in case the input device is explicitly integrated in the mechanics of gameplay, a score of 8-10 is administered, dependent of the degree to which the integration between these elements is documented."

To further ensure the comprehension of the coder manual, the analysis scheme was first applied to two cases, after which the coder results were qualitatively compared to one another. This enabled us to detect whether some of the coder guidelines contained ambiguous instructions. This appeared to be the case with respect to a number of variables (var04, var09, var17, var23 and var24), as both coders had made a different interpretation of the guidelines contained in the coder manual. After this pilot

Variable	Description	Mean/StDev Rater 1 (10 pt scale)	Mean/StDev Rater 2 (10 pt scale)	ICC	F(df)
var01	General (g)	5,10 (3,032)	4,76 (2,927)	,979**	47,760(16)
var02	General (r)	8,00 (1,612)	8,18 (1,185)	,880**	8,358(16)
var03	Input device (r)	8,10 (1,165)	8,13 (,957)	,813**	5,343(15)
var04	Input device (g)	5,00 (1,974)	4,94 (1,692)	,935**	15,392(15)
var05	Feedback (r)	3,76 (1,814)	4,06 (2,410)	,952**	20,966(16)
var06	Learning theories (r)	6,10 (2,364)	5,94 (2,249)	,972**	35,272(16)
var07	Graphics (g)	4,14 (1,797)	3,53 (1,586)	,917**	12,091(16)
var08	Audio (g)	1,95 (1,857)	2,00 (2,031)	,990**	104,619(16)
var09	Challenge (g)	4,95 (2,376)	5,00 (2,398)	,987**	76,286(16)
var10	Backstory (g)	1,29 (,644)	1,41 (,870)	,921**	12,600(16)
var11	Cut scenes (g)	1,43 (1,568)	1,41 (1,460)	,987**	79,235(16)
var12	Mission statements (r)	2,05 (2,269)	1,65 (1,693)	,995**	194,500(16)
var13	Tactical play (g)	4,05 (1,830)	4,24 (1,985)	,980**	49,810(16)
var14	Free play (g)	2,52 (1,209)	2,29 (1,047)	,907**	10,758(16)
var15	One to one mapping of existing therapies (r)	7,19 (2,040)	7,06 (2,221)	,975**	40,656(16)
var16	Personal interest (g)	1,62 (,973)	1,65 (1,057)	,937**	15,882(16)
var17	Personal rewards (g)	1,76 (1,091)	1,65 (,931)	,915**	11,813(16)
var18	Social contact (g)	2,33 (2,799)	2,35 (2,597)	,989**	87,857(16)
var19	Therapy rewards (r)	4,81 (2,442)	5,12 (2,667)	,984**	61,767(16)
var20	Freedom of choice (r/g)	1,76 (,625)	1,65 (,786)	,765*	4,255(16)
var21	Sequence of events (r/g)	1,86 (,727)	1,76 (,831)	,847**	6,524(16)
var22	Personalized character (r/g)	1,71 (,717)	1,65 (,786)	,873**	7,882(16)
var23	Action consequence (r/g)	2,90 (1,221)	2,94 (1,249)	,851**	6,697(16)
var24	Conflict (g)	3,38 (1,564)	3,94 (1,853)	,948**	19,321(16)

Table 3.1: Description of the variables included in the coding scheme, and statistics for inter-coder reliability. ICC = Intraclass correlation coefficient, (g) = focus on gameplay, (r) = focus on rehabilitation.

study, the instructions were rephrased so as not to contain any fundamental ambiguities. As is demonstrated in Table 3.1 the application of the coding manual resulted in strong inter-coder reliability statistics. A comparison of the mean and standard deviation of each variable provide a first, weak, indication that there is a large overlap between the scores administered by both raters. Additional analysis of the inter-class correlations provides stronger support for this observation. With the exception of one case (var20), all variables are characterized by an inter-coder agreement of .80 or stronger, which can be considered as a strong to very strong indication of coder reliability [171].

3.5 Results

This section presents the results of the document analysis that was performed, and presents these with special attention for different concerns. The description starts with a focus on rehabilitation concerns, and how these are included in games for physical rehabilitation. Next, the results are presented with an emphasis on game design issues and the way in which these are encountered in the design of games for physical rehabilitation. Finally, the section elaborates on possibilities to use several game design parameters in the future development of physical serious games.

3.5.1 Focus on rehabilitation issues

Descriptive statistics, as shown in Table 3.2, indicate that a large majority of the selected studies have strongly taken into account rehabilitation concerns. Congruent with the results from the literature overview, all studies had a moderate to strong focus on these issues, with only two dealing with these elements to a moderate degree. Based upon the instructions provided in the coding manual, the main difference between studies that deal with these matters 'strongly' (N=12) and studies that deal with these matters 'very strongly' (N=7) resides in the extensive use of rehabilitation research and motivational learning research as a source of inspiration in the development process. In studies rated as 'very strong' extensive documentation is provided of literature on learning and physical therapy, and in addition these learning models are strongly integrated in the design of game missions and tasks. Studies within this category aim to translate existing therapy sessions to a virtual environment and include gaming elements in order to increase the patient's practice time and intensity. Studies rated as 'strongly' make use of theories on game-based learning and/or physical rehabilitation in order to motivate the use of a gaming or virtual reality context. Compared to studies in the 'very strong' group these investigations do not extensively document the integration of learning principles in the design of specific game

	Weakly	Moderately	Strongly	Very Strongly
General	0	2	12	7
Input devices	0	0	15	5
Feedback System - simplicity	10	7	4	0
Feedback system – based on learning theories	3	5	10	3
Mission statements	17	1	3	0
One-on-one mapping of existing therapies	1	2	14	4
Reward system	7	5	9	0

Table 3.2: The importance of therapy and rehabilitation related concerns in the development process

missions and tasks.

A closer examination of the specific domains in which rehabilitation concerns are accounted for, demonstrates that the creation of a dedicated input device is the most commonly used procedure to translate a physical therapy session to a virtual environment (strongly important in all investigated games), followed by the mapping of therapy sessions to a set of game mechanics (strongly important in 14 cases) and the use of a dedicated in-game feedback system (strongly important in 10 cases). On the other hand, a majority of the selected studies did not make use of mission statements (N=17) or a dedicated reward system (N=12) in order to turn a virtual therapy session into a more efficient, motivating or intense experience. Additionally, while in some studies it was considered an explicit design goal to provide the patient with simple and direct feedback (N=4), a large majority of studies considered this only moderately important (N=7) or did not take this issue into account (N=10).

An exploration of each individual case, as seen in Table 3.3, demonstrates that in almost every case a rehabilitation game had been developed by integrating multiple therapy-related parameters described in the analysis scheme. A majority of the games (n=16) incorporated two (n=6), three (n=5), four (n=4), or five (n=1) parameters, out of the ten presented in total. The remaining games (n=5) included only a single parameter. This suggests that in most cases, an interest was shown in improving the quality of the overall rehabilitation process on more than one level.

Publication	Variables				
Andrade, et al. [70]	Var03				
Adamovich, et al. [172]	Var03	Var05	Var06	var15	var19
King, et al. [71]	Var03				
Notelaers, et al. [158]	Var03		Var06	var15	var19
Vanden Abeele, et al. [82]	Var03				
Golomb, et al. [156]	Var03			var15	var19
Broeren, et al. [155]	Var03			var15	
Goude, et al. [165]	Var03			var15	var19
Vanacken, et al. [173]	Var06				
Betker, et al. [73]	Var03		Var06	var15	var19
Burke, et al. [79]	Var03	Var05		var15	var19
Curtis, et al. [160]	Var03			var15	var19
Cameirão, et al. [154]	Var03		Var06	var15	
Alankus, et al. [167]	Var03		Var06	var15	
Dimovska, et al. [168]	Var03			var15	
Annema, et al. [166]	Var03				
Decker, et al. [80]	Var03			var15	
Ma, et al. [157]	Var03		Var06	var15	var19
Taylor, et al. [174]	Var03		Var06		
Xu, et al. [159]	Var03		Var06		
Fukamota [72]	Var03		Var06		

Table 3.3: Rehabilitation parameters per game rated ‘strongly’ to ‘very strongly’

	Weakly	Moderately	Strongly	Very Strongly
General	9	3	7	2
Input devices	3	10	7	0
Graphics	9	9	3	0
Audio	18	1	2	0
Challenge	6	5	10	0
Backstory	20	1	0	0
Cut Scenes	20	0	1	0
Tactical Play	10	5	6	0
Free Play	18	3	0	0
Link with personal interest of target group	20	1	0	0
Reward System	20	1	0	0
Social Play	17	1	2	1
Freedom of choice	21	0	0	0
Sequence of events	21	0	0	0
Personalized character	21	0	0	0
Action consequence	16	5	0	0
Conflict	13	6	2	0

Table 3.4: Importance of game design principles in the development process

3.5.2 Focus on game design issues

Table 3.4 provides descriptive statistics of the degree to which game design guidelines are accounted for in the development process of the selected cases. Although a large majority of studies (N=9) were rated as 'weakly', nevertheless an important amount of studies did account for specific design-related characteristics to varying degrees. Nine cases were rated as 'strongly' or 'very strongly', indicating that the developers aspired not only to implement an effective rehabilitation experience, but in addition, to include game elements that are not directly linked to the strict goal of having patients perform a therapy-related activity. The main reason why such elements are included in these games resides in their potential to create an immersive or motivational experience. The inclusion of, for example, a compelling visual illusion or a set of challenging puzzles, may not necessarily be directly related to the rehabilitation goals of a game, but can nevertheless produce a stronger sense of player involvement, and therefore effectuate a longer playing time and a stronger involvement with therapy-related aspects.

Although a significant amount of games have been developed from a game designer's perspective in addition to the rehabilitation perspective, the examination of the different game design layers that are considered relevant, demonstrates that certain areas of game design remain underemphasized. In none of the selected games aspects such as 'narrative', freedom of choices', 'free play', and 'establishing a link with the personal interests of the target group' were attributed a strong importance. In addition, 'social play' (N=3), 'conflict' (N=2), 'graphical quality' (N=3) and 'audio feedback' (N=2) were strongly valued in only a limited amount of cases. On the other hand, Table 3.4. also reveals that, regarding a number of other layers, issues of game design did play an important role in the development process. The use of an input device that is not only considered efficient (with respect to therapy), but also fun, appeared moderately to strongly relevant in a majority of the selected cases (N=12). Similarly, the inclusion of 'challenge' (N=15), 'tactical gameplay' (N=11) and 'compelling graphics' (N=12) was considered moderately to strongly important in more than half of the analyzed cases. Finally, several types of in-game conflict that were identified as beneficial to the immersive potential of digital games, were accounted for in the development of a large amount of selected games (N=8).

A closer examination of the cases that were rated as 'moderately' or 'strongly' (with respect to the inclusion of game design parameters in the overall development process) indicates that two categories can be identified. First, a considerable amount of game systems made use of existing game titles that have already proven successful in a non-rehabilitation context (i.e. in most cases the use or adaptation of a Wii game for therapy purposes). Although this decision was not categorized as an explicit attempt to investigate the role of game design as a motivational factor in the rehabilitation process, nevertheless it provides an indication of the developer' awareness of the immersive and motivational potential of digital games. Second, in a number of games, specific design guidelines were formulated regarding how the process of rehabilitation and the design of an enjoyable experience can be used to complement one another. As outlined above, this was most specifically observed in the context of social elements, the use of a specific input device, of in-game challenges and of tactical play elements.

An exploration of each individual case, as seen in Table 3.5, shows that a large majority did not adhere to a design approach in which multiple design-related parameters are accounted for. Apart from cases that were not rated strongly on any design-related parameter (n=9), a majority of cases (n=8) included only a single parameter, reflecting the ambition to improve the overall gameplay by improving one area. The remaining games (n=4) varied as to the number of parameters, taking into account two (n=2), four (n=1), and up to five (n=1) parameters, out of the sixteen presented. In these latter cases the game design process is approached as a complicated and integrated one.

Game	Variables							
Notelaers, et al. [158]				var09				
Vanden Abeele, et al. [82]		Var07		var09		var13		var24
Vanacken, et al. [173]							var18	
Burke, et al. [79]			Var08					
Curtis, et al. [160]							var18	
Alankus, et al.[167]		Var07	Var08	var09		var13	var18	
Dimovska, et al. [168]	Var04			var09				
Annema, et al. [166]					var11			
Decker, et al. [80]	Var04							
Ma, et al. [157]				var09				
Taylor, et al. [174]	Var04							
Xu, et al. [159]	Var04	Var07						

Table 3.5: Design-related parameters per game rated ‘strongly’ to ‘very strongly’, excluding the games without design-related parameters

3.5.3 Descriptions of the parameters

The previous sub-sections demonstrate that therapy-related parameters are, to a certain degree, more prevalent in the design of games for rehabilitation than design-related parameters. It remains, however, unclear whether and how this affects the motivational capacity of the resulting games. In order to provide clarity in this matter, a better understanding is needed of the impact of a 'game design' approach on the resulting play experience. In order to make a first exploration of this, a list is created containing in-depth descriptions of each design-related parameter that was used in the analysis scheme. These descriptions highlight elements such as immersion, motivation or fun, and additionally relate to the play experience in general. Each parameter is discussed separately to maintain a clear view of the layers constituting a game system. However, it is important to note that, in practice, most parameters will influence one another, as the design process should be considered as an exercise in balance whereby different content areas impact, inspire and communicate with one another.

Each description is divided into multiple segments. The first segment contains information on game design as described in the most influential references [62, 169, 170, 63]. Where necessary, a second segment is added to describe our own experiences in order to provide a better understanding of the parameter. Complementary, we refer to commercial games as examples. While these games are, to a certain extent, different from games for rehabilitation (e.g. patient requirements, available resources, etc.), we believe they can provide useful working examples of how the inclusion of these parameters can result in an immersive, motivating, or enjoyable experience. In the final segment, a description is provided of one or more reviewed publications that have successfully incorporated the corresponding parameter.

3.5.3.1 Input devices

Every digital game requires an input device to allow the player to communicate with the virtual world. On today's market, a wide variety of input devices are available. Some of the most popular controllers are those used for the Nintendo Wii, the Microsoft X-box 360 and the Sony PlayStation 3, in addition to the traditional keyboard and mouse, and touch-tablets (e.g. Apple iPad). Each of these devices use different interaction methods to facilitate the communication between the player and the game world, ranging from the traditional press of a button with a finger to the detection of full body movements. Each interfacing method requires a specific mapping procedure [63] to translate real world actions into virtual activity. Rouse [169] warns that obscure and illogical mappings can be particularly frustrating. A player wants to play, and not be preoccupied by the workings of the input device.

Based on our experience as game designers, it is possible that, dependent on the general game design goals, one specific interaction method will stand out as inherently more enjoyable than others. For example, in case one wants to create a game that simulates a specific motor skill, it is advised to employ gestures rather than pressing a button. Some interaction methods can best be combined with the mechanics of a specific game genre. For instance, sports games are very popular on the Nintendo Wii system, while first person shooters are more popular on other devices such as the Microsoft Xbox and the Sony PlayStation 3. In a number of the reviewed cases, a custom input device has been built, as opposed to the use of a trailed and tested commercial device. In these contexts it becomes very important to document and evaluate the relationship between those devices and specific types of gameplay: what types of games do or do not work very well in combination with this device? What possibilities does this device offer for innovative gaming interactions?

> *Use in games for rehabilitation:* Dimovska et al. [168] integrated a Nintendo Wii Balance Board in their system. Their game was inspired by the already proven concept of We Ski [175]. By doing this, their team has implicitly matched the input device to gameplay. Taylor et al. [174] developed a custom input device. One of the requirements they set forth, was to create "instant fun" [174, p. 54] as soon as the device is turned on. Furthermore, their device not only facilitates rehabilitation, but also supports the gameplay as the resulting games can be played with only two 'handles'.

3.5.3.2 Graphics

Most games depend on graphical images to present the game world. According to Crawford [170], the main reason to use 'good' graphics is to effectively communicate the game world to the player. Every image included in a game should have a well-defined function. For example, Crawford posits that the use of shadows can reveal the position of a player, and therefore contribute to the overall gameplay. Similarly, Rouse [169] claims that a characteristically bad design cannot be transformed into a good design by adding better graphics.

A game designer also has to decide on the visual style of the graphics, and use elements such as colors, brightness, or level of detail to build a specific atmosphere or visually convey an emotion. For example, bright and colorful images may induce positive feelings, while dark, shadowy graphics may suggest a sense of horror such as displayed in Figure 3.1. Once a visual style is chosen, the game designer has to ensure it is consistently applied throughout the game. A failure to do so can result in an unfinished look or a failure to create an authentic player experience. Canonical

Figure 3.1: indicating the dark and mystical atmosphere of Limbo resulting from its graphical style. (Image reproduced with the permission of the owners [148])

examples of digital games that make excellent use of visual style are Limbo [148] and Alan Wake [176].

> *Use in games for rehabilitation:* Vanden Abeele et al. [82] present the player with a consistent graphical style perpetuating the game's thematic content, namely a 'Kung Fu Kitchen'. The targets the player is supposed to hit, are ornamented with clear, red shapes, which explicitly communicate their importance in the gameplay. Vanacken et al. [173] present a game for rehabilitation that makes use of a clear and consistent graphical style which results in a finished look.

3.5.3.3 Challenge

Challenge is a key ingredient of every game as it directly influences the player's level of excitement. Salen and Zimmerman [62] point out that, based on Csikszentmihalyi's [64] theory of Flow, a well-balanced game can put the player in a state of deep concentration, during which his attention is fully absorbed, and his awareness of other tasks diminishes. To reach this state, the skills of the player are essential. If a game proves too difficult, the player will only experience frustration, and, conversely, when the game is too easy, boredom.

Different types of challenge can be implemented in a game [170], of which physical and mental challenges are two main forms [177]. We believe, as game designers, that no one form can be considered as superior over the other, and that both can introduce equally interesting experiences. Physical challenges have often been successfully combined with creative, exploration-based or arousal-driven play, while mental challenges have traditionally been related to tactical, puzzle-based or competitive play.

> *Use in games for rehabilitation:* Alunkus et al. [167] report that, initially, the games they had developed were causing the player to be bored, and related this to the concept of flow. In order to improve their application, during a later stage they developed a system that automatically adjusted the difficulty level, based on the player's performance. Vanden Abeele et al. [82] integrated a combination of physical and mental challenges to make their game appealing to a very diverse audience (in terms of physical and cognitive capabilities).

3.5.3.4 Audio (music and sound effects)

Music and sound effects carry the potential to enhance the sensory experience of playing a digital game, because compared to visuals, they add a more visceral and direct feeling to the game [63]. Audio can also be used to convey information that is essential to understand the gameplay [169]. For instance, in certain games the player can use the sound of footsteps to determine the position of another player. In fact, the output system of a game can consist entirely of sounds instead of graphics (e.g. Deep Sea [178] which creates an original, unique or particular experience. Finally, music can influence the mood of the player on a personal level [63] and, usually, in combination with visuals, add a compelling atmosphere to the game.

> *Use in games for rehabilitation:* Alunkus et al. [167] reported that the use of sounds was well appreciated among their test subjects. Sound effects were used in their game to mitigate the visual difficulties of some patients, and thus to augment the visual interface with an auditory one. Burke et al. [79] used different sounds to indicate when a player misses and hits a certain target. This was identified as an incentive for the player to perform better, and as a system of additional clues indicating whether or not the player was successful.

3.5.3.5 Narration (backstory and cut scenes)

A backstory adds depth to the story of a game because it provides the player with an overall context [62]. This creates a certain perspective from which the player experiences the game's main events. Although a backstory can enrich the content of a game, at any point the designer has to be aware this is only an added value [170]. Many games, including the highly popular Tetris [77], manage to appeal to a broad audience without making use of any narrative element.

Cut scenes are cinematic clips that do not allow the player to perform any actions. As a consequence, during the time of such a cut scene, the role of the player is very similar to that of the spectator of a film or television program. These clips often convey information about the backstory [169], but they can also be used to establish a certain mood, mark the transition between different parts of a game, provide feedback, maintain a certain rhythm or pacing, and reward the player [62]. Crawford [170] cautions that cut-scenes should not be considered as essential elements of the gameplay experience, as they do not live up to the interactive potential of games. Despite this observation, others have argued that cut scenes can contribute to the overall enjoyment derived from playing (e.g. Shell [63]).

> *Use in games for rehabilitation:* No publication in the presented analysis strongly incorporated a backstory or cut scenes. It is worth noting that Annema et al. [166] consciously avoided cut scenes, as they take up a significant amount of time in an already short therapy session.

3.5.3.6 Rules (tactical and free play)

Rules define the actions a player can or cannot perform and, according to some authors mark the very essence of the gameplay experience (e.g. [62]), as they have a significant impact on how the game is played and experienced. Based upon the nature of game rules, Callois [179] distinguished between two essential forms of play that have later been adapted to the area of digital games [180, 153]: ludus (tactical play) and paidea (free play). In tactical play, very strict rules are implemented to set up a well-defined goal for the player (e.g. the card game Solitary). In free play, open or emergent rules are used to establish a free, explorative or creative style of playing, whereby the player usually has the option to choose her own goals (e.g. The Sims 3 [181]). It is possible for both forms to coexist in one game. Within both types of play it is important that the rules are unambiguous and understandable, because confusion about the game goals might cause the player to become frustrated or lose interest [63].

> *Use in games for rehabilitation:* Free play was not strongly or very strongly applied in any of the reviewed publications. Tactical elements

have been more frequently used in games for physical rehabilitation, as most of the reviewed cases had applied a strict, predefined path for the player to follow. Vanden Abeele et al. [82] and Alankus et al. [167] included strategy and tactics as essential ingredients of gameplay.

3.5.3.7 Social play

Games can encourage social play by enabling multiple persons to visit the virtual world simultaneously. There are two immediate advantages associated with social play. First, social play allows for social interactions to be formed [169] based on competition, collaboration, meeting up, and the exploration of friends or the self [63]. As in real life, these in-game interactions can bring about diverse and complicated experiences, even within simple games [62]. Second, the decisions and actions of the player are given a more realistic feel when one's opponents or co-players are real persons instead of computer-generated characters [169]. This sense of realism is constructed through the complicated and often unpredictable behavior a person can offer. Examples of games that integrate social play as a key part of the gameplay are those included in Wii Sports [182] and Little Big Planet [183].

Use in games for rehabilitation: Vanacken et al. [173] integrated collaboration between a patient and a relative or therapist as a main feature of the gameplay. As such, their development team takes advantage of the engaging potential contained within the formation of the social interactions, and uses this to increase the motivation of their patients.

3.5.3.8 Reward system

The experience of playing a digital game is shaped by the game's system of reward (and punishment)[62]. Rewards communicate to the players how well they are doing and thus add to the motivational capacities of a game [63]. In order to accomplish this, it is important that the reward system is balanced correctly [170]. The value and timing of a reward are essential means to steer the player's experience in a desired direction. For instance, in the beginning of a game a significant reward can be given for simple tasks, whereas later on similar tasks cannot be rewarded to the same degree, as the game should not become too easy to master, and the game experience cannot be solely based upon repetition of identical rewards [169].

Use in games for rehabilitation: No publication in the presented analysis effectively incorporated a reward system to improve the play experience.

3.5.3.9 Meaningful play/choice

Playing a game largely consists of making choices [62]. However, not every type of choice is equally constructive to the overall gameplay. A choice has to be meaningful and make sense in relation to the game context, virtual world, game rules and reward system, in order for her actions matter [63]. If a player does not experience a sense of control, frustration or boredom might follow.

> *Use in games for rehabilitation:* In order to practically asses the construct of meaningful choice, we devised four separate categories: 'number of actions to choose from', 'the player's influence on the sequence of events', 'personalization of a character' and 'the player's influence on the outcome of the game'. All four categories were not used strongly or very strongly in any of the reviewed cases. It is worth noting that Burke, et al. [79] discussed meaningful play, but did not include a strong rationale for how it was integrated in their games.

3.6 Implications

The design of a game from a rehabilitation-centered perspective rarely exploits the full potential of design techniques to maximize the play experience. Therefore, a range of design parameters were considered which can contribute to improve the play experience of a game for physical rehabilitation. The descriptions of these parameters provided in the list above, indicate that the play experience in a digital game is influenced by a variety of elements. Consequently, a digital game should be understood as a collection of multiple layers which all contribute a distinct 'piece of experience' to the overall play experience in terms of immersion, motivation or fun. For instance, a motivating horror game with explorative features might contain a dark and shadowy visual style, free play and a reward system. When not taking the visual style into consideration, the game will presumably still be explorative (due to free play) and motivating (due to the reward system), yet, the horror atmosphere will be absent in the overall play experience. Thus, not taking into consideration one or more layers takes one 'piece of experience' out of the overall experience. This is especially important in light of the important layers (e.g. rules), of which the absence might too negatively impact the integrated gameplay. Furthermore, excluding less important layers (e.g. social play), removes the possibility of a motivating experience which goes beyond 'absolute necessity'.

It also becomes clear that the discussed parameters need to include specific requirements to effectively generate a desired experience (e.g. the choices of a player in a digital game need to be meaningful). The experience of immersion, motivation, or fun is thus not inherently contained in a digital game or in its different layers, because the implementation of a layer that is not well-considered may just as well deliver negative experiences such as frustration and boredom (see, for instance, the layer of ‘challenge’). Therefore, it is not only important to implement certain layers, as described in the previous paragraph, but also to shape them correctly. In order to do this, design-related knowledge of each parameter (such as is found in the previous section) is needed in order to profit from the opportunities of developing games for rehabilitation with an effective play experience.

The examples of the reviewed publications included in the descriptions, in combination with the results of the analysis scheme, show that, thus far, few cases have adopted an integrated design approach. As a consequence, it is possible that not all reviewed games have effectuated the holistic experience that characterizes good gameplay. However, some examples do show an interest in living up to the requirements associated with one or multiple design-related parameters.

3.7 Conclusion

The claim that games for physical rehabilitation have too often been developed from a rehabilitation-centered perspective is true to a certain degree. Whereas almost all of the selected cases strongly incorporated rehabilitation issues, a large amount did not strongly take into consideration any game design concern. However, a significant number of studies did demonstrate interest in certain aspects of the game designer’s perspective to improve immersion and motivation. Overall, ‘challenge’, ‘tactical gameplay’, ‘compelling graphics’ and ‘input devices’ were considered as important design concerns in a majority of cases. In a limited amount of cases, design elements like ‘social play’, ‘conflict’, ‘graphical quality’ and ‘audio feedback’ were also accounted for as key factors. Certain areas of game design have been largely neglected in the cases we evaluated: ‘narrative’, ‘freedom of choice, ‘free play’ and ‘establishing a link with the personal interest of the group’. Finally, in a majority of cases only one single aspect of game design was emphasized, as opposed to combining or integrating multiple elements.

While games for rehabilitation are by definition developed with the goal of rehabilitation in mind, the risk exists that they are negatively evaluated in terms of immersion, motivation or fun if not enough emphasis is put on design-related issues. This becomes apparent when the point of view of the game designer is investigated. Authors who have analyzed gameplay based upon their experience as designers, usually understand game design as an intricate process in which a combination of different layers results in a desired play experience. When certain layers are excluded or not accounted for during that process, the desired play experience may possibly not be effectuated. Similarly, in each separate layer a number of quality requirements need to be met in order for the layer to have a desired impact on the play experience. Even if further research is necessary to fully exploit the benefits of game design in the context of serious gaming, as outlined below, we do hope our current investigations and considerations will inspire serious game designers and developers in their future work.

In the next chapter, the design-related knowledge on rehabilitation games is further investigated in practice. Specifically, we will examine which preliminary game elements can or should guide the practical creation of a rehabilitation game style. In this investigation, we develop a rehabilitation game prototype that incorporates rehabilitation exercises and takes into account the capabilities of the specific target user group (e.g. persons with a disability).

Chapter 4

Deep Content in Rehabilitation Games: on Game Mechanics and Game Conventions

4.1 Introduction

The previous chapter revealed that digital games consist of different layers which act as a 'toolbox' for game designers, and described how this toolbox is applied according to the current literature on rehabilitation games. While this provided us with a clear outline of the literature on a theoretical level, our elaboration in the previous chapter did not show how such a toolbox can be used practically. The game designer's perspective in the current literature is still in its infancy and, as a result, our knowledge of the design methods and creative practices most appropriate for creating rehabilitation games is still limited. Nevertheless, in the general context of game-based learning (which has the similar overall goal of integrating learning and training content with game design elements), several scholars have posited that additional design knowledge is needed to develop relevant and engaging learning experiences [184, 185]. For instance, Van Eck [75, p. 18] points out that a marginalization of game design knowledge (as well as instructional design knowledge) often results in "boring games and drill-and-kill learning."

Currently, it is still unclear what form a rehabilitation game style should or can take, and preliminary elements should therefore be defined to practically guide and structure the formation of such a style in our subsequent design process (see also the notion of a primary generator ([186] described in [125] and [94]). Specifically, these elements support the integration of rehabilitation therapy and digital games in the following chapters of this dissertation. However, a clear understanding is first needed of the important features we wish to embody in those elements, which we believe can be found in the notion of "deep content" [187, p. 2043] in general game-based learning. Although such an understanding is vital in general educational games, few rehabilitation game authors have explicitly grounded and communicated their research according to this concept.

In line with methodology on design research (e.g. [92, 94, 96]) we create a generative digital game prototype [133], reflect on our own artistic practice and process, and use these insights to uncover the rationale underlying the design decisions we made. More specifically, we describe how physical rehabilitation characteristics were used as input for the creative process, aiming to support the exploration of game design practice in relation to motoric learning in our further research. First, we compare rehabilitation games with general learning games based on the works of Prensky [188], Gee [189] and Van Eck [75], and thereby shift the focus from creating 'fun' rehabilitation games to creating well-integrated rehabilitation games. Secondly, we discuss the relation between rehabilitation characteristics and digital games in current research. Lastly, we discuss the developed prototype and provide an overview of the design possibilities and limitations [134] found during the iterative process of prototyping. Afterwards, a discussion is provided on how this is relevant to the current research and the larger community of rehabilitation game research.

4.2 Deep content in educational and rehabilitation games

In this section, we first introduce the concept of 'deep content' in general educational games by providing a short overview of the literature on game-based learning. Afterwards, we identify this concept as valuable for current research on physical rehabilitation games.

4.2.1 Deep content in educational games

Physical rehabilitation games are a subclass of educational games in the larger field of game-based learning. Like other educational games, rehabilitation games are virtual play environments in which external learning and training goals are embedded (cfr. [190, 191]), be these of physical or cognitive nature. Yet, although educational game designers often strive to create 'fun' or motivating games, the surplus of resources on how to design fun in games testifies that this is particularly hard to achieve.

Learning and training games are an interesting topic of research because they support learning styles and experiences that are increasingly being used in today's society. Prensky [188] claimed that digital technologies have tremendously changed how past generations of children and young adults (which he refers to as 'digital natives') perceive the world. They have grown up playing digital games and are familiar with all sorts of innovative media offering fast, complex, and active access to information. As a consequence, digital natives have become skeptical of the old learning styles of previous generations (digital immigrants) and reject its slow, linear and passive form of learning. Thus, Prensky does not immediately refer to fun – although he does later on -, but recognizes in the first place that digital games possess the right qualities for a new type of learning. Similarly, Gee [189] identifies 36 qualities that transform digital games, when designed well, into highly effective and engaging learning environments. For example, Gee claims that games allow learners to freely explore learning content, and contextualize meanings through specific situations they encounter in game worlds. Both authors thus highlight what is often overlooked when the concept of fun is investigated: that digital games are, in the first place, the right medium for a specific type of learning through their formal qualities, such as game dynamics, mechanics and aesthetics [76]

The formal qualities of digital games can be more easily understood than the ambiguous concept of fun, and more clearly conceptualize the essential characteristics of learning games. Fun is by definition not the goal of learning games. Rather, fun needs to be created through the learning experience, and it is thus the close integration of fun and the learning experience that is of central importance. Van Eck [75] discusses how a disregard for either instructional design or game design during the development process creates bad learning games. He refers to the fact that games do not spontaneously provide a good integration of good learning and good game play. A lot of active effort is required of the designer to achieve this [192]. Therefore, instructional designers and game designers need to acknowledge one another's expertise and adapt their design procedures and knowledge accordingly [193]. In other words, it is only by intertwining the learning content and the formal qualities of games that learning can eventually become fun [194], and it is important that these efforts are supported by practical guidance on how to effectuate this [75].

Regarding the integration of the learning content and the formal qualities of digital games, Isbister, et al, [187, p. 2043] state that learning games need to contain "deep content". Deep content refers to content that is tightly connected to a game's structure, and can consequently be experienced as an integral part of the game (see Figure 4.1). If the content fails to connect to the game's structure, it will simply be experienced as separate from it as well as the play experience. As a result, the aim of creating more motivating learning content would fail as the content is simply presented alongside the game. Therefore, creating fun through learning primarily entails creating games in which the game concept resonates with the learning content it perpetuates [195].

The formal qualities of a game should therefore not be developed in isolation

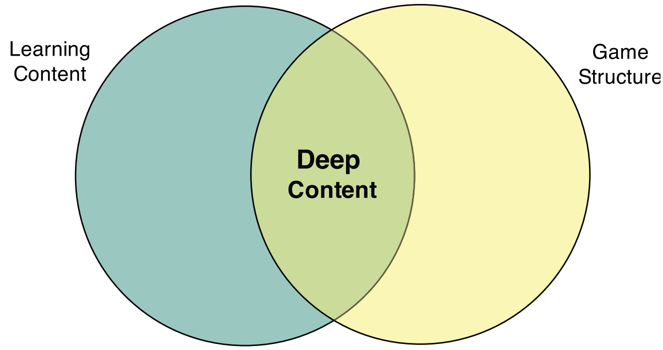

Figure 4.1: A graphical representation of deep content as a part of the learning content as well the game's structure. Adapted from[196, 194, 187, 197].

of the actual learning content. Rather, a reciprocal relation between such qualities and the learning content should be established, in which the game elements stimulate the progression of the rehabilitation therapy and vice versa. Else the game simply becomes a sugar coating for the learning [198]. Several authors have addressed similar concerns. For example, Van Staalduinen & de Freitas [197] developed a model wherein they link specific game elements, such as challenges, goals and objectives to existing pedagogical models. Similarly, Bellotti, et al. [199] explore how the level of interaction and the type of feedback used in games (both essential components of a game's design) can enhance both the game world and the educational strategy.

4.2.2 Deep content in rehabilitation games

Although physical rehabilitation games do not cover the same learning content compared to non-physical learning games, the idea of deep content, we believe, nevertheless remains of critical importance. Similar to learning games, one of the main goals of rehabilitation games is to generate a motivating learning or training experience (see Figure 4.2). However, if the content of the rehabilitation therapy is not connected to the structure of the game, it will be difficult for this content to become motivating through the play experience generated by that structure. Two prominent rehabilitation characteristics that could potentially be important in this respect are the physical rehabilitation exercises and the patients' disabilities.

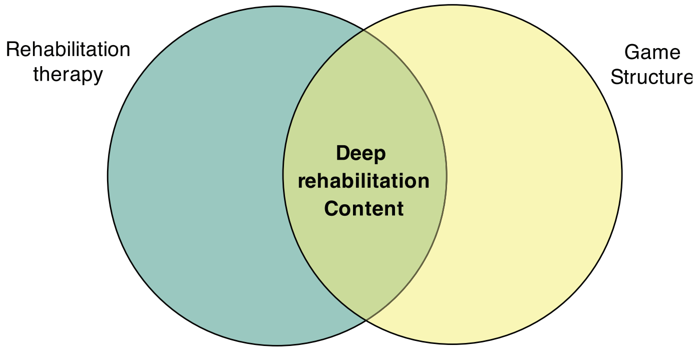

Figure 4.2: A graphical representation of deep rehabilitation content (see also Fig. 4.1)

4.2.3 Rehabilitation exercises

It is commonly agreed upon [49] that physical rehabilitation therapy is particularly effective when patients perform physical exercises repetitively and intensively. Similarly, digital games can often only be won when certain physical skills are repeatedly practiced in order to overcome the game's challenges. As a result, an opportunity lies within matching the formal qualities of physical rehabilitation games with the virtual environment for physical learning through these physical skills (cfr. [74]). As has been noted by Perry, et al. [74] and Rego, et al. [69], research on rehabilitation games often fails to meet these expectations, which has been supported by our analysis in Chapter 2.

Only a small amount of studies on games for rehabilitation were concerned with the close integration of rehabilitation and games, as most have rather highlighted only one of both topics. Many investigations aim to functionally improve the rehabilitation therapy through technology or to explore the technology's efficiency. This is the case, for example, with Betker, et al. [73] who investigated the practice volume and attention span during game-based therapy, as also is the case with Broeren, et al. [155] who addressed the general usefulness of a 3D-virtual environment as a rehabilitation tool for patients with cognitive and physical deficits. While both studies demonstrate that smaller, classical games could improve physical rehabilitation, they refrain to discuss how different game elements could support specific rehabilitation characteristics. In another case, Beursgens, et al. [200] developed a jacket that provides haptic feedback when patients perform undesirable, compensatory movements. While this is mainly a technological addition, they simultaneously also use a knife and fork as part of the input device, thereby stimulating task oriented-training. Furthermore, Annema et al. [166] defined several design features to facilitate the rehabilitation therapy itself, such as consciously avoiding cut scenes to take full advantage of short therapy sessions, thatgreatly improve the practical application of games in rehabilitation therapy. Other studies emphasize the game side of rehabilitation games. For instance, Alankus, et al. [167] identified the concept of flow and suggested adapting the difficulty levels based on the player's performance as a manner to relieve patients from boredom (see also [201]). Finally, Burke, et al. [79] introduced the concept of meaningful play and challenge from Salen & Zimmerman [62] to rehabilitation games. These are however, general design concerns that apply to virtually all games, and they offer little connection between the concepts of flow, meaningful play, and challenge and rehabilitation characteristics. As such no insight is offered on how the specific requirements of physical therapy can be integrated within tailor-made mechanics that intrinsically reflect the setup and purposes of physical rehabilitation exercises.

Though a large share of research does not address the issue of integrating game design with rehabilitation therapy, some make a first step in that direction. Noteworthy in this respect are the design patterns described by Goude, et al. [165], which link certain rehabilitation concepts such as "muscle weakness" to game concepts such as "right level of difficulty", aiming to bridge the language barrier that exists between rehabilitation therapists and game designers. Furthermore, hardware-oriented research often automatically integrates rehabilitation concerns and game concerns through the design of an input device. For example, some researchers [70, 72] created custom devices that literally connect the rehabilitation exercises with the virtual world. Others adapted existing devices in a similar manner, such as Dimovska et al. [168] who implicitly matched their Nintendo Wii Balance Board input/rehabilitation device to the commercial game concept of We Ski [175]. Only one study aimed to adapt the main concepts of the game design language (e.g. [62, 63, 169]) to the specific context of game design for rehabilitation. Vanacken et al. [173] integrated collaboration between a patient and a relative or therapist as a main feature of the gameplay by using the concept of social play as a direct motivator for patients to perform physical exercises

4.2.4 Patient disabilities

Rehabilitation games are similar to other learning games because they include an external learning purpose, yet at the same time also have the added dimension of patient disabilities. As discussed earlier, patients often suffer from impairments that prevent them from performing simple tasks in daily life. These can include cognitive (e.g. slow processing [41]), physical (e.g. reduced dexterity [37]) and visual (e.g. low vision [45]) impairments. Patients might be unable to play digital games because they are unable, for instance, to operate the hardware devices [66] or the game's interface [158]. Referring to the principle of deep content (cfr. above), we argue that, in order for a customized game play for rehabilitation to emerge, these impairments need to be incorporated as essential creative elements in design process, rather than as external goals that need to be achieved. This process of customization implies that designers of rehabilitation games cannot simply create adaptations of games that have proven successful in other contexts, but instead, should engage in experimenting with new game formats that are tailored to this specific context (cfr. [75]).

Research on rehabilitation games takes patient disabilities into account both on a level of hardware as well as on the level of software. As mentioned earlier, some design custom hardware devices which are custom made for a certain target audience, and often also their disabilities. For instance, Decker, et al. [80] uses straps on a Nintendo Wii controller so that patients do not need to hold it. While this offers patients the ability to play games, it does not address the issue of how, for example, their hardware device could be integrated with specific game characteristics for rehabilitation therapy. Also on the virtual level does research take the disabilities into account. For instance, Alunkus et al. [167] reported that the use of sounds was well appreciated among their test subjects. Sound effects were used in their game to mitigate the visual difficulties of some patients, and thus to augment the visual interface with an auditory one. Burke, et al. [79] used different sounds to indicate when a player misses and hits a certain target. This was identified as an incentive for the player to perform better, and as a system of additional clues indicating whether or not the player was successful. Both studies thus indicate that sound is a welcoming addition to rehabilitation games. However, they present sound as an additional layer on top of the game, and not so much as a connection between the game world and the rehabilitation therapy. Also, Notelaers, et al. [158] note that the game interface should be adapted to accommodate the patient disabilities by avoiding classical interface elements which cannot be used by patients with specific impairments. Here, the interface is also seen as an additional layer on top of the game which can easily be adapted, without necessarily taking into account the game play.

While the discussed research primarily directs itself towards a functional gain for rehabilitation in the virtual environment, Vanden Abeele, et al. [82] also incorporated, we believe, a direct gain for their gameplay. While their visual design style is directed towards making players see more easily, it is at the same time aesthetically pleasing, similar to the case of Notelaers, et al. [158]. However, in the case of Vanden Abeele, et al. the visuals simultaneously improve the functional for the rehabilitation therapy as well as the aesthetics in the game world, thereby forming a connection between the therapy and the game. Also, in the work of Jacobs, et al. [201], they left out game elements such as music and rich graphics to avoid cognitive overload. On the level of patient disabilities, there are thus some incentives to adapt the game world to the abilities of patients.

4.3 Research questions

In the previous section, deep content has been identified as an important goal for the design of physical rehabilitation games, both regarding rehabilitation characteristics of physical exercises and patient disabilities. In a first instance, it is the designer's task to align the qualities of the virtual play environment with these two characteristics. While there are some, although few, examples which cover either of these instances, they often lack the situational knowledge as described by Schön [92], Cross [94] and Frayling [96] in general design research (see also Chapter 2), which is needed to transfer their results into concrete practice. Therefore, in order to practically create a design style, we investigate how we can include the concept of deep content into a rehabilitation game. Accordingly, the following research questions have been formulated:

1. Which game design elements support the integration of physical rehabilitation exercises and rehabilitation games in order for deep content to emerge?

2. How do patient impairments influence the design process when aiming to create deep content in rehabilitation games?

4.4 Exploring deep content through the design of a digital game prototype

We have developed a generative digital game prototype (cfr. [133] on generative prototyping) in which the concept of rehabilitation exercises has been integrated and patient impairments have been taken into account. During the process of prototyping, which has been suggested as a valuable practice for the designer of rehabilitation games [74], the design was considered as an interaction or 'conversation' (cfr. Chapter 2) between the artist and the material of digital games which is considered an essential requirement of design research [92]. This interaction was intended to support the discovery of possibilities and constraints in the design space afforded by those materials [134] which could be used in the further development of our own rehabilitation game style. The design space (cfr. Chapter 2) contains many possibilities and constrains and is too big to explore exhaustively [98, 131]. Accordingly, the prototype was considered to expose some, but not all relevant features regarding the research questions. The chosen materials significantly influence which features will eventually be represented in that prototype [133], which is why we chose the game's code as our main material [103]. The code, when put into motion with a digital device, generates the interactive [62], ergodic [202] or gamic [203] dynamics of digital games that are essential for rehabilitation games and, thus, should be represented in the prototype.

4.4.1 Rehabilitation characteristics

As discussed in the previous sections, deep content necessitates a structural connection between the rehabilitation characteristics and digital game components. This project takes these characteristics as a starting point - as opposed to the game characteristics - because they are fixed and required for a rehabilitation therapy session to occur. In contrast, it matters less which game components are applied, provided that a rehabilitation therapy is ultimately presented in a pleasurable fashion. Thus, a first step was to outline the relevant rehabilitation characteristics: the physical exercises (RQ1) and patient disabilities (RQ2).

In 1, upper-limb rehabilitation therapy was characterized as containing physical exercises that are practiced in full or in part while focusing on one or more parameters such as strength and speed. In the first game prototype, the design approach of De Weyer, et al. [204] and Octavia, et al. [205] was followed in which several simple exercise goals are integrated, including the performance of horizontal, vertical and circular motions. These motions were not intended to represent a complete rehabilitation therapy session yet, but enabled us to experiment with simple exercises. Moreover, these exercises are basic components of more complex exercise goals, thus providing extensibility to a complete rehabilitation therapy in further research. Specifically, the parameters shown in Table 4.1 were included, resulting in exercise goals in which patients follow a trajectory, rather than, for instance, lift weights (strength) or steady their hand and arm (stabilizing). This allowed us to integrate common components of rehabilitation therapy, while limiting the design space and thereby focusing the design process.

Additionally, the real-life rehabilitation context was taken into account as is displayed in Table 4.2. For example, rehabilitation sessions typically last between 45 and 60 minutes, though the actual time to play the game will be five to ten minutes as exercises outside of the game have to be performed too. Furthermore, in practice these rehabilitation sessions are spread out over multiple weeks as patients need to rest and recover in between.

Lastly, a number of impairments were defined to be accounted for during the design process. First, the patients' reduced physical dexterity in the upper-limb (prevalence up to 38% in stroke [206] and 50% in MS [207]) to operate the game [37] was considered relevant as it may prevent the use of a game (e.g. to press a small in-game

	Planting a seed	Planting a flower	Coloring a flower
Physical parameters			
Free movement (2D)	-	-	-
Average precision	x	x	x
Accuracy	-	x	-
Cognitive Parameters			
Visual recognition	x	x	x
Hand-eye coordination	x	x	x
Creative thinking	x	x	x

Table 4.1: The physical and cognitive skills required to perform the main actions in the game.

button). Secondly, visual difficulties to perceive the virtual game world [45] were also included (prevalence up to 51% in stroke [208] and 34% in MS [209]. Because game worlds often have complex and detailed visual elements, they may be difficult to perceive (cfr. [158]). Finally, memory difficulties (prevalence up to 41% in stroke [210] and 27% in MS [211]), and cognitive processing (prevalence up to 50% in stroke [41] and 38% in MS [211]) problems to understand such a game world were also considered. Games often contain a wide array of complex elements which need to be recalled and processed, sometimes even after several days. While there exist other impairments , we believe that these are three of the most significant ones in relation to digital games.

Rehabilitation Exercises	Impairments	Contextual Factors
Horizontal motion	Reduced dexterity	Multiple sessions
Vertical motion	Visual difficulties	5 to 10 minutes of play time
Circular motion	Reduced memory	Sitting position
	Slow cognitive processing	
	Play with worse hand	
	No use of fingers	

Table 4.2: Rehabilitation therapy characteristics to be included or accounted for in the structure of the designed game.

4.4.2 Software and input devices

The Unity3D game engine version 3.X was used to develop the prototype using C# as the programming language as this allows for relatively fast and easy prototyping. The Novint Falcon[1] was selected as input device because of its simplicity of use and installation (making it also particularly valuable for prototyping purposes). The Novint Falcon allows patients to move their hand in three dimensions (x, y, and z) over a maximum range of 10 cm in each direction. While this range is relatively small, it sufficed for the purpose prototyping. The device also allows for haptic feedback, but this was eventually not used because the parameter of strength was not included within the rehabilitation characteristics. Based on the game's software design, the input device was open to be extended to similar devices such as a the HapticMaster[2], a touch screen or a computer mouse if desired.

4.4.3 Integrating the rehabilitation components into a digital game

The aim of the design process was to incorporate the previously defined rehabilitation characteristics into a digital game. First, at the start of this process, a creative brainstorm was held by the author in which these components were linked to virtual play environments. In total, three game concepts were formed, of which one was eventually chosen in a multidisciplinary team including computer scientists, rehabilitation scientists, a visual designer and digital game researchers, to develop into a working prototype. At that point these concepts were sufficiently general to allow for experimentation in later iterations, but already provided a general direction for the design of the game prototype.

In the first game concept, named Contraption, patients had to manipulate - by trial and error - a virtual contraption device. As is seen in Figure 4.3, this device contained different elements such as blocks, walls and springs that needed to be rotated or pushed in order to successfully move a ball towards the finish line . Specifically, the ball in the top left corner would drop down and deflect on each element depending on their position and rotation. By performing one of the three physical motions defined in Table 4.2 (illustrated with the dashed lines in Figure 4.4), patients could manipulate the elements until the goal was reached. In the second concept, Flowers, patients could design and nurture their own flowers and flower garden by applying the same motions, and plant these in a virtual community garden. For example, in Figure 4.4 patients could trace the horizontal dashed outline of the flower to let it blossom. Both of these concepts incorporated what Vanden Abeele, et al. [82] referred to as "Slow Fun" or, in other words, challenges that did not require rapid movements. In a final,

[1] http://www.novint.com/index.php/novintfalcon

[2] http://www.h3dapi.org/modules/mediawiki/index.php/MOOG_FCS_HapticMaster

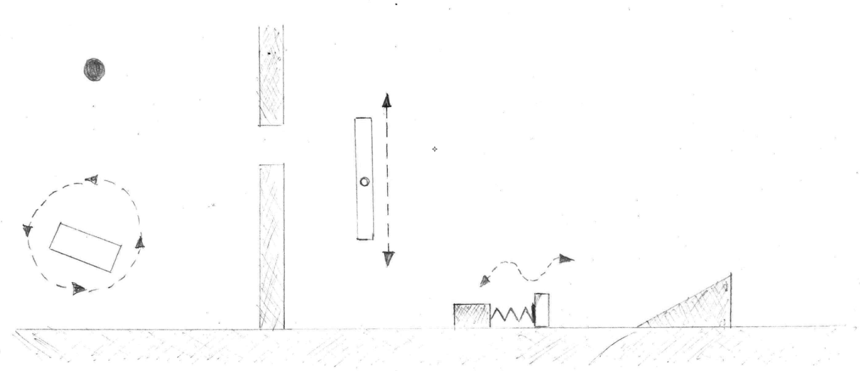

Figure 4.3: Original sketch of the game concept Contraption.

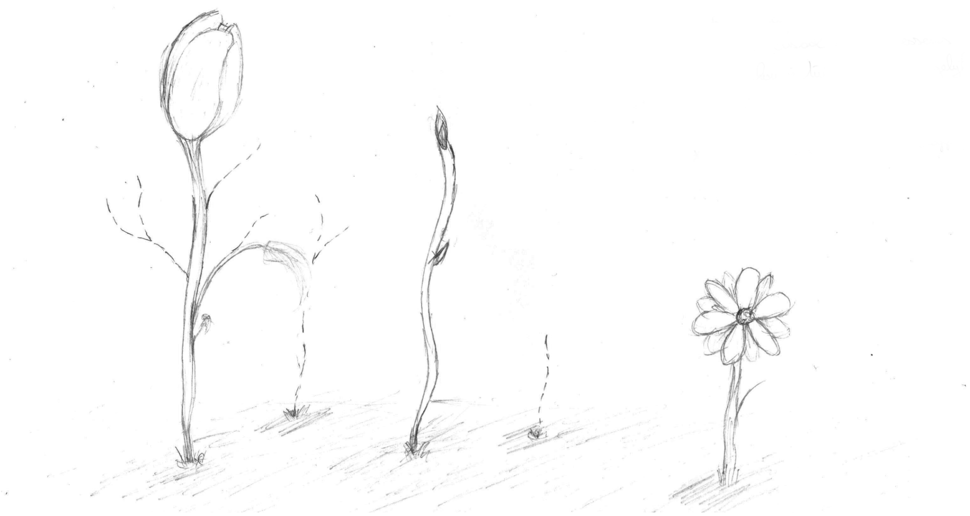

Figure 4.4: Original sketch of the game concept Flowers.

more general concept, players could play a shooter game involving different types of movements. Of these concepts Flowers was selected because it encouraged patients to be creative and stimulated interaction with other patients through the community garden.Because these are only concepts, it is difficult to find out which game would in actuality be received by patients. To remedy this, a more-user centered process could be integrated. However, the aim of this prototype was only to reveal preliminary elements for the further design process, and reception of patients was in this stage thus less important.

4.4.4 The game play of Flowers

In Flowers, patients grow and maintain flowers by performing simple rehabilitation exercises, and can later display these flowers in a community garden. The goal of the game is to be creative and keep the flowers as healthy as possible, which is directly affected by how well the predefined exercises are performed. Overall, players design flowers by executing four main virtual actions: planting seeds, growing plants, healing plants, and coloring flowers. In real-life, these actions translate to the motions defined in Table 4.2. For instance, in order to plant a seed and color a flower, players complete circular motions indicated by the dashed lines shown in Figure 4.5. These motions must be performed over a predefined distance and within a specific range from the lines. After players have planted a seed, a flower's blueprint appears on top of it. Again, the dashed lines indicate which motion trajectories players need to follow in order to effectively grow the flower. Yet, here the average precision of the player while tracing the line is taken into account and influences the health of the flower. The more precise, the healthier and greener the plant becomes and, conversely, the less precise, the sicker and redder the plant becomes. If players are not satisfied with their plant or its health, they can either regrow the entire plant or retrace only specific parts of the blueprint. Following Vanden Abeele, et al. [82], time dynamics were left out of the game, which makes the game easy to play, but also removes the possibility of time-based rehabilitation exercises.

Each time players perform a task, they receive visual, textual and acoustic feedback as well as points. They automatically collect the points in a progress bar, and can thereby unlock new levels which include new types of flowers, colors and even new virtual spaces to plant seeds. As players progress, the game gets more difficult to play as gradually less points are awarded (similar to when the same plants are retraced several times). Progression thus necessitates patients to grow bigger and more complex flowers or redraw them multiple times, and thus perform and repeat more difficult rehabilitation exercises. Technically, the shapes of the plants are loaded through an external XML file, meaning that therapists can easily modify the shapes to their desires if wanted, although a dedicated interface has not been developed for

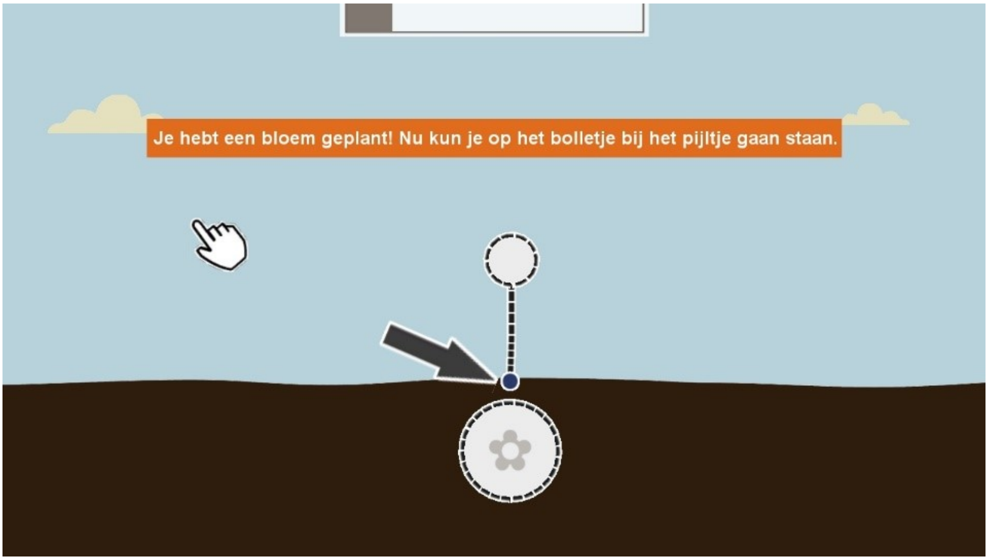

Figure 4.5: In-game screenshot of Flowers showing a seed, plant, flower and the tutorial system.

this.

The logic behind the prototype is introduced to players through a written tutorial system presented in the first level. This tutorial demonstrates how plants can be grown and that rewards can be earned by collecting points. Finally, the game automatically saves the created plants which can afterwards be displayed in a community garden on, for instance, a large TV-screen connected to a computer. A simple version of this garden was designed with sunrise and sunset animations to indicate the time of day.

4.5 Results

In the following section we describe several design features of the game prototype in relation to the concept of deep content. Specifically, we highlight the importance of game mechanics in the prototype according to Shell [63] and Hunicke, et al. [76], and discuss how genre conventions presented difficulties when taking into account patient disabilities.

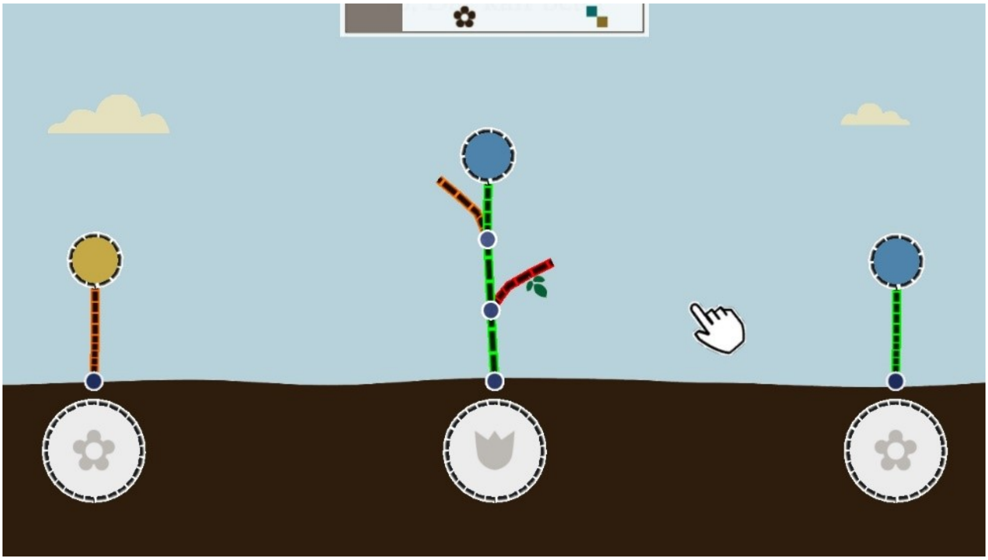

Figure 4.6: In-game Screenshot of Flowers with three seeds and two types of flowers.

4.5.1 Therapy exercises and game mechanics

The first research question posed in this chapter (RQ1) was how rehabilitation exercises can be tied to the internal structure of a digital game for deep content to emerge. Reflecting on Flowers, we argue that game mechanics [212] are a relevant link between the rehabilitation world and the virtual world, similar to the relevance of game mechanics in general educational games [213]. Game mechanics are the virtual methods performed by real-life players or virtual characters that have an effect on the game state [212]. For example, Flowers includes three main mechanics: planting seeds, growing/healing plants, and coloring flowers. In general game design, these mechanics are an essential component of digital games as they permit players to progress in a game.

As illustrated in Table 4.3, game mechanics possess six properties - actions, attributes, dynamics, rules, space, and skill/chance [63, 76] - that structurally connect the rehabilitation world to formal game elements. First, the rehabilitation motions (see Table 4.2) as well as their parameters (see Table 3.3) have been implemented in the game actions the player performs and, consequently, in the attributes of these actions. For instance, executing a horizontal motion in real-life represents growing a plant in the virtual environment. Correspondingly, how this motion is performed defines the value of the attributes. For example, the accuracy (parameter) with which a plants' blueprint is traced, determines the plants' health (attribute). The accuracy

	Game mechanics	Rehabilitation world	Game world
Physical components			
	Actions	Horizontal motion Vertical motion	Planting a flower Healing a flower
		Circular motion	Planting a seed Coloring a flower
	Attributes	Quality of motion	Flower's health Flower's type Flower's color
	Space	Motion trajectory	Seed shape Plant shape Flower shape
	Rules	Be precise while completing the trajectory	Make a healthy flower Grow a plant Color a flower
	Skills vs. chance	Adherence to a predefined trajectory	Ludus
Contextual components			
	Dynamics	Multiple sessions 5 to 10 minutes of play time	Short actions Repetition of actions

Table 4.3: An overview of how game mechanics link the rehabilitation world and the game world.

of tracing a seed regulates if a new type of flower is planted.

Similarly, the predefined contextual factors (see Table 4.2) are tied to the virtual world by the 'dynamics' of a game mechanic. For example, the game's 'growing' mechanic quickly results in a specific outcome (as opposed to, for instance, the building mechanics in Age of Empires [214] or Black & White [215] which take time), and thereby encourages a dynamic of short play time per rehabilitation session. At the same time, the game concept allows patients to perform exercises multiple times, thereby creating a repetition dynamic.

A closer investigation shows how game mechanics are also important on other levels. For instance, rehabilitation exercises are closely connected to the rules players follow when playing a game [212]. For instance, two types of rules are given for the main mechanics of planting seeds, growing/healing plants, and coloring flowers: rules directed towards the outcome and rules directed towards the trajectory (cfr. [216]). In the first case, for example when planting a seed, players need to trace the dashed lines and, regardless of how well (within a certain threshold) they perform the exercises, they receive a new flower blueprint. However, when growing a flower, players also need to trace the line, but the quality of the tracing directly effects a plant's health. On a fifth level, the rehabilitation exercises are demarcated by the shape of the seeds, plants, and flowers. Also, on a final level of skills/chance, the dashed lines represent the movements players need to perform, but at the same time impose constraints on the free play or paidia [153] of players, resulting in ludus. Players have to follow the defined pathway as closely as possible, and there is no room to deviate or do what they like themselves. Partial freedom was given to players in this regard as the shapes of flowers change and players can chose their own flowers. Another possibility would be, for example, that they could freely draw their own flower shapes, but then there would be no predefined pathways which clarify the exercises the player should do. Thus, in this prototype, there is a tradeoff between making players aware of specific exercises, and allowing them a degree of free play.

4.5.2 Patient impairments and the virtual world

The second question raised in this chapter (RQ2) was how patient impairments influence the design process of a rehabilitation game when aiming to create deep content. In Subsection 4.4.1, three of these impairments were defined. While attention was spent on taking these impairments into account, the prototype's game concept still includes unwanted elements of visual and gamic complexity which could not be removed as they were an essential part of the prototype's game genre. In Fundamentals of Game Design, Adams [177] describes various game genres and their specific individual features. Flowers is essentially a Tycoon game – or what Adams [177, p. 527] calls a "Construction and Management Game" – in which players progress by gradually earning and adding more virtual objects to a game world or model, such as RollerCoaster Tycoon 2 [150] or The Sims Social [217]. Although our prototype was not nearly as complex as either of these examples, we still experienced genre-specific problems with regards to the patient impairments, including the use of an inventory system[3] and navigating the virtual world.

An important part of Construction and Management games is the game's interface which needs to communicate the underlying game world to the player [177], which is often done through inventory systems. An inventory system is a virtual element that

[3] http://www.giantbomb.com/inventory/3015-513/

allows players to store and retrieve virtual items when appropriate, thereby avoiding the need to always have these items at hand (i.e. comparable to a real-life backpack). Such inventory systems contain many small, selectable items, which increase the visual complexity of the screen as well as the difficulty of the hand-eye coordination needed. In an attempt to resolve this, we integrated the inventory system into the planting of a seed, both visually and functionally. Each time players plant a new seed, a new icon appears in the center of the seed's circle (see Figure 4.6). Players can thus browse through the flowers automatically when planting a seed. Of course, this has the disadvantage that players are not able to see all the flowers at the same time, and the system would likely not be sustainable when more flowers would be added as it would be difficult to reach the right flower, especially for the patients that will use this game for neurorehabilitation. Additionally, if extra retrievable information is to be added (e.g. specific features of a plant), which is a common feature in the genre, the current system would not be optimal. A conventional inventory system would therefore be still one of the better solutions. Important to note is that rehabilitation games still need to include physical and/or cognitive challenges (see also [79]). However, we argue that these challenges should not be located in functional elements such as an interface in order to prevent user experience issues. Rather, these challenges should be located in the central actions (game mechanics) of a game (see the following chapters).

While the interface communicates the underlying variables of the game world, the virtual game world itself also needs to be visually communicated in the tycoon genre. In relation to possible visual and navigational difficulties of patients, the idea was to put everything on one screen so that players could easily get an overview of the screen and everything players created, without needing to navigate through the world (which is a complex activity). However, the idea of one screen did not match the concept of an endlessly expanding garden. There was only space for three plants to be simultaneously displayed before the screen design became too crowded. Therefore, some sort of side scrolling would be needed, or other measures such as leaving flowers out would have to be taken, opposing the initial idea of putting everything on one screen.

4.5.3 Other design considerations

Other smaller design considerations also emerged. During the design process, the social community garden was less relevant in terms of connecting the structures of rehabilitation therapy and digital games. Although it was an interesting idea, in this prototype it was neither essential for integrating rehabilitation exercises in the digital game, nor for taking into account patient impairments. This became apparent when the game design elements of the social community garden did not directly connect to the core mechanics of the game. In fact, the garden was more an extra type of feedback for patient instead of an element that could progress the game play. Also, on a different level, the abstract visualization of the plants allowed us to easily change the movement trajectory by changing the form of the plants. This was easily done by altering the plants' coordinates in an XML-file on which the shape of the plants is based. This was not obtrusive to the game concept, as there are many different shapes of plants in real life too. Thus, a lot of different rehabilitation exercises can be visualized with the idea of a plant.

4.6 Implications of deep content in rehabilitation games

The notion of deep content is reflected in the game's mechanics as they link the actions in the virtual play environment to the rehabilitation exercises in the real world on multiple levels. Game mechanics encompass several properties such as actions, attributes, and dynamics which, accordingly, mirror rehabilitation therapy features such as exercises, parameters and the situational context. The added value of game mechanics is that they represent concrete elements (e.g. a flower) and actions (e.g. growing a flower) in the game world, which stimulates the communication between game designers and non-designers (cfr. [76]) such as rehabilitation therapists. Therefore, we believe, game mechanics are an ideal starting point to practically design rehabilitation games which promote deep content.

Game mechanics are by definition a part of all rehabilitation games as they are an essential part of games in general [62, 63]. Hence, the value of these results does not reside in the identification of game mechanics per se, but in the fact that they connect the game's content to its formal characteristics. In this manner, the mechanics become practical tools with which game designers and rehabilitation therapists can bridge the gap between games and rehabilitation, similar to the idea of design patterns of Goude, et al. [165]. Designers and therapists can, for instance, investigate which mechanics they want to include to facilitate rehabilitation exercises, and more importantly, how to do this. The game concept presented in this prototype can serve as a first exploration and a source of inspiration for future designs.

Furthermore, game mechanics are an essential component of digital games and can easily be related to other rehabilitation game research as well. For example, Burke, et al.'s [79] analysis of Salen & Zimmerman's [62] meaningful play and challenge links to the effects and difficulty of the game mechanics. The slow dynamics of Vanden Abeele, et al. [82] are a direct result of how mechanics are incorporated in a certain game. The concept of flow [64] recognized by Alankus, et al. [167] in rehabilitation games links to the skill level used in game mechanics. For further information on game mechanics and other game concepts, we refer to the general works of Shell [63] and Hunicke, et al. [76].

In the developed prototype the virtual world and the interface were connected closely to the game's genre (see also Prensky [188]) on relating a game genre with learning content). Because we selected a certain genre in the beginning of the design process, unforeseen entertainment game conventions were unconsciously included in that prototype. Naturally, this may occur as the omnipresence of entertainment games influences our notion of what can and should be designed. Consequently, while the surface components (e.g. interface) can be adapted to patients, the deeper lying genre conventions which precede these components might be much harder to eliminate. Therefore, working with predefined concepts – which often originate from entertainment games - might be problematic for rehabilitation game design.

4.7 Conclusion

In this chapter, two questions were raised in relation to rehabilitation games and deep content. The first question was how rehabilitation exercises and the formal game qualities can be practically integrated in a rehabilitation game in order for deep content to emerge. A possible ground for this might lay in the concepts of game mechanics and game conventions. Game mechanics were an essential part of our game prototype and contained a number of practical design components such as actions, attributes, dynamics, rules, space, and skill/chance, and at the same time connect to essential parts of rehabilitation exercises such as actions, exercise parameters, and the situational context. Game mechanics thus offered us a conceptual tool to relate digital games and rehabilitation therapy together, while they at the same time offer a practical way to think about rehabilitation game design. Therefore, we believe they are a good starting point to further explore the concept of deep content in rehabilitation games. The second question we raised was how patient disabilities can be taken into account during the design of the formal game qualities of a rehabilitation game in order for deep content to emerge. In our own design, conventions of existing entertainment games unobtrusively slipped into our design concept of a rehabilitation game, as these games offered a large source of inspiration. However, these conventions could potentially conflict with the disabilities of patients. Consequently, caution should be taken that a certain rehabilitation game design concept does not include such conventions.

In the next chapter, a further exploration of game mechanics and avoiding unwanted conventions is presented. In this chapter, we have only identified that game mechanics connect the rehabilitation world with the game world through certain elements. However, we have not yet investigated how this practically affects the creation of a rehabilitation game style. Furthermore, while we recognized that unwanted game conventions can easily slip into the design process, it is not yet clear how this can be avoided. We will therefor additionally investigate the avoidance of such conventions as a vital part of a rehabilitation game style.

Chapter 5

Exploring the Concept of Abstract Minimalism in Relation to Physical Rehabilitation Games

5.1 Introduction

In the previous chapter, it was concluded that game mechanics and the avoidance of unforeseen game conventions are a relevant starting point for the development of a rehabilitation game style. On the one hand, we aimed to include a range of mechanics that connect the therapy exercises of the real world with the virtual actions of the game world. On the other hand, we simultaneously aimed to eliminate the unintentional inclusion of game design elements that conflict with the disabilities of patients. We believe that these two principles should be embodied in our rehabilitation game style. Therefore, this chapter aims to define and adopt a design approach that stresses both principles within the context of physical rehabilitation games.

The typical approach advocated in many textbooks on game design, according to which game elements are gradually added to a game concept (cfr. [218]) will be reversed. Instead, a design approach will be adopted based on the practice of reduction. Specifically, we will reduce the pictorial or fictional qualities as well as the quantity of game elements in order to reduce the cognitive and physical load that is imposed on players. To apply this design approach, a clear understanding is needed of the artistic methods of abstraction and minimalism in which the practice of reduction is systematically applied.

In this chapter, the development of an experimental game will be discussed in relation to the artistic process of abstract minimalism in order to embody the two above mentioned principles. First, an introduction to abstraction and minimalism is provided, both in a general artistic context and in a game design context. Further, two ontological perspectives on game design will be discussed in order to delineate the limitations and possibilities of the abstract minimalist approach. This allows us to construct our own version of the abstract minimalist approach through experimental design. Finally, the created game will be presented and discussed.

5.2 Abstraction and minimalism in art

5.2.1 Abstract art

Abstract art is an art style in which the pictorial features do not simply mimic the real world as perceived by the human eye, but in which these are rather regarded in their own right independent of such a world [219]. In this sense, abstraction is often considered as the opposite of the realist style (cfr. [220]), in which the real world is mimicked as perfectly as possible. Whereas the realist style often directly represents figurative elements such as humans, landscapes and architectural spaces, the abstract style removes or at least deforms these symbolic elements (cfr. [221]). Instead, the colors, lines, shapes, and materials that archetypally represent the elements, become in themselves the vital components of the work. Several notable abstract artworks are Wassily Kadinsky's Composition VIII, Kazimir Malevich's Supremus nr. 56, Pablo Picasso's Guernica, and Piet Mondriaan's Broadway Boogie-Woogie.

5.2.2 Minimalist art

Minimalist art is a style which is only completed when no more elements can be removed from a work in order to improve it [222]. In minimalist works, simplicity is often a central theme, and only few elements are present, such as uniform backgrounds and shapes. Furthermore, decorative details as well as expressive qualities are often avoided [223]. In minimalist painting, the painting itself is considered as a physical object with material qualities, rather than a pictorial depiction [224]. Thus, similar to abstract art, the colors, lines, shapes and materials become in themselves crucial components of minimalist artworks. Notable minimalist artworks are Barnett Newman's Who is Afraid of Red, Yellow and Blue, Frank Stella's The Marriage of Reason and Squator, and Donald Judd's Untitled.

5.2.3 Abstract minimalist art

Abstract and minimalist art are similar in a variety of fashions, and a number of artworks in these styles are often described according to either category. A prime example of such a work is Kazimir Malevich's White on White, in which a white square is painted on top of a white background. In the current project, abstract minimalism shall specifically be understood as a style in which symbolic meaning is largely removed and in which a minimal amount of game elements are used to achieve a desired player experience.

5.3 Abstraction and minimalism in digital games

Abstraction and minimalism have also been used within the context of digital games, although in a considerably less extensive fashion than in established artistic disciplines such as painting and sculpture. Games are often considered as an imitation of reality (cfr. [225, 226]), and more often than not they contain pictorial aspects that reflect reality. These aspects can serve aesthetic purposes, but can also guide players through the game world or support the narrative [177, 227]. Yet, Nørgård [228, p. 4] argues that games do not have to reflect the real world and can even be "completely void of symbolic [...] or icon elements." Tetris [77], for example, contains few figurative elements, but is nevertheless a highly playable and enjoyable game classic.

Juul [229] asserts that players primarily identify themselves with their own actions in a game, rather than with its visual and narrative features. For instance, people who play Tetris [77] comprehend the game by the effects of their actions (i.e. correctly or incorrectly positioning a game piece) and only secondary by the meanings of the game pieces. This is in line with Malliet's [230] observation that multiple levels of realism exist in a game, of which visual realism is only one level. Thus, following Juul, the players' actions and the related feedback are considered more important than the visual representation of the game world [228].

5.3.1 Abstract games

Juul [231, 227] provides a theoretical framework for abstraction in digital games. He states that all games comprise two complementary components: rules and fiction. First, the rules of a games dictate which actions players are allowed to perform and, in return, how the games respond to those actions. Second, the fiction of the games refers to the thematic and figurative qualities exteriorizing those rules. When no fictional representation is available to clarify the rules of a game, it is entirely abstract. Conversely, when no rules are implemented into the fiction of a game, it is to no degree abstract and players will have no control over it (i.e. comparable to watching a film).

This is related to Salen & Zimmerman's [62] notion of a game's formal identity. They state that the formal identity of a certain game resides in its rules, i.e. the elements that remain when all visuals and experiential levels are removed. For example,

Characteristics of a minimalist game
Have a small set of rules.
Contain only few micro-mechanics and possibly only one (macro) core mechanic.
May have tightly coupled elements and/or (sub)systems.
Have simple, easy to use controls that blend with the underlying systems.
Are systemically and visually abstract.
Have a low perceived complexity but (possibly) deep systemic complexity.

Table 5.1: Characteristics of a minimalist game according to Nealen, et al. [233]

the game Mario Bros [232] may show an Italian plumber battling enemy turtles and other creatures to save a princess. Yet, the rules remain the same (e.g. jump on top of the enemies to defeat them, move to the right to reach the end point, etc.) regardless of whether or not the plumber is represented as Italian or the enemies as turtles.

5.3.2 Minimalist games

Nealen, et al. [233] describe how digital games can be considered as minimalist when they contain a range of different features (see Table 5.1). Overall, these features are determined by the simplicity of the digital game world or by how many elements and how much complexity are used. According to Nealen, et al., minimalist games preferably provide an elaborate and compelling play experience, though it is always a balancing act between providing such an experience and using only few non-complex elements. Nealen, et al. consider, for instance, the digital games Osmos [234] and The Marriage [235] minimalistic.

5.3.3 Abstract minimalist games

As described in Subsection 5.2.3 within the context of established arts such as painting, abstraction and minimalism can practically be combined with one another. Yet, an abstract game is not automatically the same as a simple game [236], as both can contain different types of rules, mechanics and virtual objects. On the other hand, as Nealen, et al. [233] indicate, minimalism often does imply a form of abstraction. In Figure 5.1 abstraction and minimalism are illustrated on a single graph, with Call of Duty: Modern Warfare [237] as an extremely complex and fictional game, and Tetris

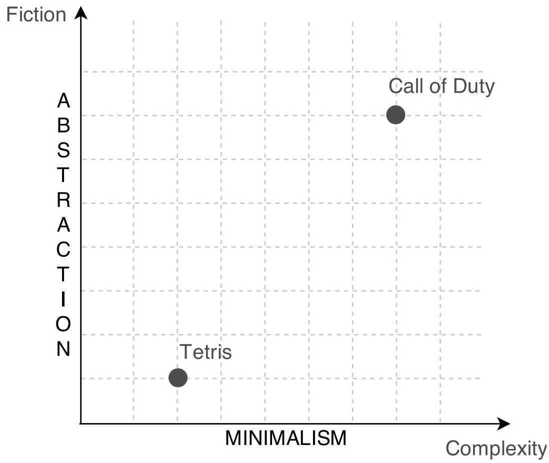

Figure 5.1: A graph indicating the relation between abstraction and minimalism.

[77] as a fairly simple, abstract game.

5.4 Essentialism vs. holism: considerations for an abstract minimalist style

In the previous sections, abstract minimalism was described as a game style in which the figurative qualities of a game and mechanics are reduced. Before applying this style in practice, it is important to discuss two opposing views on game design to contextualize this style.

5.4.1 An essentialist view of digital games

In the essentialist view, digital games are regarded as containing only a few fundamental game elements, while all other elements are essentially superfluous [238]. This way of understanding games has inspired many theorists to elaborate a definition of digital games based on their specific characteristics (see Table 5.2). The objective of these definitions is to explain what games are by examining the fundamental components shared by all games, such as rules [62, 239], a feedback system [240], or interactive fiction [241, 242]. This has resulted in a highly fragmented and diverse body of definitions [243, 239]. Most of these definitions can be considered as interpretations of the importance of one or more specific game components to the player experience, whereas an objective reflection on the interplay between these components is often absent [228].

Author	Definition
Salen & Zimmerman [62, p. 80]	A game is a system in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome.
Juul[239]	A game is a rule-based formal system with a variable and quantifiable outcome, where different outcomes are assigned different values, the player exerts effort in order to influence the outcome, the player feels attached to the outcome, and the consequences of the activity are optional and negotiable.
Tavinor [242, p. 26]	X is a video game if it is an artifact in a visual digital medium, is intended as an object of entertainment, and is intended to provide such entertainment through the employment of one or both of the following modes of engagement; rule and objective gameplay or interactive fiction.
Koster [244, p. 46]	The definition of a good game is therefore ‘one that teaches everything it has to offer before the player stops playing.
Adams [177, p. 3]	A game is a type of play activity, conducted in the context of a pretended reality, in which participant(s) try to achieve at least one arbitrary, nontrivial goal by acting in accordance with rules.
Jane McGonigal [240, p. 20]	Describes games according to four traits: Goal, rules, feedback system, voluntary participation. (no quatation)
Neitzel [245, p. 284]	A game activity or gaming is a rule-governed activity guided by the intention to win.
Schell [63, p. 47]	A game is a problem-solving activity, approached with a playful attitude.

Table 5.2: An overview of the different definitions for digital games (literal quotations unless stated otherwise)

In the essentialist view, digital games, including games for physical rehabilitation, are often described in an atomistic fashion. Many game design theorists and practitioners have a tendency to subdivide digital games into smaller individual elements. In 3, a variety of such elements have been described in detail. There is a strong advantage associated with this atomistic approach. It enables game designers and researchers to study specific parts of games individually and how they align with the exercise and patient characteristics, without being lost in the overall complexity a digital game often has. As such it can be considered a logical first step in theory building that has intensively been applied to the investigation rehabilitation games. Nevertheless there is also a disadvantage associated with this modular approach. It fails to take into account the context and interplay between the wide range of elements. For instance, Alankus, et al. [167] state that graphical elements are important parts of the content of rehabilitation games, yet do not clarify which types of graphics this applies to, or how graphical components can be integrated with other game play elements. Similarly, Burke, et al. [246] argue that challenge is a vital component in rehabilitation games, but do not take into account how this relates to other game elements.

5.4.2 A holistic view of digital games

Opposed to the essentialist conceptualization of digital games is the holistic view. This view holds that a game should be conceived according to the totality of what players perceive, hear and feel [247]. While often neglected in favor of an essentialist view, in general theory and practice on game design it is explicitly stated (cfr. [170, p. 61][63, p. 46]) that all individual components of a game should be considered in relation to one another, and to the entire play experience. Players do not experience components such as mechanics, rules, and visuals as separate elements [212]. Rather, the act of play unites these elements into a single whole, which is more than just the sum of all individual elements [247]. Therefore, if designers focus their attention solely upon individual elements, this would result in a loss of meaning. Consequently, a single definition of digital games that only reflects a small amount of 'essential' elements would not be able to adequately reflect the particular characteristics of a singular game [243, 242].

5.5 Research question

In the first section of this chapter we introduced the concept of an abstract minimalist style as applied within established art disciplines such as painting and sculpture. This introduction highlighted the style's focus on the reduction of the pictorial qualities and the amount of elements that are portrayed. Following this, the abstract minimalist style was discussed specifically in the context of game design, where the concept of reduction is also present. Additionally, two contrasting views on game design were presented to contextualize the process of reduction.

We believe that the development of an abstract minimalist style can be particularly relevant to rehabilitation games. As stated in section 5.1, the aim of this chapter is to include context-specific game mechanics in physical rehabilitation games, but to avoid the unintentional inclusion of game design elements that conflict with the disabilities of patients. Due to its reductive qualities, the application of an abstract minimalist style can be particularly useful in avoiding such elements. While abstraction and minimalism have implicitly been included in rehabilitation games that are adaptations of traditional games such as Pong and Whack-a-Mole, they have not yet been explicitly investigated as such. Thus, a deeper investigation of abstract minimalist rehabilitation games can improve our understanding of rehabilitation games. In the following sections, we describe the design process of an abstract minimalist game form physical rehabilitation games guided by the research question:

1. How can an abstract minimalist rehabilitation game be developed to avoid the inclusion of unwanted game design elements, by using game mechanics as tools?

5.6 Selected rehabilitation exercises and input devices

In the first game prototype (see Chapter 4), rehabilitation exercises were represented by horizontal, vertical, and circular motions. These exercises resulted in three game mechanics in which players trace virtual lines in order to progress in the prototype. In the current design experiment, these virtual lines are implemented again for their visual and conceptual simplicity of representing real-life motions. The contextual factors of the previous prototype are also maintained. However, the input device is changed to the HapticMaster[1] which allows for more freedom of movement. While the previously implemented Falcon input device only has a range of 10x10x10cm, the HapticMaster has a larger range of 40x40x40cm (1.3ft). The HapticMaster also provides force feedback, which will be further explored in 6. Finally, as the same software implementation is used as in 4, the input device may therefore be extended towards the Falcon, a touch screen or computer mouse.

[1] http://www.h3dapi.org/modules/mediawiki/index.php/MOOG_FCS_HapticMaster

5.7 The abstract minimalist design process

As there is no predefined method available for the abstraction and minimalization of entertainment games or rehabilitation games, it is necessary to describe in detail the design process we followed. Specifically, we applied an experimental design approach. Experimental design denotes the act of designing games with the primary intention of creating novel game forms that challenge current game conventions and traditions[2]. Compared to general game design, experimental game design puts considerably less attention on the design of a pleasurable play experience – though this is not excluded entirely. Instead, it emphasizes the discovery of new design possibilities which might generate novel game forms [248]. Examples of experimental games are Braid [249] and The Marriage [235].

The experimental game design approach usually differs from established design methods such as MDA [76] because the creative ideas of experimental designers are often too ambiguous to be captured within a straight-forward paradigm. For example, Robin Arnott stated [250, p. 29] that he created the experimental audio game Deep Sea [178] because he wanted to explore an idea which felt "radical and new". Similarly, Keita Takahashi stated [251, p. 91] that during the design process of the popular game Katamari Damacy [252], he aimed to "make something you could only do in a game". These examples, which are not isolated cases (cfr. [253, 254]), indicate that experimental designers aim to create novel artefacts, regardless of the methods used to achieve this. Experimental game design, thus, refers to the unrestricted exploration of the possibilities of games. In the current project, this is applied to the exploration of the abstract minimalist style in physical rehabilitation games, by using game mechanics as tools.

In order to design a physical rehabilitation game with an abstract minimalist style that includes game mechanics, we selected one existing game and reduced its pictorial qualities as well as the quantity of its game elements (see Section 5.3). By starting from an existing, non-abstract minimalist game, we aimed to first consider the game as a whole, and then gradually deconstruct the game towards its abstract minimalist identity. In this manner, we hoped to avoid proceeding according to a too atomistic design process. The design process is divided into seven steps (see below). The first three steps contain an analysis of the selected game (Quake Live [147]) in order to define its formal space. In the final four steps, a novel game artefact is developed based on this analysis.

1. Selecting a game: Quake Live;

2. Identifying the core game mechanics of the game;

[2] See also http://www.experimental-gameplay.org/?page_id=2

3. Defining the game's formal identity based on these game mechanics;
4. Abstracting figurative aspects according to the formal identity;
5. Abstracting the spatial dimensions according to the formal identity;
6. Integrating each selected game mechanic into a consistent whole.

The game is designed to be played with a HapticMaster input device. This device allows players to move the screen cursor by moving their arm in three dimensions (x, y, z) within a range of approximately 40cm (1.3ft). Additionally, the device can provide force feedback which will be further explored in 6.

5.7.1 Selecting a particular game: Quake Live

The popular 3D first-person shooter game Quake Live [147] was chosen as a case to abstract and minimalize. This game was selected because it provides a kinesthetic immersive experience, for which it has been recognized and applauded frequently [255, 151]. The experience results from a frantic gameplay, in which players are required to move both hands extremely quickly. Specifically, players need to possess fast reaction speeds and excellent aiming accuracy in order to navigate the 3D virtual environment and gain points by shooting opponents. As the kinesthetic immersion of Quake Live provides an enjoyable experience, we believe it can offer an appropriate challenge for a rehabilitation therapy.

In order to overcome the challenges and win the game, players continuously need to maneuver both of their hands with a specific purpose. For instance, if they want to walk around in the virtual environment, they need to interchangeably press up to six different keyboard keys, while moving and clicking with the computer mouse. The combination of many different in-game actions warrants that players are constantly acting with their hands. Similarly, in upper-limb rehabilitation, patients need to perform a range of physical exercises with their hands in order to successfully complete a rehabilitation session. Therefore, the game play type in Quake Live generally aligns with the motoric challenges in rehabilitation therapy (cfr. [256]). If we can succeed in aligning the requirements to complete Quake Live with the requirements to complete a rehabilitation therapy, significant progress can be made in the design of games for rehabilitation.

5.7.2 Identifying the core game mechanics

In the next step, a small set of core game mechanics (cfr. section 4.5.1 on game mechanics) was identified, while less important ones were excluded in order to minimalize the game [233]. We follow Sicart's definition of core game mechanics, stating

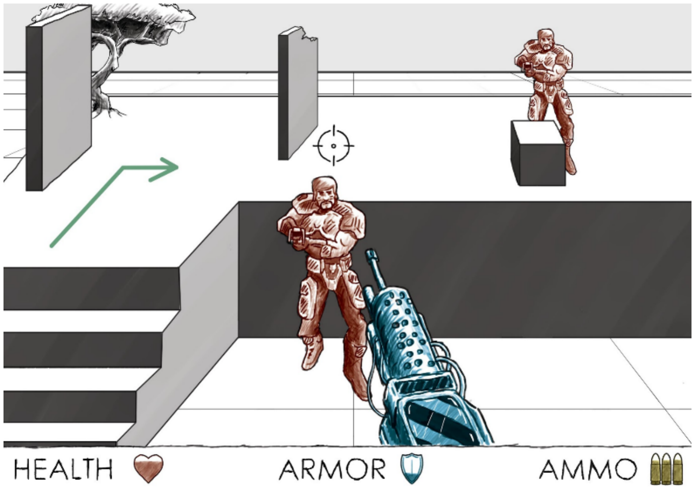

Figure 5.2: A 3D representation of the attacking and retreating mechanic.

[257, no page] that they are “the game mechanics (repeatedly) used by agents to achieve a systemically rewarded end-game state.” In other words, the core mechanics are the mechanics that directly and significantly contribute to winning a game, although no objective benchmark exists to identify these mechanics [212]. For example, the mechanic of walking is often important to win a first person shooter game, but players can also win by continuously standing still (camping) in the same spot. Therefore, the identification of core mechanics we present below should be considered as partly subjective, based on 5+ hours of Quake Live play time in Clan Arena Mode. The mechanics we observed as essential to win the game were: attacking and retreating, aiming and shooting, and navigating.

5.7.2.1 Attacking and retreating

In Quake Live players advance towards opponents in a 3D environment in order to shoot them and gain points. Simultaneously, players run the risk of being hit themselves while doing this, as they need to expose themselves first in order to take a shot. Therefore, it is important that players find a balance between attacking and retreating. We consider both mechanics as essential to the game experience, because the acts of attacking and retrieving provide tension and suspense.

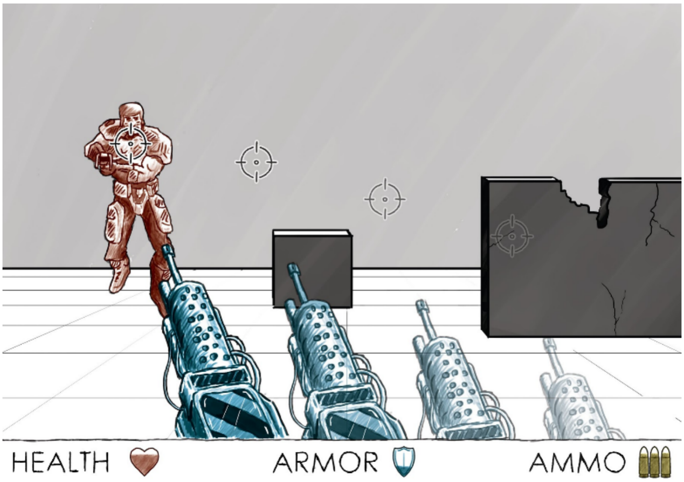

Figure 5.3: A 3D representation of the aiming and shooting mechanic.

5.7.2.2 Aiming and shooting

When players attack, they simultaneously need to aim and shoot to be able to hit their opponents. Players first aim their gun by spatially directing it towards the opponents, and subsequently evaluate which is the ideal moment to pull the trigger. If players pull too fast or too slow, they will miss the opponents.

5.7.2.3 Navigating

In Quake Live, players navigate through 3D spaces in order to find and attack opponents. As such, they have to actively search in buildings and rooms to see where others are hiding. More advanced players are able to predict, to a certain degree, where the opponents are located by analyzing their movement patterns. We consider this an important characteristic because it allows players to feel part of a spatially bigger game world.

5.7.3 Defining the formal identity of the selected mechanics.

In the third step we established the formal identity of Quake Live based on its core mechanics. As stated above, the formal identity of a game is the basic rule-system that remains when all redundant elements are excluded. As such we deconstructed the five selected core mechanics according to the most basic rule-system we could formulate. This resulted in the following descriptions:

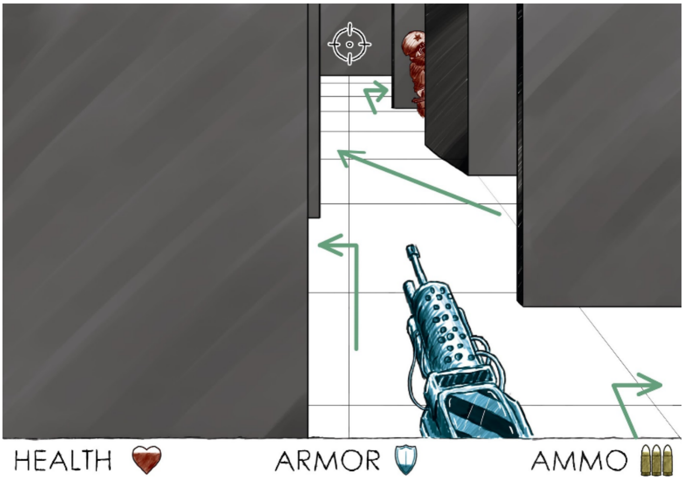

Figure 5.4: A 3D representation of the navigating mechanic.

5.7.3.1 Attacking and retreating

1. The player needs to move on the ground towards the opponent;
2. The player dies and loses a point when an opponent hits him;
3. The player may move away from the opponent during an attack.

5.7.3.2 Aiming and shooting

1. The player needs to visually superimpose (aim) their cross hair on an opponent;
2. The player needs to choose when to effectively release a shot;
3. The player earns a point when they hit an opponent;
4. The player can perform these actions while attacking;

5.7.3.3 Navigating

1. Opponents must be able to tactically hide themselves in the space of the virtual world;
2. The player must navigate the space in order to find and attack the opponents.
3. How the player navigates, effects the outcome of the attack.

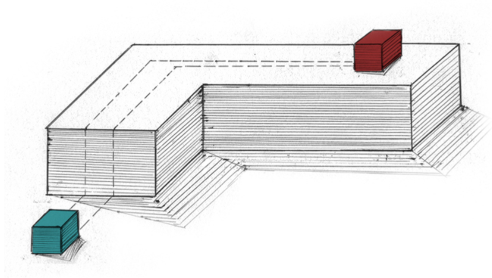

Figure 5.5: The game mechanics attacking and retreating after a reduction of their figurative qualities.

5.7.4 Creating the abstract minimalist game world

In the previous steps, we have defined and analyzed the game concept of Quake Live. Based on this analysis, a formal identity of Quake Live has been defined. In the following sections, this formal identity will be used to practically create an abstract minimalist game.

5.7.4.1 Attacking and retreating

Reducing the figurative qualities of the core mechanics In the first step, the figurative qualities of the game's core mechanics were reduced. This was done by removing the virtual objects and attributes [63] that were not described in the formal identity. For instance, in the mechanics of attacking an retreating, only the player, the opponent and the ground were selected. The rest of the virtual components were dismissed, such as trees, the sky, and textures on walls. The resulting game world is illustrated in Figure 5.5. The blue cube represents the player-character, yet its particular shape, colors, and other details have not been included as they were not included in the formal identity of the game. Similarly, the opponent is represented by the red cube. Though the real version of Quake Live integrates guns and bullets, these were considered as an extension of the player-character's and opponents' virtual bodies. Thus, whereas typically in shooting games the player is hit with bullets, in the abstract version the opponent has to be touched instead. Finally, the dashed lines represent the acts of running towards and running away from the opponent.

An abstraction of the spatial dimensions of the attacking and treating After having removed the undefined figurative qualities of the original Quake Live game, we made an abstraction of the actions contained within the mechanics in terms of their spatial dimensions. As illustrated in Figure 5.5, the player has to jump on the

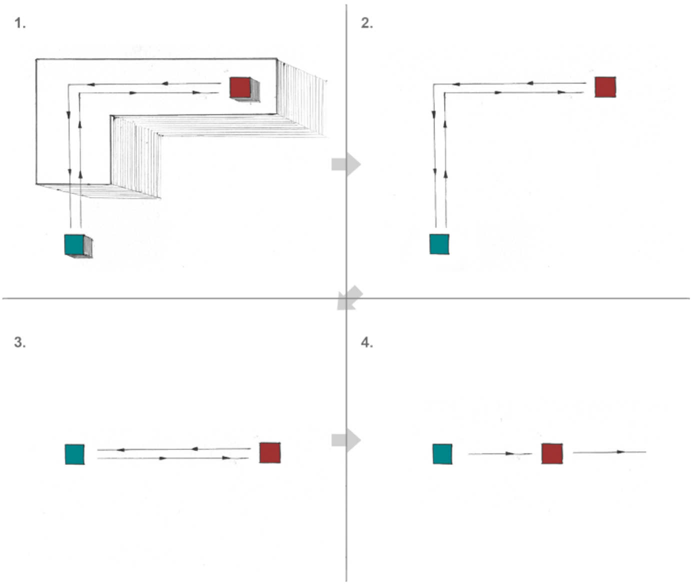

Figure 5.6: An abstraction of the attacking and retreating game mechanics their spatial dimensions.

block, turn to the right (i.e. advance, aim and hit) in order to hit the opponent, and then repeat these actions in reverse (i.e. withdraw). As illustrated in Figure 5.6, after a subsequent phase of abstraction, the 3D space was transformed into a 2D space with a switch from a first-person perspective to a top-down perspective. Following this, the movement trajectories of the player-character were further broken down, with a removal of the ability to navigate on the same spatial axis as the opponent. Additionally, the direction of the player-character's movement was constrained to the right, as seen in Figure 5.6 in the fourth quadrant. In real-life, the player moves the play-character by dragging the blue square along the lines with the HapticMaster input device.

Adapting the attacking and retreating mechanics In the next step, the mechanic was adapted to enable players to move past the opponent. In the previous step, the spatial dimensions and direction of the player-character were reduced in a manner that made it impossible to pass an opponent. As this restrained the player to retreat (an essential component of the formal identity), the behavior of the opponent cube was modified: we added a rule stating that the opponent continuously moves up and down (see Figure 5.7). As such players have the ability to navigate underneath it and retreat behind it to the right, as is also possible in the Quake Live game. Additionally

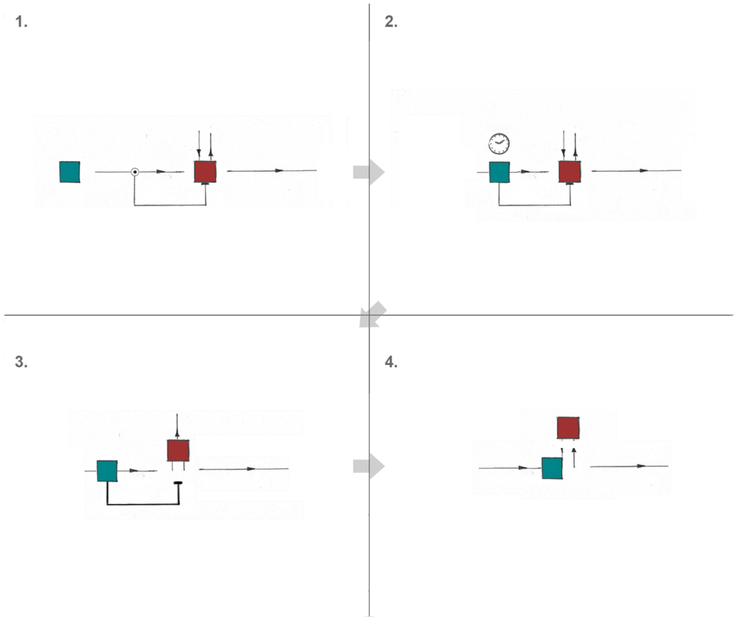

Figure 5.7: An adaptation of the attacking and retreating mechanics with timing and a pressure button.

a timing feature was added. Because fast responses can be problematic for patients [82], a pressure button was included (cfr. The circle with black dot in the middle on the left line, Figure 5.7, first quadrant) which triggers the movement of the opponent's cube when the player-character navigates over it. Patients can thus decide for themselves when to cross the cube by choosing the trigger moment, and prepare themselves for the action according to their own pace. This ties in to the observation of Pitaru [67] who literally slows down a commercial game in order to enable patients with specific disabilities to play it. However, in the presented case, the structure of the game environment itself is slowed down in its concept by removing elements that require speed, instead of slowing it down afterwards. Only the main mechanic requires speed, but this is in itself is slowed down by giving patients the time to decide when they make the action instead reacting to the game.To still make the mechanic unpredictable [63] a small delay was added between the trigger and the movement – both upwards and downwards - so that each time this mechanic is used, different time settings can be implemented.

Reconceptualizing the attacking retreating mechanics according to their behavior Finally, the above mechanics were visually simplified. The timing and movement behavior of the red square were transformed into a rectangle that is continuously expanding and contracting, as indicated in Figure 5.8. The left column illustrates the movement of the red cube as it goes up and down with timed intervals. In the right column, an almost identical behavior is shown although it is mapped on top of the rectangle form (indicated with dashed lines) which represents the artificial intelligence of the red cube. As a result, the temporal intervals in the left column are transformed into spatial relations in the right column (see Figure 5.8, quadrants two and five), making the mechanics visually more explicit.

This enabled us to implement the behavior of the red cube according to a circular motion, projected on a curved line. In Figure 5.9, this motion is indicated by the red line. In the resulting mechanic, players have to move towards the opponent (red cube), use timing skills to avoid touching it, and eventually retreat.

5.7.4.2 Aiming and shooting

Reducing the figurative qualities of the core mechanics In a similar manner the figurative qualities of the aiming and shooting mechanics were reduced, with a removal of the objects and attributes not included in the formal identity. The game world constructed in the previous steps was used as a foundation for the reinterpretation of the aiming and shooting mechanics. In this respect, repeating the abstraction of the spatial dimensions was unnecessary, and the act of moving over the straight line was instead incorporated. In a first instance, this resulted in the game world displayed in Figure 5.10. The player (changed to a circle in order to visually differentiate it from the opponents) is placed between black red rectangles that move to the right. These rectangles should not be touched. Consequently, the player has to move along with the two rectangles and constantly aim or stay between them. To make this more challenging, a second gray circle was added to the player-character that the player needs to push to control the blue circle. Furthermore, according to the formal identity, players need to be able to score a point by hitting the opponent. However, the player-character cannot touch the opponent's red cube itself (see the attacking and retreating mechanics above). Therefore, we added a star right in front of the player which could be picked up to earn a point. When the player-character reaches the endpoint (the small blue dot on the right), the cubes automatically disappear.

Adapting the mechanic In a later instance, the player character (the blue circle with the grey circle as a tail) was placed outside of the two black rectangles. The grey horizontal rectangles in Figure 5.11 were added to dynamically vary the distance between the two black rectangles. For instance, the horizontal rectangles gradually

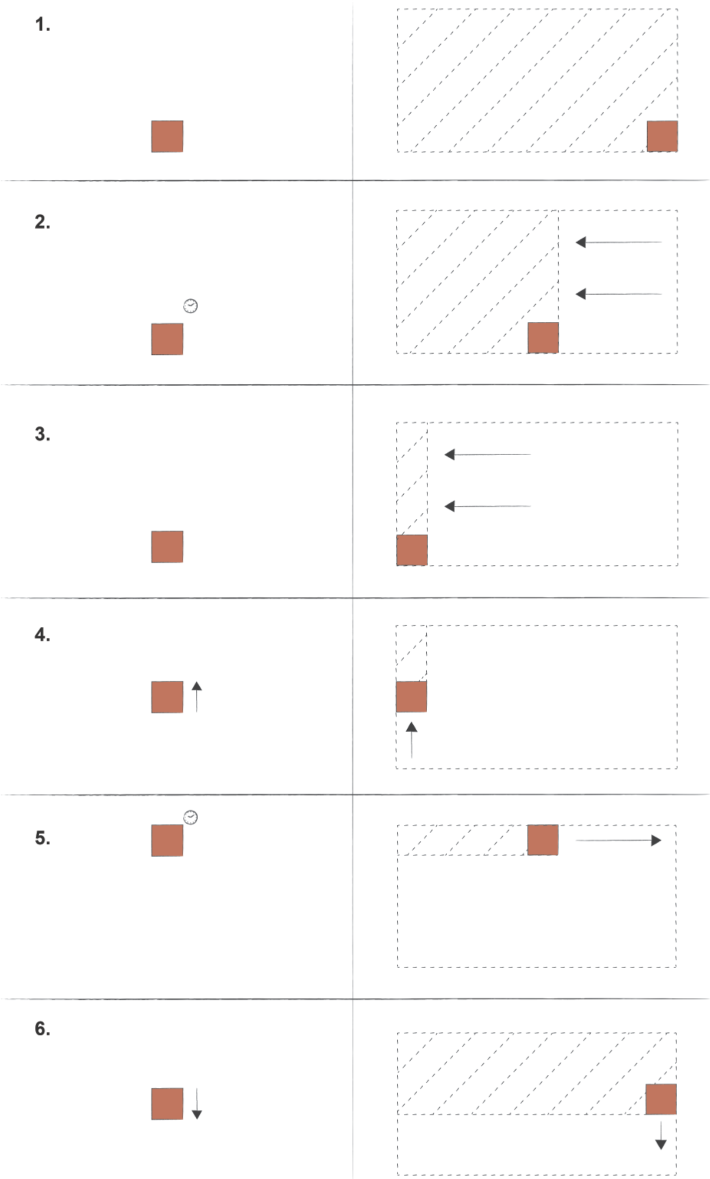

Figure 5.8: A visual simplification of the attacking and retreating mechanics.

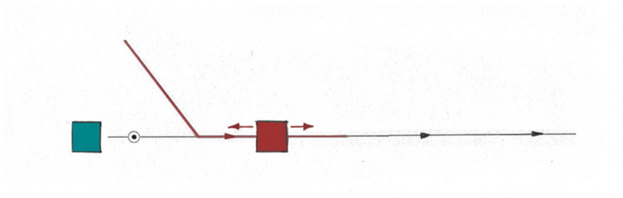

Figure 5.9: The behavior of the red cube (opponent) projected onto a curved line.

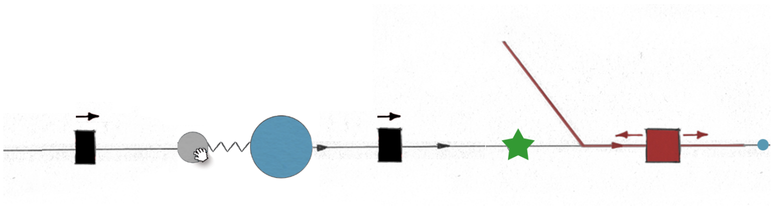

Figure 5.10: An abstraction of the aiming and shooting game mechanics.

move upwards and when a new rectangle reaches the horizontal line, the position of the two black rectangles will switch to the position of the outer ends of that rectangle, thus expanding or reducing the space in between both rectangles and requiring less or more accuracy in subsequent actions. Then, whenever the player hits the aiming point, the configuration at that particular time frame is selected and the rectangles will gradually start moving forwards to the right.

Reconceptualizing the game mechanic according to its behavior In a final instance, the grey horizontal rectangles were replaced by a blue circle that moves upwards in order to further reduce the elements used within the setup (see Figure 5.12). The distance between both black rectangles expands whenever the circle touches the aiming point. Thus, if the player hits this circle at the correct time at the aiming point, the distance of the rectangles becomes larger and more space is given to aim, making the challenge easier.

5.7.4.3 Navigating

Reducing the figurative qualities of the core mechanics Again in a similar fashion, the movement of abstract shapes along straight lines was applied as a starting point for a transformation of the navigation mechanic. In order to ensure that the

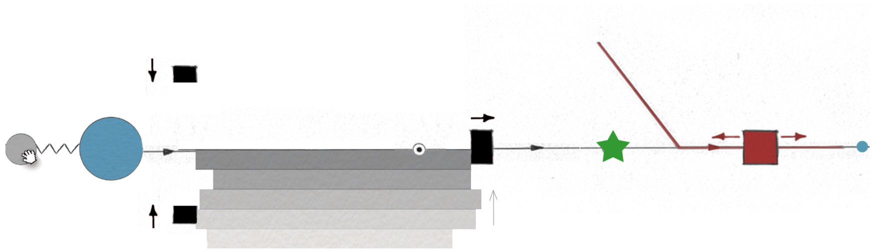

Figure 5.11: An adaptation of the aiming and shooting mechanics.

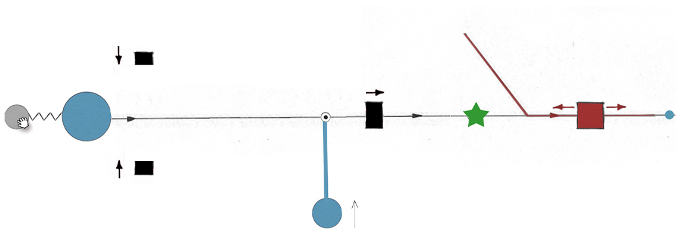

Figure 5.12: The final setup of the aiming and shooting mechanics.

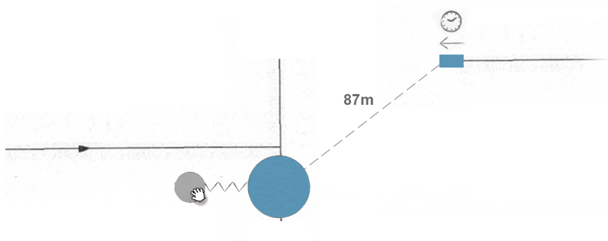

Figure 5.13: An abstraction of the navigating game mechanic.

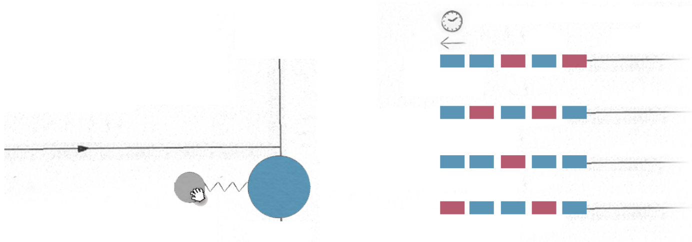

Figure 5.14: An adaptation of the navigating mechanic.

player could navigate different parts of a game world, and not only along one given line, the device displayed in Figure 5.13 was used. The small blue rectangle on the right slowly moves towards the left. The player-character can move up or down the vertical line to hit this rectangle. When the player does this, a new line opens up and the player-character can move forward along this line arriving in the aiming and shooting mechanic (see Figure 5.12). As a result, the rectangle simulates the rooms that players can enter in a shooting game by progressing in the correct direction, with this exception that in the abstract game the room moves towards the player.

Adapting the mechanic In a second instance, more rooms were added to represent a large game world in which the player can navigate and select different rooms to enter (see Figure 5.14). Additionally, in some of the rooms opponents were positioned that could not be touched, indicated by the red rectangles.

Finally, the number of rooms was reduced (see Figure 5.15). Moreover, the length of the blue rectangles was made to indicate the accuracy of the aiming and shooting mechanic after they touch that rectangle (the distance between the two black rectan-

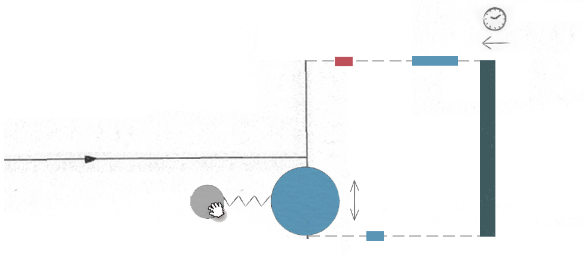

Figure 5.15: The final setup of the navigating mechanic.

gles in Figure 5.12). As a result, players can gradually become to understand that wider cubes are advantageous to them.

Integrating each selected game mechanic into a consistent whole. In a final step, the above presented mechanics were merged together into a single game, and interface and visual elements were added to present the game as a playable and consistent whole (see Figure 5.16). The interface elements were mainly added to keep track of the players' points throughout the game (see Figure 5.17). Additionally, the visual elements were added to make the game more comprehensible. The resulting game is described below.

In the resulting game, players push a blue circle through a 2D virtual world in order to collect six stars to win. Players first click and select the player-character, first represented by the grey circle. This player-character, together with the blue circle, is attached to a horizontal line, so it can only be moved forward and backward but not up and down. Additionally, the blue circle moves forward automatically, which makes it difficult to control the movement of the 'character'. If the player-circle moves faster than the blue circle, the blue circle will be pushed. Conversely, if it moves slower or goes backwards, the blue circle will slow down and follow the player-circle if the distance becomes too large. In short, the blue circle is loosely attached to the red circle, as if a shadow, and with delay mimics the behavior of the red circle.

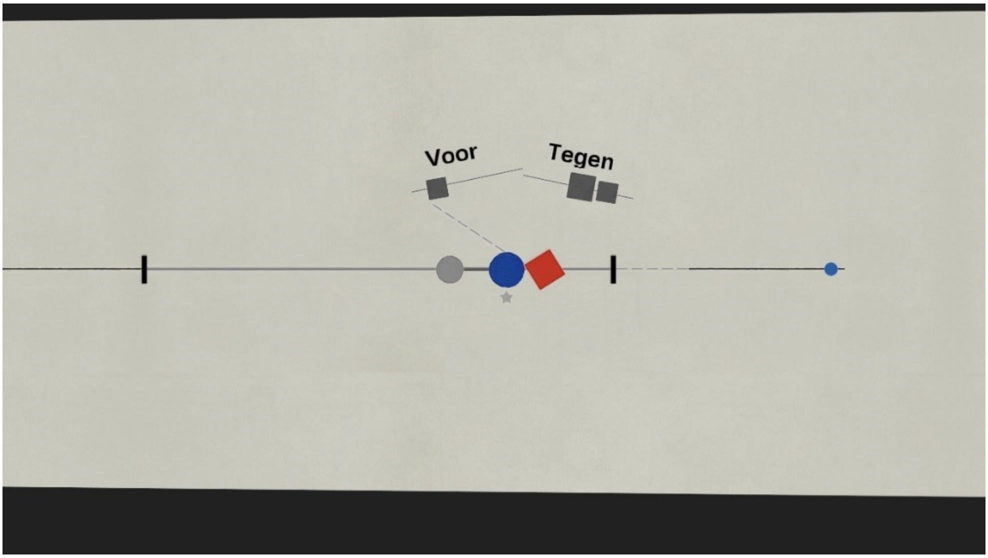

Figure 5.16: A screenshot of the resulting game showing the interface keeping track of the points ('voor' and 'tegen').

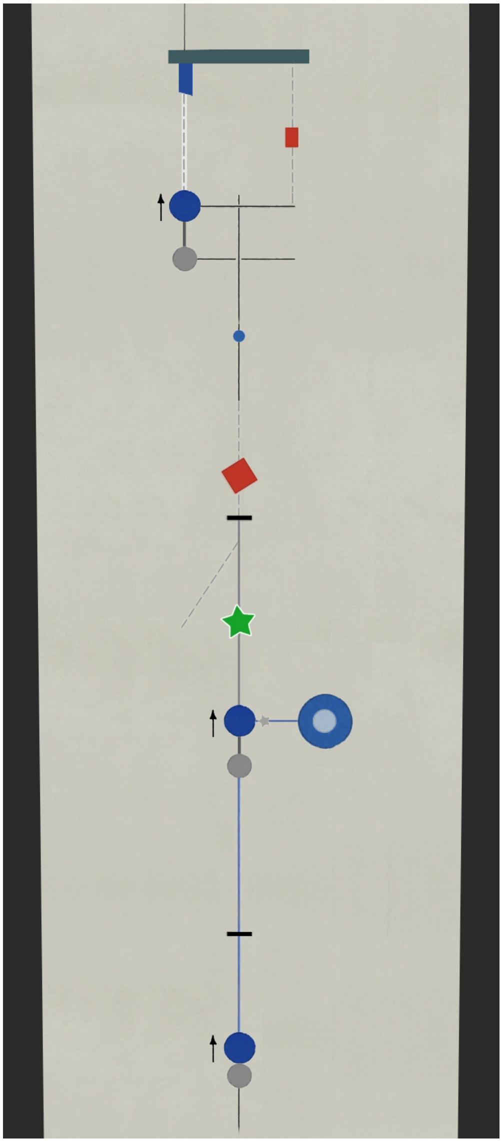

Figure 5.17: The final game with all the mechanics (multiple screenshots attached to one another for the purpose clarity. In actually, players encounter each mechanic one after the other).

Throughout the levels in the game, players encounter several challenges. First, players have to aim and hit a blue circle that is moving perpendicular to the horizontal line. Timing is essential in this challenge, although not fast movements are required. If players are too fast or too slow they will miss the blue circle and lose a reward for the next challenge. When the aiming challenge is completed two small, black rectangles enclose the two circles (see Figure 5.12). Depending whether players have hit the blue circle in the previous challenge, more space will be left between these two rectangles. More space is advantageous for players, as the circles are not allowed to touch the rectangles. The difficulty of this challenge, then, is that the two rectangles gradually move forward. Thus, players need to physically balance the two circles between both rectangles while moving.

Players encounter the final challenge during the balancing puzzle previously described. A red square slowly moves towards the circles following the dashed line indicated in Figure 5.9. Players have to steer the circles under this red cube when it moves upward. Again they can't move too fast or they will hit the red cube and lose a point. Additionally, the red cube also moves backwards when it is at the end of the dashed line, so players need to make sure it does not hit the circles from behind. The challenge is finished when players reach the blue dot at the right of the screen.

These three challenges – aiming, balancing and avoiding the red square – are repeated in each level. After a level is finished, players can navigate to different levels with the device displayed in Figure 5.15. When players reach this navigation device, they can move up and down along the vertical lines and superimpose the blue circle in front of one of the two dashed horizontal lines. By doing this, the navigation device will be activated, implying that red or blue rectangles appears and move towards players.

5.8 Discussion

In this chapter, the abstract minimalist style was explored in the context of rehabilitation games. On the one hand, this resulted in the description of a design process whereby an existing game was transformed into an abstract minimalist game with a drag game mechanic at its core. On the other hand, this process effectively entailed the development of a concrete game that displays the results of this process.

The first three stages of the design process show the initial steps of minimalizing the existing game. By selecting only a few game mechanics that we considered as essential to the game experience, a wide range of other mechanics (as well as their associated virtual objects) were excluded. This was further extended by defining only a small set of rules for each mechanic in the formal identity. As a result, the game was simplified on a conceptual level according to Nealen, et al.'s [233] theory of minimalism. In the latter four stages, the focus of the design process changed from conceptual analysis towards actual creation, whereby the process of abstraction was emphasized. This resulted in the following three considerations.

5.8.1 Figuration and space

Compared to Quake Live, the resulting game contains considerably less representational qualities to exteriorize the formal identity. For example, while in Quake Live the player-character and the bodies of the opponents are represented by 3D human-like figures, these were replaced by a simple blue sphere and several red squares. Similarly, the floor of Quake Live was replaced by a straight line and spaces were defined by small rectangles. This was possible because the formal identity of Quake Live, as defined in this design experiment, only necessitates opponents to hit the player, and therefore only requires basic spatial qualities. Other elements were left out if they were not considered necessary aspects of the core mechanics. For instance, legs were left out as the essential game rules do not reference walking. After this process was finished, additional qualities such as color and shape (e.g. red squares vs. blue circles) were used to make opponents recognizable as opponents and the player-character as the player-character. These qualities enable players to make a distinction between the different objects in the game spaces even though they are abstract and minimal.

In a similar fashion the spatial qualities of Quake Live were significantly reduced in the experimental design process. For instance, in Quake Live, players move through 3D hallways and rooms in order to find opponents, while in our game the hallways are geometrically reduced to a one dimensional line. The distance players need to travel in a 3D environment between two rooms was first replaced by an abstraction in the form of numbers (e.g. 87m), and later by a time constraint. As such, players do not literally walk through the space of our game, but rather wait for the space to come to them. Consequently, the process of abstraction was performed on the level of visual fiction [239] as well as on the level of interaction.

5.8.2 Challenges

Several of the virtual objects used in Quake Live were removed. To illustrate, in Quake Live, opponents hit players with guns and bullets in order to affect them with damage. These guns and bullets are essentially extensions of the opponents their virtual bodies, as they only perform the action of reaching out towards and hitting the player. The underlying concept behind being shot by an opponent, which is reflected in the formal identity, remains the same even though the guns and bullets are removed. As such, in our game, opponents represented by the red squares represent both the original opponents, their guns, and their bullets. Similarly, the rooms in the game do not contain any other objects as they are only depicted as small rectangles.

The challenges of Quake Live were also iteratively modified, without however changing the core formal identity. For instance, in Quake Live, attacking and retreating requires fast movement skills, while in the presented game the pressure button (see Figure 5.7) largely reduces the need for fast movement, as it rather requires a predictive ability of players. This is also the case regarding the aiming and shooting mechanics. While speed is a much desired skill in Quake Live when aiming and shooting, in the developed game there is little to gain by moving faster. Rather, the player-character and the sphere behind it need to be balanced in order to reach a target at the appropriate time. The presented game's main dynamic can best be described in terms of timing and balance of movement between several small time slots, rather than moving quickly within one time slot.

5.8.3 Visual representation of the game mechanics

The five game mechanics developed in Section 5.7 each demonstrate a specific behavior based on the game's formal identity. However, the visual representation of this behavior was changed in order to make the behavior visually more understandable. For example, in Figure 5.8, the left and the right side of the illustration display similar behavior of movement, yet the right side is visually more expressive about this movement. It is possible to change these visuals, because the formal identity only describes the game in broad terms. There are, for instance, no specific visual qualities that are dictated by the theme or narrative of the game. This provides the designer the opportunity to easily adapt the visuals of the game to the rehabilitation context.

5.9 Play tests with rehabilitation therapists

As the presented abstraction and minimalization process was experimental, it was important to contextualize the relevance of the developed game style to rehabilitation therapy. Therefore, two play sessions were held with a number of rehabilitation therapists (first session: one, second session: four). The objective of these tests was to assess whether the game and its abstract minimalist style warranted further development and testing with actual patients. The tests were informal as they only focused on playability and artistic reflection rather than player experience or effectiveness to the rehabilitation therapy. The first session was organized during the development process, where the features were set up as presented above. The physical and cognitive requirements needed to perform the core game mechanics, together with their

	Moving the player-character	Attacking and retreating	Aiming and shooting	Navigating
Physical parameters				
Free movement (1D)	x			
Precision*		x		x
Accuracy*		x		
Timing*			x	x
Acceleration			x	
Reaction speed			x	
Range of motion	x			
Stabilizing	x		x	
Cognitive parameters				
Visual recognition	x	x	x	x
Hand-eye coordination	x	x	x	x
Predicting	x	x		
Anticipating action		x	x	
Strategic thinking		x	x	x

Table 5.3: The parameters and difficulty adjustments included in the abstract minimalist game. *parameters that can be adjusted in difficulty.

difficulty adjustments, are presented in Table 5.3.

The play sessions revealed that the therapist had a generally positive impression of the game, stating that it could potentially be relevant to a physical rehabilitation therapy (if further tested with patients), and made some extra suggestions and remarks (e.g. more variety in the position of the horizontal line in Figure 5.15). The second session was organized at the end of the design process, and the game was as described in Subsection 5.7.4. Though their general impressions were also positive, three suggestions for improvement were made: provide the possibility for more variety in the exercises, less precision should be required in order to complete the main challenges, and provide cues in order to make the game more understandable. These suggestions were taken into account in the further development of the game as described in the next chapter.

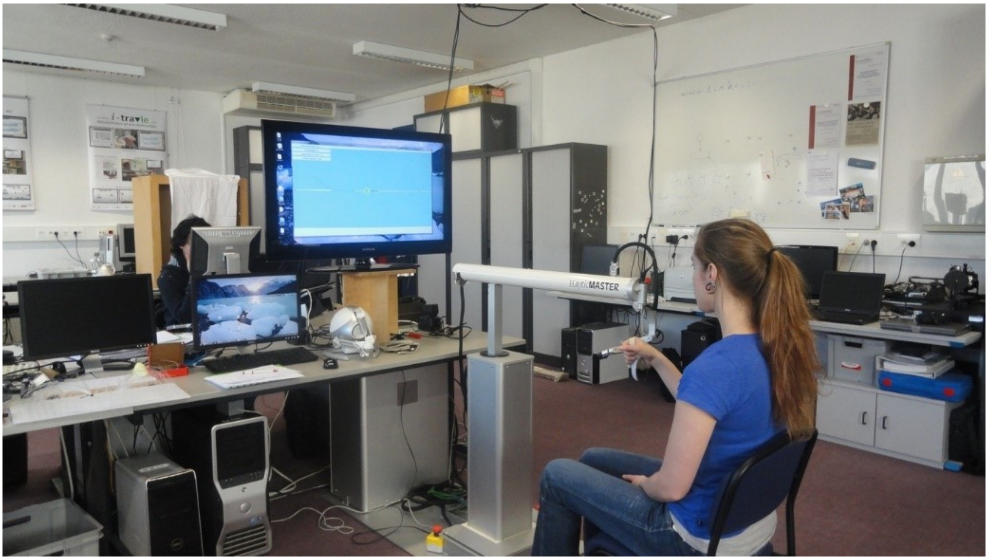

Figure 5.18: A rehabilitation therapist playing a prototype of the game during the first playtest.

5.10 Implications of the abstract minimalist style

In this chapter we practically explored the development of an abstract minimalist style in a physical rehabilitation context. Specifically, a design experiment was performed that resulted in an abstract minimalist game that revolves around a simple drag mechanic. This design experiment and its resulting game are relevant to the area of rehabilitation game research in two manners. First, other researchers and game designers may apply the developed design process in their own research. As such, they will be able to include a dedicated game concept into their own research instead of an adaptation of more traditional games such as Pong [258] or Whack-a-Mole, an ambition expressed by a number of researchers (e.g. [73, 155, 160]). The degree to which these dedicated game concepts are abstracted and minimalized depends on how the design process is applied. Furthermore, work such as Jacobs, et al. [201] that also applies abstraction, could be further informed as the presented process starts from an existing game concept.

Second, the developed game allows us to reflect on the specific characteristics of the abstract minimalist style. Three elements were discussed that revealed to be prominent features in the design process: spatial dimensions, challenges and visual representation. While abstract minimalist game are applied in rehabilitation games in the form of traditional games such as Pong and Whack-a-Mole, the specific style features are rarely investigated as such. This design experiment directs the attention to these three specific features. In general, the experiment indicates that spatial dimensions, challenges and visual representations are not solid elements, but can be adjusted and simplified. More importantly, the game provides a concrete example of what this entails for a physical rehabilitation game with a drag mechanic. Consequently, the designed game's concept may serve as a practical foundation for future research.

5.11 Limitations of the abstract minimalist style

As an experimental design approach was maintained, the results should be regarded as experimental and directed towards design features. Consequently, the play experience, the usability of the game, and the suitability of the game to an actual rehabilitation therapy cannot be commented on. Tests with actual rehabilitation patients need to be performed in order to fully discuss these features. The play tests we organized with therapists indicate that the game concept has potential, yet also reveal that several challenges (e.g. therapy customization) need to be overcome.

5.12 Conclusion

This chapter started with an introduction to the concepts of abstraction and minimalism as established in art forms such as painting, that were then further explored in relation to digital games. Building on the previous chapter, stating that the unintended inclusion of disability conflicting design elements needs to be avoided, these concepts were suggested as potentially valuable, as they are based on the principle of reduction. In order to investigate this, an experimental approach was maintained and an existing game (Quake Live) was abstracted and minimalized. This approach allowed us to define a specific abstract minimalist design process, and build a game in which three design elements were abstracted and minimalized: the spatial dimensions, the challenges, and the visual representation. The design process as well as the game provide novel information on how the abstract minimalist style may form a basis for physical rehabilitation games.

Chapter 6

Taking into Account the Player Experience and the Playability of Rehabilitation Games

6.1 Introduction

The previous chapter presented how patient disabilities as well as physical rehabilitation exercises can influence the look and feel of a digital game. While this broadened our insights on how digital games and rehabilitation therapy can be combined, it was predominantly intended to explore and create an experimental game form, which takes into account patient disabilities and incorporates simple physical challenges. At present, this form lacks the aesthetic and user experience features needed in order to let patients play and enjoy it (cfr. [63]). Additionally, while the style did incorporate physical challenges, it did not yet integrate the option to adjust these challenges to the individual patient's rehabilitation therapy. Yet, as previous research [164, 259] shows, all patients have different needs, and therapists need to be able to easily adapt a game to those needs. Accordingly, in order to resolve these critical issues, it is necessary to further investigate the previously developed game style.

This chapter addresses the abstract minimalist style presented in Chapter 5, and describes how it can be transformed to encourage an engaging and usable play experience, which therapists can customize to an individual rehabilitation therapy. In order to do this, a creative exploration of the abstract minimalist style is needed to identify design elements, and subsequently integrate these into the current style of the game prototype. Currently, some rehabilitation games (e.g. [70]) and a range of entertainment game (e.g. Splice [260] and Eufloria [261]) are available to serve as examples of how elements from related styles have been applied in the past. Yet, these first need to be selected, interpreted and then translated to the individual characteristics of the current game style to be of any use.

Following the design research methodology (see Chapter 2), we redesigned the abstract minimalist style (see Chapter 5) according to concepts of visual feedback [170], meaningful choice [62, 63], as well as player progression [177]. As such, a novel game artefact was created containing an ambient abstract minimalist style which aims to be usable and interesting to patients, while allowing therapists to customize the rehabilitation exercises. Finally, play tests were performed in order to investigate if this design style is effectively usable and interesting to patients.

6.2 Redesigning the game world

In this chapter, an outline is provided of how we set out to create a usable and pleasurable game style based on the abstract minimalist game previously introduced in Chapter 5. Specially, the redesigned game's style, which we refer to as the ambient abstract minimalist style, and its design rationale will be presented and elaborated on, as well as contextualized according to play tests with patients following a neurology rehabilitation therapy.

6.2.1 Overview of the game play

The game, as illustrated in Figure 6.1, is situated in an ambient abstract minimalistic world which consists of a colorful void. There is only one player whose representation in the virtual world is divided into two pieces. The first piece (a series of circles) can be directly dragged by the player, yet cannot interact with the game world. The second piece (a square), behaving exactly the opposite way, can interact with the world, but cannot be moved directly. The player thus has to move the second piece via the first piece if s/he wants to interact with the world. This creates an interesting situation: the game invites players to move in the physical world, but at the same time makes it difficult for them in the virtual world.

The goal of each level (12 in total) is to move the square piece of the player towards another smaller square. Both squares are connected by a waving line that calmly floats in the spatial structure of the game world. There exists no up or down, left or right; only further and closer along the line. This limits the player's spatial immersion, yet at the same time provides a sensory reward as the line constantly moves and is surrounded by little responsive squares. This, nothing more than a subtle line and some squares, in combination with the two-piece player representation, gives the player an illusion of being in the game world: the world moves when the player moves her arm, and the player's representation moves when the world moves,

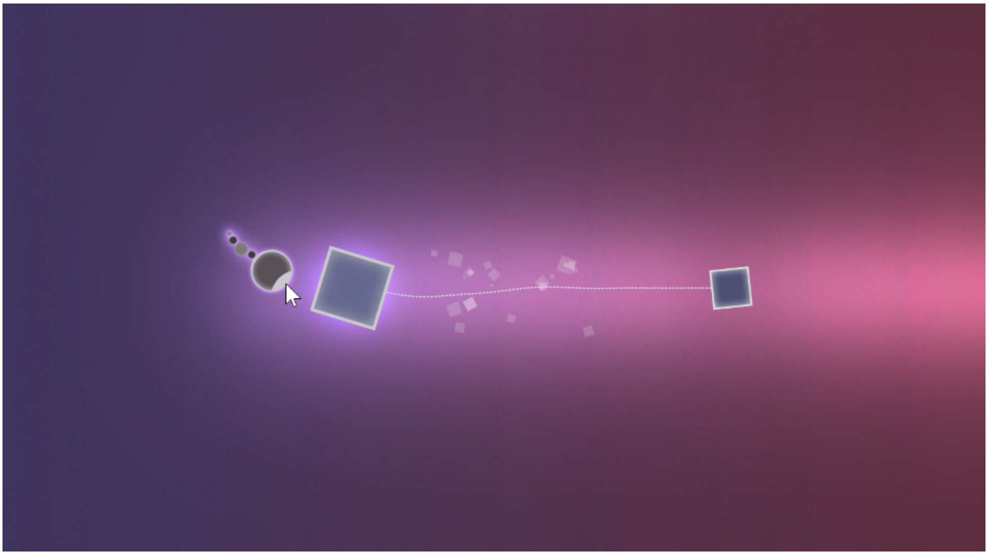

Figure 6.1: The first level of the game in which the player-character needs to push the larger square against the smaller square.

therefore the player must be part of that world (cfr. [262]).

Throughout the game, the player encounters opponents in the form of triangular shapes that move along different, intersecting lines. While these opponents are, like all other objects, represented in a simple, minimalistic fashion, the underlying play dynamics are complex. The game play is hidden in the curves and shapes of the lines; the challenges change when the lines change. Throughout the game levels, these challenges become more complex and difficult. Finally, in later levels, the player encounters obstructions that are removed by picking up points and in so doing permits the player to access branches of the main line.

6.2.2 Rehabilitation exercises and input devices

In the described game, the concept of representing real-life rehabilitation exercises by means of virtual lines is maintained (see Chapter 5). However, as a result of the redesign, the concept's implementation has resulted in four adjusted game mechanics: moving the player-character, pushing the square, passing a triangle, and collecting a point (see below). Executing these mechanics requires several physical and cognitive skills from the patients as indicated in Table 6.1. Additionally, the same contextual factors as in Chapter 4 and Chapter 5 are taken into account, and the HapticMaster is again used as the input device, though expansions towards other devices are also

	Moving the player character	Pushing the square	Passing a triangle	Collecting a point
Physical parameters				
Free movement (2D)	x			
Precision*		x		x
Accuracy*		x		
Timing*			x	
Acceleration			x	
Reaction speed			x	
Range of motion	x	x		
Cognitive parameters				
Visual recognition	x	x	x	x
Hand-eye coordination	x	x	x	x
Interpreting causal relations	x	x		
Anticipating action			x	
Strategic thinking		x	x	x

Table 6.1: The physical and cognitive components needed to execute the core game mechanics.*parameters that can be adjusted in difficulty.

possible with the current software implementation (see Chapter 5).

6.2.2.1 Moving the player-character

The first mechanic of moving the player-character does not support a specific rehabilitation exercise or goal directly, but rather facilitates the three other game mechanics that do. This is done by providing players the basic capability of moving freely in the two-dimensional virtual space and correspondingly also in the real-world space.

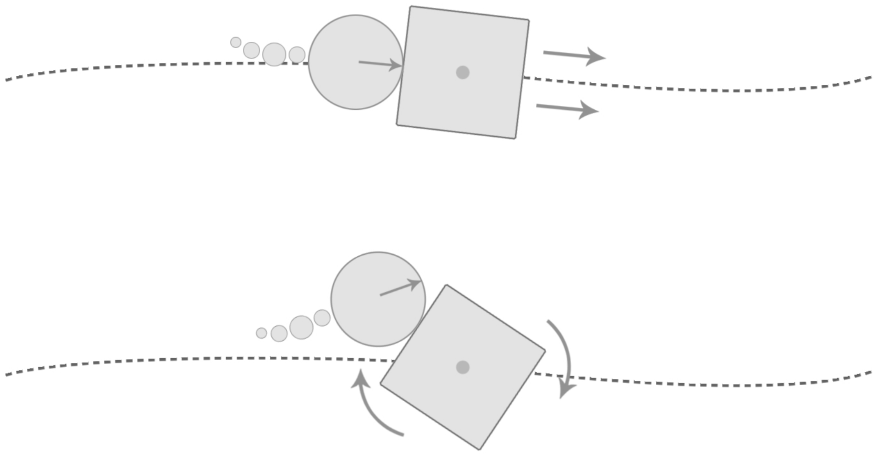

Figure 6.2: Implicit feedback provided by the rotation of the cube in order to encourage the player to stay close on the trajectory.

6.2.2.2 Pushing the square

The second mechanic of pushing the square provides a first challenge to simply moving. In order to push the square, players are required to follow the trajectory of the dashed line to which the square is attached. As the trajectory varies between levels, this mechanic may be used to let patients perform different motions in the real world. The end points of the trajectory may be placed within a comfortable range of the patients' abilities or, conversely, be rather placed towards the outer boundaries of the screen and thereby encourage patients to practice their range of motion abilities. In addition, pushing the cube naturally promotes players to closely trace the trajectory and thus to train their accuracy over the trajectory. As illustrated in Figure 6.2, when the player-character pushes against the center of the cube (e.g. close to the line), the player is able to push the cube without much problems. However, if the player deviates from the center, the cube rotates and the higher the deviation, the more likely the player misses the cube. Thus, the cube and line present the player with implicit and integrated feedback to stay on close to the line.

6.2.2.3 Passing one or more triangles

The third mechanic of passing one or more triangles builds upon the two previous mechanics. Though players still travel over a certain trajectory, the added triangles require them to also anticipate when to move and with which speed. On the one hand, this presents a relatively simply cognitive challenge to players. On the other hand, it provides a physical challenge based on timing, yet does not necessitate too quick or complex movements often associated with physical challenges in games (e.g. first person shooter games such as Call of Duty [237]). The different trajectories of each triangle allow for variation in both the rehabilitation exercises as well as the game play. A combination between multiple types of triangles (e.g. yellow triangle) further enhances this variation.

6.2.2.4 Collecting a point

Finally, there is the fourth mechanic of collecting a point, which is mainly a cognitive task. In level eight, players are able to see the first point, which they need to collect in order to remove the barrier on the trajectory. This is, arguably, one of the more difficult tasks in the game and is mainly an incentive to travel on branched side-lines of the main trajectory providing, again, more variation on which movements are made.

6.2.2.5 Difficulty adjustments

However, rehabilitation therapists stated (see Chapter 5) that the real-life exercises required more variation, which has been addressed in the design. First, the virtual lines are no longer horizontal, fixed and one-directional. Instead, they are spread out over the screen and are positioned in a variety of directions. Additionally, after level eleven there are branched lines that allow for a combination of directions in a single level. In this respect, the virtual lines resemble those of the game Flowers (described in Chapter 4), yet with greater flexibility and in a different virtual world. Secondly, the resistance with which the cube rotates (see Subsection 6.2.2.2) can be increased and decreased, requiring players to be less or more accurate. Finally, the speed with which the triangles travel is also adjustable, creating an option to increase the speed of the exercises.

6.2.3 Relevant game elements

In this section, the previously described game's design rationale will be elaborated upon. Overall, notable similarities as well as differences can be observed between the described game and the abstract minimalist game introduced in Chapter 5. The most noteworthy similarity is that players simultaneously have to guide two objects over a line, and at the same time have to avoid other objects. The biggest difference resides in how the game is presented to the players, specifically in terms of visual feedback [170], meaningful choice [62, 63], as well as player progression [177].

6.2.3.1 A revision of the game's graphics

The graphical style of the previous game resulted from the abstract minimalist process, and therefore did not take into account how potential players will use and experience the game. To address this, changes were made to the current game's graphics. The concept of graphics has already been discussed in Chapter 3 (Subsection 3.5.3), where it was concluded that graphics have to effectively communicate the game play [170, 169], but at the same time should also create an interesting atmosphere to strengthen the play experience. In an attempt to achieve this, consistent changes in colors, gradients, lighting, and details were added to the graphical style, as described below.

Background style We aimed to create a background that gives the impression of an expansive virtual world, but which at the same time remains easily comprehensible. Inspiration (cfr. Chapter 2) for this came from the virtual world of Splice [260], in which detailed background objects are replaced by nebulous colors and gradients. This concept appeared to be useful in a rehabilitation game, as patients with difficulties regarding visual perception would perhaps not be distracted by the background, yet still be under the impression of being in a complete game world. In this way, they would be able to focus entirely on the foreground where the rehabilitation exercises are displayed. Consequently, similar use of colors and gradients has been applied in the current game style, although other more specific elements such as the small dust specs were left out, as they were less relevant to the 2D environment.

Exposition, light effects and graphical details We attempted to make the abstract visuals more comprehensible by adding light effects and graphical details, and in this way aid players in understanding the actions and goals of the game world. A difficulty with abstract visuals is that they usually do not have any representational affordances [239], which are important in figurative games to guide players towards the main goal. For example, characters with a human body and guns, such as those in BioShock Infinite [263] and Call of Duty: Modern Warfare 3 [237], provide the player with visual directions of how to walk and shoot, and thereby implicitly explain how the game world works [177]. Additionally, figurative games also often apply narrative techniques [62] (e.g. The Lord of the Rings Online [264]), or superimpose additional interface layers on the game world (cfr. the goal indicator in the game Mirror's Edge [265]) to guide players through the game. However, these techniques often make a game considerably more complex and would remove us further from the abstract minimalist style identified in Chapter 5. Therefore, two visual, non-figurative techniques have been applied in the current game: exposition and composition.

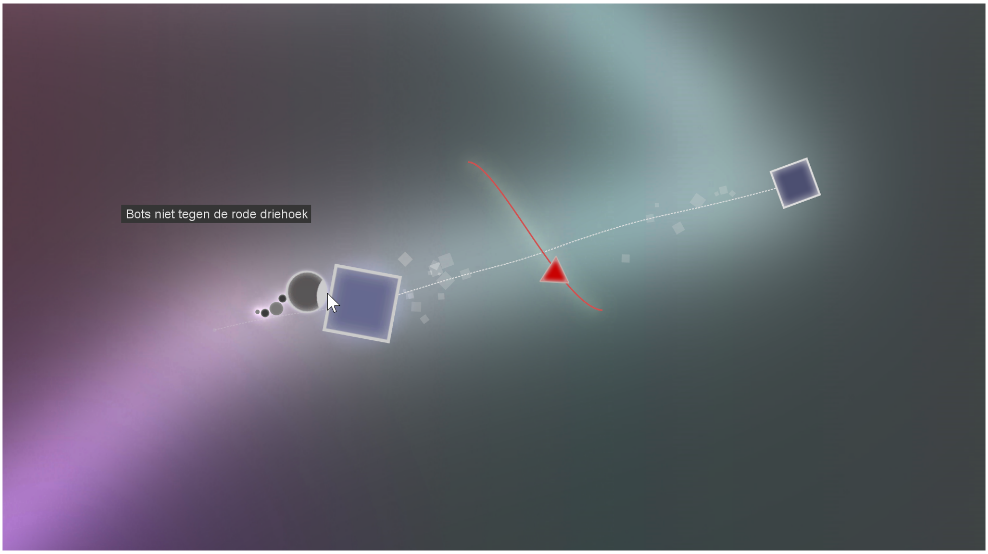

Figure 6.3: Level three of the game in which the player encounters a red triangle for the first time.

Exposition When players first play a digital game, they are generally not familiar with its meanings and goals. As a result, they may become frustrated and even leave the game when they are unable to familiarize themselves with it. Expositional techniques are therefore used to gradually introduce the players to the virtual world in a structured fashion. While this is often done using narrative techniques [177], the abstract minimalist style prevented us from using these. We therefore instead focused on introducing the game mechanics step by step by gradually building up the virtual world, centered around the player-character. Similar techniques have been applied in other abstract minimalist games, such as Eufloria [261], Hundreds [266], Osmos [234]. We anticipated that these techniques could be interesting in a rehabilitation setting, as patients would not have to instantaneously comprehend the game world, but rather get to know it at a slow, self-determined pace. First, only the important virtual objects which can be interacted with are shown, while all other superfluous objects are left out. This guides the actions of the players to certain objects without them having to know what it will do. Where leaving out the surrounding environment would be illogical in most figurative games, abstract games make this perfectly possible as their elements often do not contain a predefined representational logic. This technique is maintained throughout the game, as new levels constantly appear out of thin air. However, should this not be clear enough, short informative captions automatically appear after several seconds when new elements are introduced. Additionally, throughout the game, the player-character remains attached to the cursor, eliminating the need for players to perform certain actions again.

Composition In addition to the expositional techniques, compositional techniques have also been used to direct the perception and understanding of players in the game world. While expositional techniques mainly rely on time-based events, compositional techniques rely on the visual characteristics such as color and form. When applied correctly, these characteristics guide the attention of players to specific virtual objects. Influenced by the abstract game Proun [267], certain elements drew more attention to some objects than others. In Proun, the 3D one-point perspective directs the visual attention of players towards their goal, and big, bright objects indicate what players cannot hit. While the 3D perspective is less relevant in the 2D game environment, the size, shape, color and position of objects were used to indicate the importance of objects. For instance, the player-character is still drawn as a circle, but now also contains a small black elliptic shape which allows, in accordance with the cursor, players to focus on the front of the player-character and see the direction it is headed into. Furthermore, the character's smaller 'tail-like' circles (cfr. Tron [268] and Flow [269]), together with their physical properties, visually suggest the path they came from and as such highlight the dragging movement of players. The game world itself is also visually designed to stimulate the interaction of patients with the environment. While in the abstract minimalist game of Chapter 5 players simply moved on a never-ending horizontal line from one screen to the next by completing levels, here there are a demarcated beginning and ending represented by two squares. Although this might not make the task of connecting the two squares instantaneously clear, it guides the eyes of players from one cube to the other, and indicates that something needs to be done with these elements and players should explore this. Furthermore, by making the two squares resemble one another, we hoped to suggest that both squares in some way belong together through the principle of similarity (cfr. Gestalt Principles [270]). The dashed lines in between are intended to reinforce this without drawing too much attention to itself. However, only the left cube can be moved, which is why it was made bigger and supported by a pulsating backlight to indicate its importance. While these element aim to implicitly guide the interactions of players when they explore the game world, it may of course still not be clear as they remain abstract signs. Hence, two short captions stating "Push the square.." and "against this square" were included, together with an animated moving arrow demonstrating the preferred trajectory of players.

Meaningful choice vs. structure of the world

The horizontal lines in the previous game restricted players in their physical freedom and meaningful choices. As the player-character was completely attached to the line, players could only move forward and backward. However, Chapter 3 (Subsection 3.5.3) revealed that games do not have to solely incorporate strict game play, but can simultaneously integrate free play. This would allow more agency [262] for the player or, in other words, more pleasure of being in the virtual world as a result of increased freedom and coherent feedback. At the same time, this could provide more variations on the physical exercises. Naturally, caution was required because the game cannot be completely free as it also needs to represent rehabilitation exercises.

Guided freedom To accommodate partial freedom, one half of the player-character has been detached from the guiding line so that the player can move freely about the game world, but still needs to follow the line in order to progress through the game world. A similar approach has been noted in Proun [267] and Pivot [271] where the player-character is also attached to a line, but still has the freedom to turn, respectively, concentrically and perpendicular to it. In this manner, the player can feel free in the game world, while still being guided by a predefined line. In the current game, by separating the two halves of the player-character in the game, players can wander the entire 2D space. However, in order to keep both halves still useful, the half controlled directly by the player cannot interact with the rest of the game world, and therefore needs to push the other half to be able to finish the game. Additionally, an extra degree of freedom is added to the square as it can rotate. As such, players have more bodily choices, but need to control these well in order to be able to push the square correctly.

Physics structure We aimed to offer players a more intuitive understanding of how the virtual world functions by emphasizing the physical causes and effects surrounding the player-character. Early abstract games such as Pong [258] and Arkanoid [272] – often used in related rehabilitation game research - communicate the game's logic primarily through their physics engine. For example, by having seen the ball bounce against virtual objects and the boundaries of the screen, players comprehend through cause and effect how the virtual world operates. Recent abstract games such as World of Goo [273] and Crayon Physics Deluxe [274] similarly use a physics engine and also make it an integral part of the challenge: the player must control objects falling. While these are interesting examples, other abstract games such as Osmos [234], Hundreds [266] and especially Splice [275] do not only incorporate physics in their challenges, but explicitly use it as an aesthetic feature which still communicates the virtual world. This technique is interesting to the current game, as it does not require any changes to the challenges, but still allows us to make use of a physics engine. Consequently, to accommodate this, the dashed lines connecting the squares were given physical properties, resulting in slow and waving movements. While in the abstract minimalist game of Chapter 5 those lines were solid and gave little visual feedback, now the physics of these lines provides feedback to players, making everything feel less artificial.

Finally, this physical structure of the world has been further emphasized by adding white cubes close to the dashed lines. Originally, we attempted to create an interesting background by painting a texture on it, such as the brush strokes on a painting. However, the static nature of that background did not respond to the interactive movements of the players, and therefore seemed unnatural. In reflection of the previous paragraph, the background was cut into smaller pieces and physical qualities were given to them to respond to the movement of the player-character. We found that this worked rather well, and stylized these pieces of background texture to the cubes now seen in the game. As such, they function as an interactive background, which does not directly contribute to the goal of the game, but does make the game feel more alive as it further emphasizes the physical structure of the game world, as well as making it visually more pleasing.

6.2.3.2 Progression in the game world

Progression [177] is an important concept in digital games as players need to feel that their actions will eventually lead them to finishing the game (as discussed in Chapter 3, Subsection 3.5.3). In the previous game, progression was generally made clear by the points earned during challenges: the more challenges were conquered, the more points were gained and the closer players came to winning the game. However, this might be close to the notion of ‘pointification’ [192, 276], wherein points are given as rewards, but have little meaningful contribution to players and does not encourage them to keep playing the game. To make sure this was not the case, progression was expanded on in the game.

As is common in most games, be they abstract or not, each level of a game should provide a sense of progression to the player in order for the player to know they will reach a goal, and keep interested in the game. In Pulse [275] and Hundreds [266], for instance, this is done by gradually increasing the difficulty, but also introducing new element of game play in different levels of the game. Additionally, in Proun [267] and Pivot [271] the following of the line indicates that the game is progressing, as was similarly the case already in the abstract minimalist game of Chapter 5. Finally, the camera work in Splice [260] also feels as if it progresses the game. Each time a level is finished, a completion message is displayed as illustrated in Figure 6.4 after which the camera moves towards a new level, and as such creates a feeling of progression

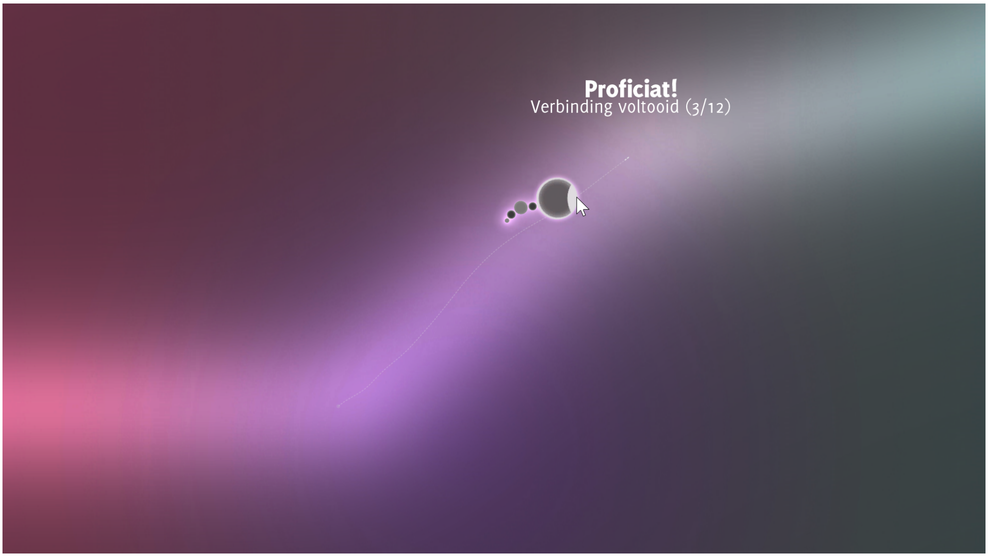

Figure 6.4: An indication (in dutch) of progression at the end of each level stating: congratulations, connection achieved!'

even though the game world stays on one screen. All these techniques were also used in the current game. First, the game starts with no opponents, then one simple opponent, and then gradually more opponents are added per level. Although there are different types of opponents (e.g. the yellow triangle in level seven pushes players instead of killing them), they are all built on the same concept of a triangle moving along a path. Players could then recognize the same challenges throughout the game, yet in a varied fashion. This was further emphasized by adding new gameplay elements in level seven. Furthermore, the lines in the game are varied and indicate that the players are not constantly in the same space, but are actually progressing over the line. Finally, so as to keep the game on one screen, we used a sliding camera to indicate that the player is progressing spatially.

Finally, progression is also emphasized through visual cues. First, the colors of the game each level indicate that players are moving in a different space than the other levels. Furthermore, the flashing light at each stop of the level makes it clear that a level has been finished. Also, the interface which states how many levels have been done further emphasizes that a level has ended.

6.3 Research questions

In the previous section, an altered version of the abstract minimalist style of Chapter 5 has been introduced (the ambient abstract minimalist style). This version was created with the ease of use and the pleasure for potential players in mind, while at the same time maintaining the advantages of the abstract minimalism style. However, we have not yet verified if this style can be used and enjoyed by patients during their rehabilitation sessions. Therefore, three research questioned were defined based on the MDA framework [76].

1. Does the developed game encourage tactile immersion and/or cognitive challenge to promote movement as a game experience rather than a rehabilitation experience (aesthetics)?
2. Is the developed game user friendly in a manner that patients can use the game without too much problems (mechanics)?
3. Is the developed game conceptually understandable regardless of its abstract minimalist form (dynamics)?

6.4 Testing the usability and playability of the redesigned game

Player tests with patients in the rehabilitation center have been performed on the previously described game in order to determine how the patients played and experienced the game. In reference to the MDA framework [76], these tests were divided into three distinct topics, each reflecting a critical component in game design on a functional as well as an experiential level. The first two topics relate to the usability of the game, the first on the level of game mechanics and if patients could properly execute them, and the second on the conceptual level of the game and if players could properly understand the meanings and purposes of the virtual world. Finally, the third topic involves not the game itself, but rather the experience of patients while playing the game. By considering these three features simultaneously, insights about both the player's play experience in relation to the design of the game were hoped to be achieved.

It was decided that a mixed-method approach would best suit the multidimensional aims of this experiment, while at the same time reflecting the complexity of digital games on both a functional as well as an aesthetic level. Digital games are regarded as immersive artefacts [177] which, when designed well, encourage players to ignore stimuli from the outside world [64]. As such, interrupting the play sessions

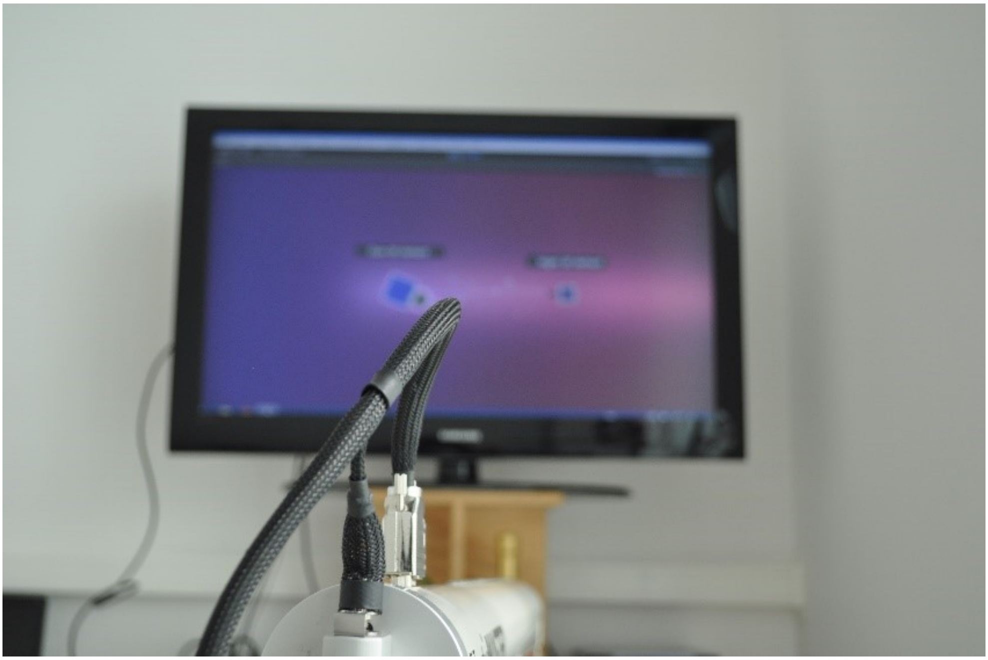

Figure 6.5: The test setting from the perspective of the participants, with the Haptic-Master directly in front of them and 'Collider' on the display screen.

of patients could be detrimental to the play experience of the patients, and thereby negatively affect the test results. However, at the same time, it would be profitable to understand how patients respond to specific elements of certain levels of the game, which may be difficult to investigate after the play session is over, as players may have forgotten important nuances already. Therefore, a middle-ground was explored. During a first play session, structured observations based on play heuristics [277] (see appendix A) have been carried out, together with a post-game interview adapted from the Game Experience Questionnaire [278] (see appendix B). These two non-obtrusive methods ensured that players would not be disturbed during their game play, but that information nevertheless could be gained about their experiences. Additionally, during a second play session, an in-game interview has been performed where the game was paused on predetermined locations in order to inquire players about specific elements recently encountered. Naturally, the danger exists in the second play session that players are already familiar with some game elements. This shall be taken into account in the discussion section of this chapter (cfr. Section 6.7).

6.4.1 Participants

Eight patients either suffering from stroke or multiple sclerosis were recruited by rehabilitation therapists working in the MS and Rehabilitation Center in Overpelt, Belgium to be included in this experiment. The therapists were asked to select a variety of patients in terms of their physical as well as cognitive abilities. However, patients who were expected not to be able to play a video game with their affected hand and the specific hardware were asked to be excluded, as they would not be able to partake in the observations and interviews. Consequently, the profiles described in Table 6.2 were included in this study. During the tests, one patient had to be excluded from the tests as she encountered severe difficulties in understanding the game and suffered too much pain in her affected arm. We suspect that due to a cognitive dysfunction she could not properly see from left to right. She herself also indicated that prior to the experiment she received medical shots which affected the pain in her arm.

Age	**Gender**	**Impaired Limb**	**Affliction**	**Physical Difficulties**			**Cognitive and visual difficulties**
				EDSS	MA	MI	
38	F	Left	SPMS	3,5	2	76	-
67	M	Left	PPMS	7,5	2	83	-
23	F	Left	RPMS	6,5	0	76	Limited concentration
38	M	Left	RPMS	7	2++	60	Limited vision (left-side)
64	M	Left	PPMS	6	0	50	-
				Neglect	**Physical difficulties**		**Cognitive and visual difficulties**
64	M	Left/right	CVA	-	Medium difficulties		Minor Attention problems, performing double tasks
46	M	Right	CVA	-	Shoulder flexion/abduction, Limited exorotation and extension, spasms with intentional movements, non-functional hand		Expressive Aphasia

Table 6.2: Profiles of the patients included in the tests. EDDS = Expanded Disability Scale, MA = Modified Ashworth Scale, MI = Motricity Index.

6.4.2 Procedure

First, the participants were greeted, and they were asked several short questions about their personal profile, and individually introduced to the general aim of the experiment. They were informed that they were going to play a digital game that might someday supplement the non-digital rehabilitation therapy. It was expressively clarified that the aim of the experiment was to test the game and not the participants themselves, as to reduce the degree of them playing any different than in a non-test setting. Their participation, they were told, would allow us to discover positive and negative elements of the game, which would inform us for the further development of the game. Furthermore, no information about the game itself or how it is played was mentioned. Instead, participants were informed that the game itself would guide them. In this manner, if they encountered a (non-technical) problem and asked for help, the test coordinator needed to encourage them to find a solution for themselves. Yet, if participants asked for three times, the test coordinator was allowed to assist in solving the problem.

The participants were asked to play the game two times in a row. In the first instance, participants needed to complete as many levels of the game as possible, with observation (see appendix A), but without any questioning from the test coordinator. The participants received a predetermined time limit (~ 7 minutes) to ensure that they would not get stuck playing the game for too long the first time. However, to ensure that no artificial time pressure was added to the experiment, the participants were unaware of this. It should be mentioned that two patients did not finish all the included levels, which will be elaborated on in the limitations section. Afterwards, the participants were interviewed according to appendix B. Finally, the participants needed to play the game for a second time, during which the test coordinator paused the game several times and asked questions based on the scheme provided in appendix C. The experiment was then finished, and the participants were thanked for their contribution. Each of the experiments lasted for approximately 30 minutes.

6.5 Results

6.5.1 Usability on the level of mechanics

The results of the observations and the post-game interview indicate that participants are able to use the game mechanics in order to progress through the game world, although some difficulties were reported. **Starting the game by selecting the cursor and starting to push the square can be considered as a functional and conceptual task which all participants could manage.** This is evident from the observations where every participant was reported to start almost instantaneously or within a short amount of time (~ 5 seconds) after seeing the setup of the virtual world. This is corroborated by the post-game interview, where all patients noted that they had no problems starting with the game. However, two minor problems were encountered by one patient. He was at first not aware that the cursor was located outside of the display screens' (hardware) boundaries, and afterwards also pushed the wrong square to begin with. However, both of these issues were quickly resolved when the patient experimented with the virtual world.

Pushing the square over the dashed line was functionally a more difficult task, as it was observed that the rotation of the square was too sensitive. Participants often 'slipped' off of the square with the player-character, which many of them acknowledged and also reported as frustrating during the post-game interviews. After the first play session, the sensitivity of the square was lessened by increasing its virtual physical resistance for the second play sessions. Although lesser frustration was observed, one person did still explicitly indicate that he needed to be really accurate in order to properly control the square. Furthermore, all participants indicated they would be able to control the circle better when playing the game more. What is interesting to note, is that one participant pointed out that the direction of the dashed line (variable in each level) influenced the difficulty of pushing the square. For example, she considered the upward direction in level three easier than other horizontal directions.

All the participants managed to complete a number of challenges in the game without too much difficulties, however some problems were encountered in some challenges. In particular, level six, where two red triangles are located close together, appeared to be the hardest level for most participants. Mainly, the combination between being either fast enough to pass both challenges at once, or being accurate enough to pause between the two challenges was troublesome for some. One person was not able to pass this challenge, and needed to skip it completely. All other persons were able to complete this challenge in a varying amount of attempts, in which one was observed to form a tactic to beat the challenge. Likewise, level seven was also perceived by some patients as difficult during the observation, but this on a cognitive level. The combination between a red triangle and a yellow triangle was challenging to some patients in order to find the right timing to start moving. Other levels were observed as being notably less difficult. However, one person mistakenly thought he had to touch the red triangle, and tried the first challenges about seven times before needing to be informed by the test coordinator. This is further discussed in the next section. **Thus, the basic challenge mechanic with the red triangle can be functionality executed by all patients, although more complex versions sometimes proved difficult.**

Finally, during the post-game interview, **most participants reported that the**

challenges were difficult, but that they also enjoyed this difficulty. Some said that if they had the option, they would use the force feedback from the HapticMaster to assist them with the exercises, as this felt easier. However, others explicitly noted the reverse, and told that this would make the game too easy. The relevance of using the HapticMaster in terms of the player experience thus depended on individual preferences. On a side note, one person pointed out that she needed to practice more in order to play the game better.

6.5.2 Usability on the level of concepts

No significant problems were observed of patients being unable to understand the overall game concept, and only a few minor problems have been reported on specific elements in some levels. **All of the participants were observed being able to easily push the two squares together, and appeared to know how to achieve this.** As a result, none of them got persistently stuck in a certain part of the game world. All of the participants were observed to comprehend that their actions had a real effect on the outcome of the levels as well as the entire game. **Furthermore, all of the participants indicated that it was not difficult to understand how the overall concept of the game functioned, and that they understood what the goal of the game was.**

The text captions provided when introducing new game elements did assist several participants in better understanding the game concept. During the observations, some participants positively acknowledged these captions by repeating their texts out load to themselves, as one said: "the yellow triangle pushes you. . . " in a reflective manner, or another affirmed them by saying, for instance, "ok" as a response to some texts. Furthermore, as previously noted, one participant thought the goal was to actually touch the red triangles. During second play session in the in-game interview, he saw the caption again, and exclaimed that he misread the caption's text the first time, which he believed resulted in the previous confusion.

The biggest difficulty of understanding the game concept was noted in level nine where the blockage mechanic was introduced. In this level, participants had to, for the first time, collect 'a point' in order to remove a barrier which inhibited them from continuing. While a caption stating "Collect the point.." was provided, one person did not understand what was meant with "a point" and needed to be informed by the test coordinator. Another participant knew what the point was, but at first attempted to collect it with the player-character instead of the square. However, once this was learned, no troubles with this mechanic were encountered further in the game.

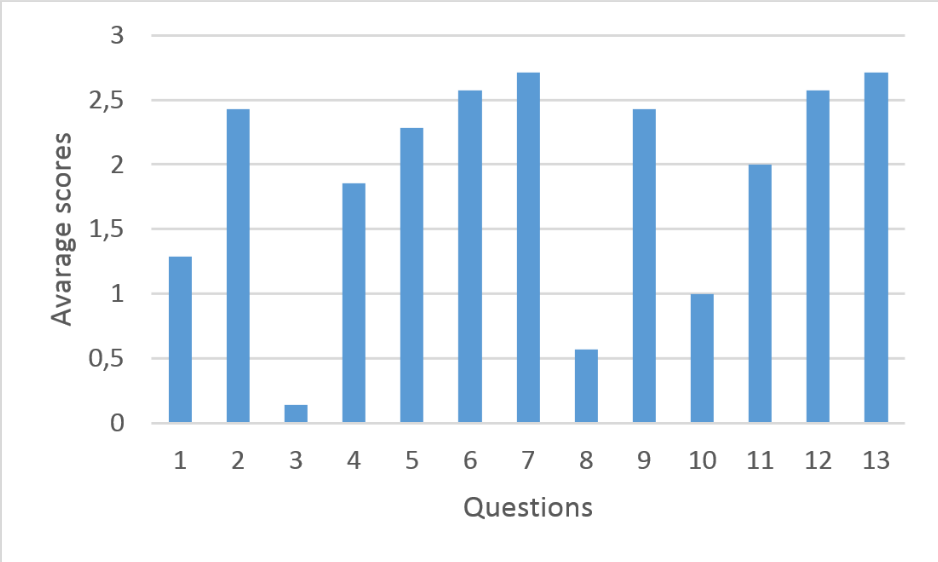

Figure 6.6: The average responses to the post-game questions of the seven participants who completed the interview.

6.5.3 Experience of the player

It was observed that all but one participant showed a significant interest in playing the game, especially during the moments when a challenge needed to be overcome, but one participant had too much pain in his arm to enjoy the game. For instance, many participants showed outer signs such as joyfully laughing when getting hit by a red triangle, or exclaiming, for instance, “no no no” or even swearing when a red triangle was about to hit the square, indicating that they were involved in the challenge. Nonetheless, there was one person who was less concerned with what happened during these challenges, as he fixated more on his arm. Later, during the in-game interview, he expressed that his affected arm caused too much discomfort when moving, which prevented him from concentrating on the game. Although one person appeared less challenged in the first three levels where no red triangles were integrated, the rest of the participants did appear to be considerably focused on the virtual world.

The post-game questionnaire similarly conveyed that most participants were playing a game rather than performing physical rehabilitation exercises. Only two out of seven patients said that the game felt like a chore, while the rest felt this was less so (q. 1). Even more participants indicated they liked to move in the game, with only one who did not like to move at all, which was the person earlier identified as having too much pain (q. 2).

However, no participant felt that playing the game was a waste of time - not even the person having pain - with only one indicating this was slightly so (q. 3), while all participants indicated that they were doing something useful (q. 6). Conversely, the majority of participants ranged between somewhat and notably proud of playing the game (q. 5), and four even stated that it was they considered playing the game a victory, although the other three found this less so (q. 4).

In terms of challenge, diverse responses were given on if the patients found it difficult (q. 7), indicating **that the difficulty depended on personal preference. However, most participants expressed they were challenged by the game**, whereas one person did not find it challenging at all (q. 9). It is noteworthy that the only one who responded that it was severely difficult was the participant with trouble in his arm. A majority of the participants indicated that they felt no pressure at all while playing the game, reflecting the game mechanics calm time dynamic (q. 8). Two players indicated that no or only a little effort was needed to play the game, where the first also responded that the game was not challenging (q. 9).

Overall, **five participants indicated that they considerably or severely wanted to play the game further.** Only one person suffering from pain in his arm had to give up on playing. Finally, **all the participants expressed that they liked the visuals of the game**, with a large majority considerably so.

6.6 Level of cognitive ability and input devices

The tests described above suggest that the game Collider can be played and enjoyed by stroke survivors and individuals with MS on a general level. Two more research questions were formulated in order to investigate Collider further:

1. Can a link be observed between the cognitive abilities of a patient and the game play experience of Collider?

2. Can a link be observed between the input device and the game play of Collider?

The first question is important to consider as the cognitive abilities of stroke survivors and individuals with MS may vary significantly and be related to different game play experiences. The second question is relevant as a wide range of input devices exist today that may be suitable for physical rehabilitation games. It can therefore be hypothesized that different input devices might be linked to different game play experiences. Tests were performed to provide an initial exploration of the two questions above. The setup of the tests was not intended to for making causal connections between the different variables.

6.6.1 Participants

Six participants (CVA = 3 and MS = 3) were recruited through rehabilitation therapists in the Rehabilitation and Multiple Sclerosis Center, Overpelt, Belgium. In order to examine how different levels of cognitive ability are linked to the game play of Collider, participants in both the CVA and the MS groups were assigned to either one of three categories: high, medium, or low cognitive ability. These categories were based on processing speed (SDMT) and memory (7/24 SRT, CLTR) skills for individuals with MS, and on processing speed (WAIS VI), memory (VGLT), and attention (Bourdon Vos) skills for stroke survivors. An exclusion criterion was the presence of physical problems that would inhibit participants from playing a game with the Hydra Master. This resulted in the recruitment of the participants described in 6.3. Of the six participants, one had significant experience with digital games, citing Mario Bros [232] as one of the games he played fanatically when he was younger. All others reported no prior experience with digital games and digital technology in general.

Age/ Gender	Impaired/ dominant hand	Affliction/ Level of Ability	Neglect	Cognitive Abilities			Physical difficulties
			-	**SDMT**	**7/24 SRT**	**BSRT (CLTR)**	
38F	R/R	MS - High	-	54	-	8 (pc < 5)	Limited strength (L) Spasticity (R) Exhaustion
35M	L/R	MS - Medium	-	49	34 (pc 75)	18 (pc 10)	Limited speed of execution
38F	L/R	MS - Low	-	26	24 (pc <5)	17 (pc 5-10)	Limited strength (L)
				WAIS VSI	**Bourdon Vos**	**VLGT**	
54M	L/L-R	CVA - High	-	70 (pc 2)	pc 60-70	3 (pc 10)	Slightly limited strength (L) Slight coordination problems. Slight tremor (R)
71M	L/R	CVA - Medium	-	55 (< pc 10)	pc 50	0 (pc 10)	Difficulties w/ bimanual tasks (R) Tremor Less spontaneous movement (R)
76M	L/L	CVA - Low	Visuo-spatial	45 (pc < 0.1)	-	3 (pc < 10)	Difficulties w/ bimanual tasks Limited coordination in L hand

Table 6.3: The profiles of the participants categorized according to their level of cognitive ability. SDMT = Symbol Digital Modalities Test, 7/24 SRT = 7/24 Spatial Recall Test, BSRT = Buschke Selective Reminding Test, WAIS = Wechsler Adult Intelligence Scale, VLGT = Verbal Learning and Memory Test.

6.6.2 Input devices

A Razer Hydra and a Dell Precision m3800 laptop with touch screen capability were selected as input devices. The Hydra device offers movement options comparable to those of the HapticMaster (see Section 6.4), however does not provide specific haptic feedback. Nevertheless, the Razer Hydra is significantly more affordable and easier to set up than the HapticMaster because of its small size and weight. The device is therefore relevant to explore in relation to the game Collider as it may be practically more easy to integrate in rehabilitation therapy.

The touch device offers different movement options than the Hydra and HapticMaster. Importantly, it only registers input on the screen's 2D surface, and is limited by its physical boundaries. On the other hand, the touch screen provides virtual visual feedback located at the exact point where the users interact with the screen in the real world. Additionally, touch screen devices are rising in popularity due their low technological barrier and overall ease of use. Touch screen devices may therefore be potentially relevant to include to take advantage of both these points.

6.6.3 Setup

The goal of the tests was to explore how the participants with different cognitive abilities handled the game Collider by playing either with a Razer Hydra or a touchscreen. In order to do this, a case-based approach was maintained in which the Serious Game Usability Evaluator (SeGUE)[279] was used to observe the participants playing the game. Using the SeGUE entails the recording of predefined user events (e.g. being excited) and system events (e.g. interface issues). The main advantage of the SeGUE is that it adequately captures a range of relevant game events during game play in a manner easily assessable afterwards. While using the SeGUE, the suggestion of Sauro and Kindlund [280] of defining tasks or 'error opportunities' has been taken into account. This resulted in the two matrices presented in appendix D and E. Compared to the observations and interviews of the previous tests (see 6.4), this setup provided a much more detailed registration tool.

6.6.4 Procedure

The same procedure as used in Section 6.4 was applied to introduce the participants to the tests. After the introduction, the participants were asked to play the game with the Razer Hydra for 15 minutes in total or until completing the 12 available levels. However, before doing so, they were allowed to familiarize themselves with the device by controlling the screen cursor in a level with no game elements. After this first play session, the participants were asked several short questions relating to

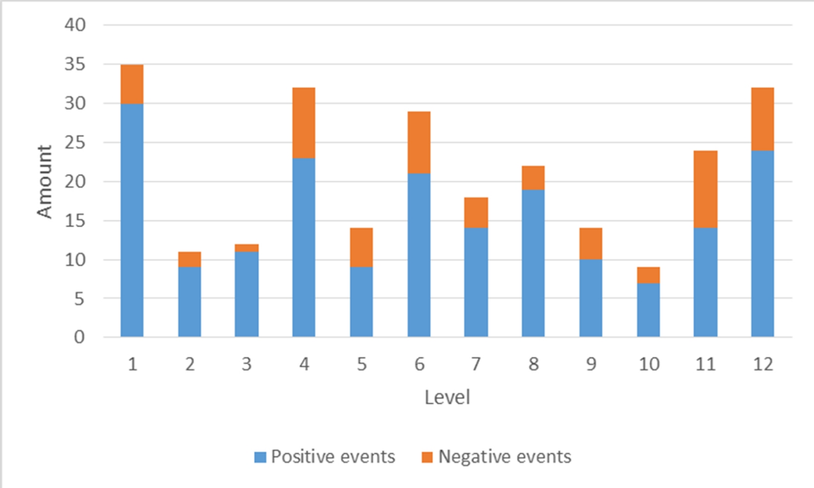

Table 6.4: The total positive and negative events registered during each of the twelve levels.

how physical and mental effort, as well as the visuals and experience of the game. Afterwards, the participants could play the game for another 15 minutes using the touch device. They were then asked which device they preferred and why. During both play sessions, two observers registered the game events as described above.

6.6.5 Results

Overall, five out of the six participants took between 16 and 21 minutes to complete the game with the Hydra device, and between 10 and 14 minutes with the touch device. Though the provided time was initially set at 15 minutes, the five participants were at the final levels of the game and wanted to proceed playing when made aware of the timing. However, one participant (CVA – low ability) was not able to get past level six in the available time, neither with the Hydra nor with the touch screen (see further below).

Of the 308 user events registered, 191 were positive and 61 were negative (see Table 6.4). Most user events were registered in the levels where a novel element was introduced and had to be learned, or where difficult challenges were located. Important to note is that both negative and positive events often depend on one another (e.g. confusion leads to reflection which leads to learning). Also, reflecting and learning appear to be an important part of the game, as can be seen in Table 6.5. Conversely, annoyance was registered only five times throughout the entire six sessions, suggesting that although participants would get confused (29) and frustrated (27), they did

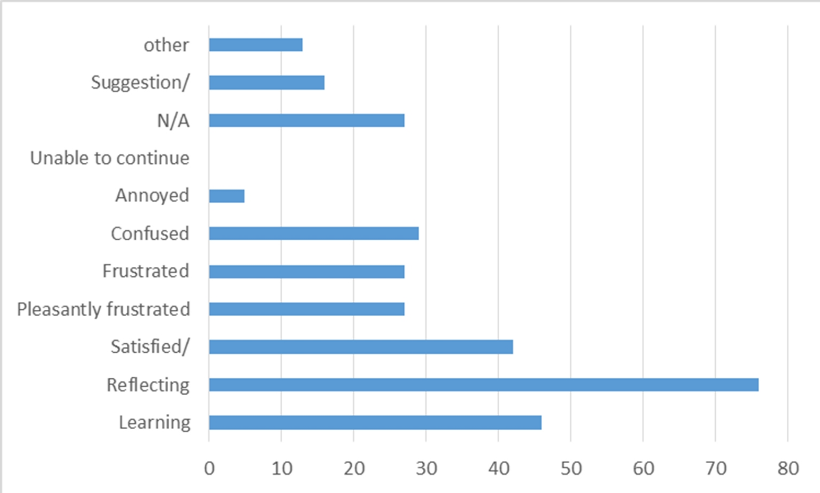

Table 6.5: The amount of total registered user events per event type.

not feel negatively about having to perform the tasks in the game. Interestingly, in all cases where satisfaction/excitement was registered, this was either at the start of the game, or when having to pass a red triangle or finishing a level. This suggests that the challenges as well as the action of finishing a level positively contributes to the player experience.

In terms of system-related events, most participants read the textual captions provided in new levels, suggesting that these can help participants understand the virtual world. However, in level six, the caption was perceived ambiguous and caused confusion for two participants. Also, two technical bugs did appear during most sessions, one in level nine and the other in level twelve, where the square moved to the wrong place (outside of the screen) after hitting a red triangle. This was resolved by the observer by pressing a short cut that resets the level. In certain levels, some participants wanted to control the smaller cube instead of the large one. Furthermore, several 'other' events were registered, primarily entailing participants physically struggling to perform an in-game task (i.e. due to inaccuracy or fatigue). Two participants explicitly rested their arm during the play sessions, though they continued shortly afterwards.

During the interviews, all participants indicated that they found the visuals beautiful and wanted to play the game further during another time if they had the chance.

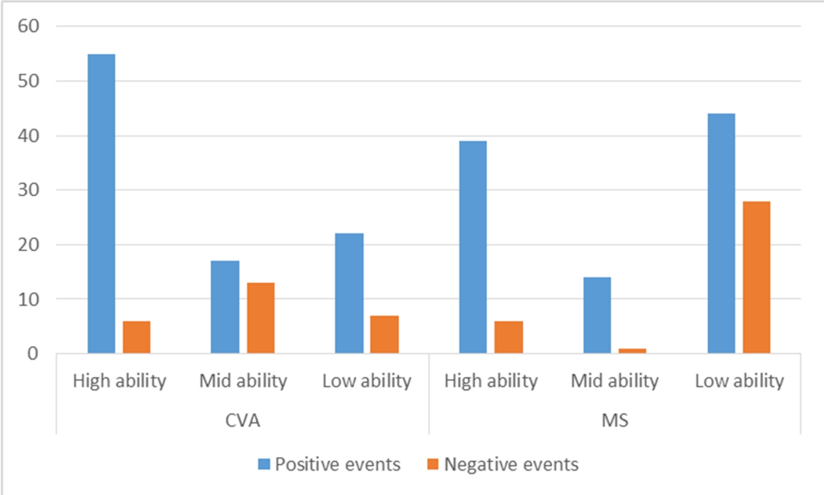

Table 6.6: The positive and negative events per ability level per group. CVA - low level only includes the events until level six, as the participant was not able to go farther.

6.6.5.1 Cognitive ability

In terms of cognitive ability, the most notable are the lower levels of ability in both the CVA and MS group. One participant (CVA – low ability) was not able to finish the game and only reached level six both with the Hydra and the touch device. The participant suggested this was due to his unfamiliarity with digital devices and games. Looking into more detail, the participant often failed to understand the role of the red triangle, assuming its trajectory should similarly not be touched. The task of pushing the square presented (non-physical) additional problems as the participant often failed to get behind the square. It is unclear whether this was a result of his low cognitive ability or unfamiliarity with digital games. However, the participants in the CVA group with mid-level ability as well as high-level ability also indicated they had no prior experience with digital devices and games (as well as two from the MS-group), yet had much less problems than the participant in question. However, these two participants did express less concern for using digital technology.

In the MS group, the participant with low ability did experience significantly more negative events in total (28), compared to the high ability participant (6), the medium ability participant (1) and overall second highest number of negative events (14). These negative events were primarily frustration and confusion, with frustration highest in the last two levels when pushing the square on a branch, and when passing level six. However, many positive events were also registered during the par-

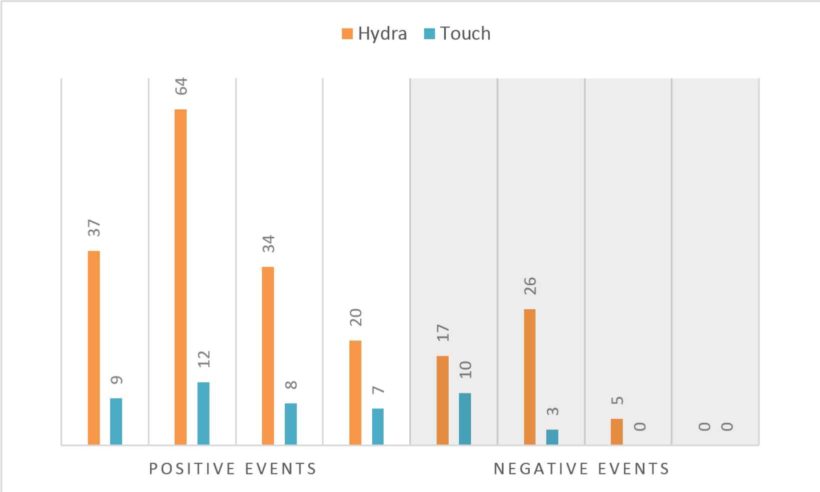

Table 6.7: The amount of positive and negative events per device.

ticipants' play sessions, and she expressed that the game was pleasant to play during the interview afterwards. Thus, having significantly more negative experiences does not automatically result in a unsatisfactory play experience.

Both in the high ability CVA and MS group a large difference between positive and negative events was observed. This may indicate that for the two participants in question, a higher-level of cognitive ability is linked to an overall more positive play experience. In the MS group, the medium ability participant was observed not to experience many negative events, yet also the least number of positive events. This may be connected to his prior gaming experience.

6.6.5.2 Input devices

During the interview, all participants expressed a desire to play the game with the touch device if they had to choose. One reason was that the direct visual feedback was enjoyable while another reasons was that the touch screen provided more physical control. One participant remarked that though he preferred the touch screen, the larger movement space of the Hydra offered him more of a physical challenge.

In all cases there were less registered events with the touch screen than with the Hydra (see Table 6.7). While for some events this difference was minimal, for others this amounted to 52 positive events vs. 23 negative events. This may be logical given that the touchscreen was used during the second play session, as a result of which they had already learned how to play the game.

Nevertheless, there were also notable events registered during the touch screen session that were specifically related to hardware issues. Most notable was the instability of the screen due to the adjustability of the laptop. Some participants pushed against the screen, causing it to hinge back further and further, with one participant pushing it all the way back. Another participant remarked that due to his tremor, in combination with the adjustability of the screen's rotation, he found it difficult to continuously and steadily keep his finger on the screen, making it harder to play the game. He suggested that a tablet, which he uses himself, could potentially resolve this issue as it provides more stability (i.e. by placing it on his own lap).

In contrast, the Hydra as a hardware device did not present such problems. Only one participant was observed to push the Hydra's buttons even though it had no effect in the game, which was mentioned on beforehand. Also, during the play session of another participant, the table had to be raised in order to raise the Hydra's central point because the participant could not reach the top of the screen where a cube was located (in spite of calibration at the start of the game).

6.7 Discussion

By redesigning the abstract minimalistic game style from Chapter 5 in relation to usability and play experience, as well as customizability for rehabilitation therapy, a specific game has been developed. Apparent is that the game shares several similarities with other physical rehabilitation games (e.g. [79, 173]), most notably its abstract minimalistic style. Yet, several significant differences exist within this style. Current rehabilitation games often contain a figurative style, and as well include elements such as an interface and a point system. Nevertheless, the presented style applies several visual, expositional and compositional techniques, involving color gradients, lighting and fine graphical details, which not only guide patients through an elaborate virtual world, but also offer them a specific aesthetic look and feel. Additionally, the simple, yet engaging challenges have almost entirely removed the need for an interface or point system. Furthermore, many of the existing rehabilitation games are directly or indirectly constructed on older game concepts such as Pong [258] or Arkanoid [272]. Conversely, the style presented in this chapter bears more resemblance to games such as Splice [260] and [267], by making more use of current physics systems as well as a large continuous virtual environment, giving it a modern look and feel.

In general, the game was well received by patients to support their rehabilitation process not only in terms of play experience, but also in relation to its style and usability. Consequently, the ambient abstract minimalist style as presented in this chapter can be considered as promising to be used by patients in a rehabilitation context.

The elements of starting the game, navigating through it, and the simple challenges could all be interested to take inspiration from in future research, as patients did not seem to have too much trouble with these and enjoyed. This is notable considering the game world is fully abstract and minimalistic, yet extensive. However, several minor problems were experienced and should be taking into account. Specifically, when patients experience too much discomfort as a result of their impairments, the game may not be enjoyable enough to make the exercises more pleasant. Of course, care should also be taken that a rehabilitation game does not worsen this discomfort. Additionally, an expansion of the challenges and the game concept, mostly in order to add progression, could cause problems. Therefore, new elements should always be properly introduced. Nevertheless, most issues were minor throughout the tests, and overall the game was found usable and enjoyable. The cognitive level of patients as well as the input device with which they play may be linked to how the game is played and experienced. However, further testing with a larger and more controlled sample is needed to make more conclusive statements on this.

Finally, the presented ambient abstract minimalist style also added opportunities for the rehabilitation therapy, which were not present in the abstract minimalistic game described in Chapter 5. More variation (e.g. direction of the lines and rotation of the square) was put into the game world, which allows therapists to add more variation to their rehabilitation exercises too. The combination with the fully abstract style further facilitates this. Exercises can easily be modified because there exists no up or down, left or right in the game world. In a figurative style, this would be harder to accomplish as the conceptual understanding of the game world would probably not resonate with significant modifications.

6.8 Limitations

The current study does not indicate how each individual game element contributes to the experience and the understanding of players throughout the game. For instance, the effect of the calm waving motion of the dashed lines, the responses of the cubes, and the overall atmosphere of minimalism cannot be assessed with the performed tests. Of course, games can be considered as holistic artefacts in which individual elements cannot be separately assessed in terms of experience and understanding. Therefore, while it would be useful, it is questionable if it would be possible to discern the exact role of each individual game element. However, the tests presented in Section 6.6 do provide more detail into the positive and negative events that could occur in each level, though further testing is needed. Furthermore, the presented ambient abstract minimalistic style is not the only possible instance of the style. As discussed in Chapter 2 (Section 2.4), design solutions are always influenced by both design context as well as the background of their designers. Further explorations could thus result in other or modified styles.

Because the ambient abstract minimalist style visually represents game objects in an abstract fashion, it may not stimulate the often preferred task-oriented [50] approach to rehabilitation. For instance, it could be argued that the game's challenges bear no resemblance to tasks patients find meaningful in their daily lives. It would therefore be interesting to explore if - within the characteristics of the style - cues could be added to the abstract objects in order to provide better analogies to real-life tasks.

Finally, the play tests were performed with a relatively small sample size, and not all participants reached the final level, more tests could therefore be relevant.

6.9 Contribution

This study contributes to the field of physical rehabilitation games in two manners. Related research, as shown in Chapter 3, only minimally focuses on the creative design of rehabilitation games and often does not provide a critical reflection on the design rationale used. Here, we specifically showed how we creatively integrated patient disabilities and rehabilitation demands into the core of the game itself with the aim of developing an overall rehabilitation game style. Secondly, we provided a specific rehabilitation game which other researchers can use as a strong example case to build their rehabilitation games on. The provided player tests offer contextualization of this case, which can guide the design decisions of their future research.

6.10 Conclusion

In this chapter, the abstract minimalistic style presented in Chapter 5 was further refined in terms of usability, play experience, and customizability towards the rehabilitation therapy, thereby creating the adapted ambient abstract minimalist style. A range of modifications have been made and subsequently tested with rehabilitation patients. Overall, the current style was received positively, although minor problems were observed. Both the design process as well as the resulting style itself could contribute to further research.

In the next chapter, the physical aspect of a rehabilitation game style will be investigated as the current ambient abstract minimalist style only includes elements relating to the virtual world. However, the physical world is also often considered an important part of digital games. A concluding rehabilitation game will be introduced and described in terms of the game style. Play tests with patients following a neurorehabilitation therapy will finally be elaborated on.

Chapter 7

Combining the Virtual World with the Physical World in Rehabilitation Games.

7.1 Introduction

During the previous chapters, our investigation primarily focused on the virtual world of rehabilitation games. While this resulted in a range of relevant findings, it would be too limited to solely examine rehabilitation games in terms of the virtual world in which they take place. Outside of the context of digital games, the attention of stroke survivors and individuals with MS following neurorehabilitation therapy is directed towards the qualities of the physical world (e.g. manipulating a non-virtual physical object). This is markedly different than dividing the attention between the physical world where exercises are performed, and the virtual world on a display screen where feedback on these exercises is provided. Simultaneously, in general game design, the concept of game play is often extended outside the virtual world to also include the physical real world [281]. An opportunity therefore exists to, as a final, additional step in this research, investigate how the concept of ambient abstract minimalism (cfr. Chapter 5 and Chapter 6) can be extended towards the physical world where rehabilitation exercises are actually performed in order to integrate digital feedback in that world. Specifically, a novel rehabilitation game Shapes and its design process are presented.

7.1.1 The play space of physical rehabilitation games

In mainstream games such as Call of Duty [237] or BioShock [263], the virtual world is arguably the most important part of the game experience. Players mainly play to be immersed in the virtual world presented on a TV or computer screen, while the real world momentarily becomes less significant. According to Salen & Zimmerman [62], this separation between the virtual game world and the real world can be described as a 'magic circle' [62]. The magic circle conceptually demarcates the meanings present in the virtual world from those in the real world. For example, in the game Mario Bros [232] players enact the role of an Italian plumber who fights turtles and other peculiar personas in order to save a princess. While this role may appear coherent and logical in the virtual world, it would be experienced as absurd in the real world.

While in many games the virtual world can be separated from the real world, this is not the case for all games [281, 282, 240]. In many recent games the demarcation of the real and the virtual becomes blurred. To make the relation between the virtual world and the real-world more understandable, we follow Nitsche's [283] distinction between the mediated space and the play space. The mediated space refers to the virtual space that is represented through a display screen or, more generally, a digital medium (e.g. computer, mobile device, etc.). Differently, the play space is the space where this medium is physically located, together with the players. Although the game elements are represented within the mediated space, the game experience results from the interplay of both spaces [283].

We believe that the play space is especially important in the context of rehabilitation games, as it is the space where the actual rehabilitation exercises take place. The overall integration of rehabilitation therapy into games can strongly benefit from an investigation of the play space. We relate this to the research of Kirkpatrick [203], who considered the act of playing a game as analogous to performing a dance. Similar to dancers, Kirkpatrick argues, players move their bodies – often time their hands and fingers –, and sway from button to button on the hardware controllers. The virtual events of the game control the pace and movements of this virtual dance, and the form and setup of the hardware controllers guide the movements of the players. For a large part, the experience of playing relies, according to Kirkpatrick, on the experience of this dance. If we follow this analogy of players as dancers, not only the virtual representation of rehabilitation exercises becomes important for the integration of rehabilitation exercises into rehabilitation games. The configuration of the physical space, or the play space, will also take a central role.

Currently, rehabilitation research largely emphasizes the play space of rehabilitation games by creating input devices that functionally support physical exercises (see Chapter 3). For example, Decker et al. [80] adapted the Nintendo Wii controller to the impairments of patients, while Fukamoto [72] accommodated foot-drop rehabilitation by building a custom input device. A limited number of researchers specifically address the play space in relation to the mediated space. For instance, Jacobs, et al. [201] utilize cutlery such as a knife and a fork as input devices, thereby transposing a real world mediated space (e.g. dining space) on top of the digital world and stimulating task-oriented exercises. Also, Hondori, et al. [284] apply augmented reality to combine real world objects with acoustic feedback. Vandermaesen, et al. [285] asses Sifteo Cubes in relation to a spatial rehabilitation game concept. In these latter two examples, replacing the input devices with other devices would most likely alter the game play itself, which indicates that these devices have in fact become an integral part of the game play. Nevertheless, these are only a limited amount of cases, which predominantly explore technological devices and do not fully explore the mediated spaces themselves.

7.1.2 Observations on the play space during a rehabilitation session

In a first instance, we explored the concept of play space win a real-life rehabilitation setting by performing small-scale observations in the MS- and rehabilitation center of Overpelt, Belgium. Observations are valuable to gain insights into the context and physical environment in which multiple actors operate during a certain activity [286, 287]. Therefore, the aim of these observations was to gain information on how the concept of (play) space was used in a specific rehabilitation therapy session. In order to do this, we requested therapists if it was possible to observe a therapy session, without any intervention from ourselves apart from sitting in the same room. Over the course of three hours (a full afternoon of rehabilitation therapy), unstructured observations [286] were performed of a number of patients - both CVA and MS-patients - and therapists who worked together during rehabilitation therapy. In the following two sections, the observations as well as our reflections on these observations [287] will be discussed.

The rehabilitation session took place in a large open space (see Figure 7.1). Although there were no walls, the space was divided into multiple areas with the use of a table, desks, and cabinets. On several of the desks, digital computers were located that were attached to different input devices (e.g. keyboard and mouse, etc.). In the cabinets, non-digital items and games were stored, such as play cards, board games, wooden puzzles, and nuts and bolts. Before the beginning of the therapy session, the table was completely empty and surrounded with chairs.

During the therapy session, five therapists were located within the open space and received a range of patients over a period of three hours. Patients entered and exited the space following a fixed schedule, often by themselves, but in some cases with the help of personnel of the center. Each patient was given a specific place to sit or stand. This place was dependent on either the exercises they needed to perform (i.e. on

Figure 7.1: A picture of the described rehabilitation setting.

a computer or non-digital exercises), or where smaller rehabilitation items could be placed (e.g. on the table). The therapists selected these items from the cupboards and placed them in front of the patient, while subsequently providing a short explanation of what exercises they needed to execute them with. In some cases, the patients were required to wear wristbands with weights during the exercises.

Patients were given specific exercises to perform (e.g. turn over each playing card), which meant that therapists did not need to constantly monitor them. As a result, the therapists continuously switched between multiple patients . However, they did stay with some individual patients for longer periods of time (e.g. ten minutes) to guide them through a specific set of exercises. In this case, therapists did not always use external aids, but also applied other types of exercises (e.g. firmly pinching the therapist's hand). Because of the space's open character, therapists could easily oversee other patients and help them when necessary, though this only happened a limited amount of times.

At peak moments, up to six patients and five therapists occupied the rehabilitation space, and more patients were standing to the side, waiting for their time slot. A number of these patients increasingly interacted with one another. For example, two patients, one active and another watching from the side were making small talk. Two other patients were playing a multiplayer board game, and naturally interacted with one another throughout the game. At one instant, a game piece fell from their board on the floor, and a patient waiting for his own therapy spontaneously entered the rehabilitation space to help pick up the piece. Not all patients engaged in interaction with others. Some were discretely doing their exercises, especially those who were located at computers.

In terms of physical space, the two aspects that stood out the most according to the observer were the physical rehabilitation aids and the social dynamics between patients. The physical aids were easy to handle by the therapists, as these could be simply retrieved from and stored in the cabinets whenever needed. Additionally, these physical aids were also easy to handle by the patients. For example, when an object fell on the floor, patients could easily fix this problem themselves, or with the help of other patients. Furthermore, the therapists were able to assign exercises to patients without much trouble. In a short conversation after the observations, one of the therapists stated that physical aids are above all useful when multiple exercises can be assigned to a patient. With a deck of cards, for instance, therapists can designate a wide range of exercises to patients (i.e. turn each card over, move each card to a different location, etc.). However, a downside of some of the physical items was that they appeared dull to use. For instance, the exercise with the nuts and bolts consisted simply in securing them to a panel without any further goal or motivation. Finally, the open character of the rehabilitation space seemed to positively stimulate social interactions between patients. Most therapists and patients seemed to enjoy the atmosphere this produced.

7.2 Shapes: an integration of virtual game elements in play space

Throughout this dissertation, digital games and physical rehabilitation therapy have been investigated by predominantly applying an exploratory design approach. This permitted us to identify a range of design elements that facilitate the integration of digital games and rehabilitation therapy. These elements mainly related to the virtual world or mediated space of rehabilitation games. However, in the previous sections, the physical space outside of the virtual world or the space in which the rehabilitation exercises are physically performed, was identified as a relevant aspect of both games and rehabilitation. As such, taking into account these two spaces reveals an opportunity to weave the mediated game world into the physical world. In particular, insights may be gained on how the virtual game elements defined in previous chapters may be translated towards physical game objects.

In the following sections, a novel rehabilitation game (Shapes) is introduced together with its resulting physical ambient abstract minimalist style. Additionally, the results of play tests of the game with patients following a neurorehabilitation therapy will be presented. First the design elements of this game will briefly be outlined. Afterwards, the design process leading up to the game artefact is summarized. Then, the designed artefact itself is described along with a reflection on the underlying design rationale. Finally, the results of play tests are presented to discuss the use and acceptance of the game with actual patients.

7.2.1 The design elements of the play space

Throughout this dissertation, a number of virtual game elements have been discussed. In this section, three additional physical game elements, taken from experimental game design, are introduced (see Table 7.1). Afterwards, these virtual and physical game elements are integrated into the rehabilitation game Shapes.

7.2.1.1 The spatial configuration of the display screen(s)

Experimental games often incorporate multiple display screens and use their spatial and dimensional properties as a crucial component of the play experience. For instance, the game Scattershot [288] is displayed on an enormous screen hanging on a large wall (similar to the showcasing of Collider (see Chapter 6) in the public art

Virtual World	Physical World
Use game mechanics as the basis of the game's design to merge virtual actions with real-life rehabilitation exercises.	Spatially configure display screen(s) to reflect the physical rehabilitation space in the game's hardware.
Use the abstract minimalist design style to incorporate a minimal amount of game elements and attributes that may conflict with patient disabilities.	Use the physical materials as an essential part of the game.
Use the abstract minimalist style to easily adjust the setup of the game;	Integrate virtual feedback into real objects;
Use simple mechanics that avoid fast reactions of patients (though not excluding it), but allow them to enjoy time-pressure.	Build upon the real life setting and the physical objects already used in the rehabilitation therapy as an example.
Apply lighting, color and graphical detail to guide the players through the game world, and offer them an aesthetic visual experience;	
Present the virtual world as simply as possible, then gradually expose the players to more challenges and meanings of the game.	
Use compositional techniques to direct the perception of players to guide the players through the game world;	

Table 7.1: The rehabilitation game design elements discussed during this dissertation divided into virtual and real world elements.

exhibition “The Bridge”). Another game, Bounden [289], requires two players to simultaneously hold a single smartphone, and provides them with visual incentives to move and rotate the device as if they were dancing partners. Finally, the game B.U.T.T.O.N. [149] draws attention away from the virtual screen and makes the space in front of this screen a battleground where players fight one another. These examples indicate that digital games do not necessarily need to be displayed on a single computer or television screen and that the virtual world can be represented through different conceptualizations of a display screen.

7.2.1.2 The material qualities of the gaming hardware

While the content portrayed inside the display screens (i.e. the virtual world) is often emphasized in digital games, experimental designers additionally focus on the material qualities of the screens themselves, and on the accompanying game controllers. For instance, the collaborative works of Eric Zimmerman and architect Nathalie Pozzi such as Sixteen Tons [290] and Interference [291] show a remarkable detail on how the game is presented in the real world, reminding at times of a sculpture rather than a game (Cross my Heart + Hope to Die [292] brings to mind sculptor Richard Serra’s The Hedgehog and the Fox, for example). In a similar instance, the game Currency [293] hides its technological and digital structure, and instead presents a more material and analogue appearance by using an antique typewriter as its outer skin.

7.2.1.3 The integration of the digital feedback in the physical world

Closely related to the concept of material qualities is the integration of digital feedback and physical materials. While the virtual and the real are often separated by means of computer and TV displays, as well as popular input devices such as keyboards and X-box controllers, several experimental games carefully combine these together. For example, the game Currency [293] provides feedback in the form of printed notes, although the input of players is processed entirely digitally. In the social game Johannes Sebastian Joust [294] and the similar Henka Twist Caper [295], the PlayStation®Move motion controller , the digital feedback is entirely provided by a single light, therefore rather resembling an object than a display screen with numerous lighted pixels. Finally, the gaming system PainStation [296] provides feedback through heat, electrical shocks, and whippings on the player’s hand, giving it an especially sensory and physical feel.

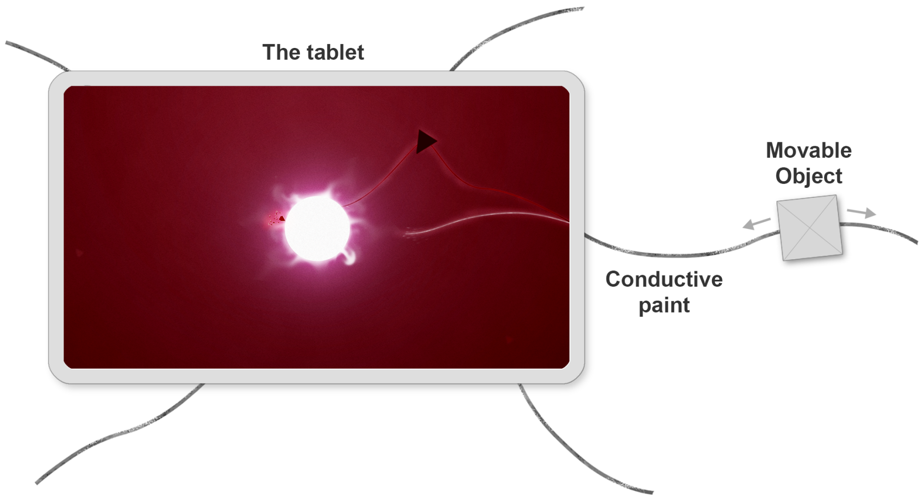

Figure 7.2: A representation of a virtual game world displayed on a tablet and connected to a real world object through conductive paint.

7.2.2 Initial game concepts

In order to produce the game Shapes, two initial game concepts were created. The first concept utilizes the virtual world presented previously in Chapter 6 as it appeared relevant to integrate due to its availability and relative success with patients. In the concept, as portrayed in Figure 7.2 the virtual world is displayed on a seven inch tablet with touch capabilities. In the virtual world, players need to connect virtual lines from the outer edges to the middle of the tablet's screen. On the outside of the tablet, in the real world, patients can push physical objects along a line of conductive paint to influence the lines in the virtual world. Thus, by moving objects along real world trajectories, patients affect the virtual world. A small prototype of this concept was developed, and while this appeared as an interesting game concept, the display screen remained largely separate from the play space in terms of virtual feedback. The creative persons' adage "kill your darlings" [297] was consequently applied to do away with the concept and establish one that fits the goals better.

The second concept used the physical world as a starting point, and was specifically directly inspired by on the play art movement[1]. During the conceptual design stage of the game, the author visited the Museum of Modern Arts in New York where a retrospective exhibition of Brazilian painter and installation artist Lygia Clark was

[1] http://www.playart.org/

on display. In this exhibition sculptures were shown that Clark referred to as Bichos: artefacts of varying sizes (typically around 40x40x40cm) consisting of thin metallic plates linked together with hinges. Different than many artworks in a museum, Bichos can be touched and played with, this by rotating and reconfiguring their metallic plates. Clark's artefacts were eventually used as a starting point because they combine the physical and the playable in a single, controllable object. The resulting concept is elaborated on in the following sections.

7.2.3 Overview of the game play

Before discussing the design rationale and how the design elements presented in Table 7.1 were used, the game itself will be described. It consists of a collection of physical interactive objects with simple geometrical forms as shown in Figure 7.3. The outline of these objects is shaped by polygons or plane surfaces. A number of these polygons provide interactive input and output capabilities. For example, these polygons light up either when players touch them or when two or more objects touch one another. As each of these interactive polygons have their own sensor and light, a wide range of light-configurations can be achieved on a single object, and even more when multiple objects are combined.

The overall goal of the game is to combine the individual objects in a wide variety of arrangements. This is done by performing basic physical actions such as lifting, rotating, dragging or pushing these objects in order to bring them together. Whenever a different combination is formed, the color and brightness of the interactive polygons is altered, and whereby new courses of action are suggested. There is not one specific goal or set of rules for the game. Rather, the objects can be arranged according to different sets of rules and goals depending on the needs of the therapists or patients. For example, one game can be that all polygons individually have to be lit, while another game can be that specific polygons need to have specific colors. The artefacts can be considered as facilitators of play, rather than concrete games. Still, the overall game mechanic of connecting these objects directs the course of the gameplay and stimulates the use of physical actions.

In the current setup, there are three different objects: a cube, a sphere and a cylinder. All three objects have different shapes and sizes, as well as different sizes of interactive segments. These shapes and sizes affect how patients perform physical actions in order to spatially configure the objects. For example, the cube has six segments with relatively large surfaces (ca. 6cm²) that are positioned in 90° angles to one another. While the sphere also encompasses six segments, these are considerably smaller (ca. 1cm²) and positioned in angles of 90° and 45°. Consequently, different rotations and accuracy levels can be established to connect objects. Also, depend-

Figure 7.3: The game pieces (a sphere, a cylinder and a cube).

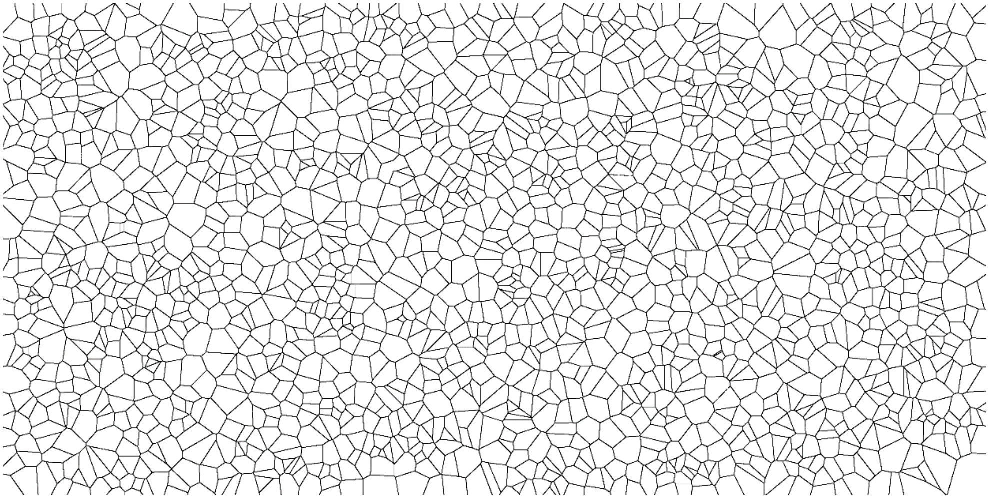

Figure 7.4: A Voronoi Pattern.

ing on how the objects are initially positioned, different paths of movement can be achieved.

Visually, the game objects are abstract and are created from simple materials such as matte plastic and wood. With only black and white, the color scheme is kept simple and is mainly used to highlight segments. The interactive segments themselves are created of Voronoi patterns[2] (see Figure 7.4), with light shining through these patterns.

7.2.4 Rehabilitation exercises and input devices

The prototypes and games presented in previous chapters employed the principle of representing real-life motions with abstract virtual lines. However, the absence of a high-resolution display screen prevents the inclusion of this principle in the game Shapes. Instead, the exercises are free and dictated by the dimensional features of the game in combination with the underlying algorithm of the lights. Consequently, these exercises can be related to daily tasks in which objects have to be lifted, transported, and rotated. In this respect, the task-oriented principle (see Chapter 1) of rehabilitation is arguably more prolific in Shapes than the previously presented game prototypes and game. An overview of the most relevant tasks and their physical and cognitive requirements is provided in Table 7.2

Unlike the games described in the previous chapters, Shapes is not controlled by a

[2]http://www.raymondhill.net/voronoi/rhill-voronoi.html

	Lifting	Transporting	Rotating	Touching
Physical parameters				
Free movement (2D)*	x	x	x	
Accuracy*		x		
Timing*			x	x
Range of motion	x	x	x	x
Stabilizing				x
Cognitive parameters				
Visual recognition	x	x	x	x
Hand-eye coordination	x	x	x	x
Spatial insight	x	x	x	x
Anticipating action	x	x	x	x
Strategic thinking	x	x	x	x

Table 7.2: An overview of the most relevant tasks and their physical and cognitive requirements needed to play the game Shapes. *parameters that can be adjusted in difficulty.

separate input device. Instead, the physical objects themselves are the input devices. The gameplay itself thus depends on the objects, and cannot be played with other input devices. Similarly, the difficulty adjustments of the game are less dependent on the virtual world, and more dependent on the physical properties of the game objects. For instance, the difficulty of handling relies on the size and shape of the objects, while the required accuracy depends on the surface size of the different segments.

7.2.5 Relevant game design elements

In this section, the design rationale of Shapes is described in order to highlight how its various design elements were incorporated. This description is divided into three subsections: the physical pieces and space, the game concept, and material aesthetics. Afterwards, the features are discussed in relation to play tests with rehabilitation patients.

7.2.5.1 The physical pieces and space

The main goal of developing Shapes was to incorporate the physical space of the rehabilitation setting into the game's concept. To achieve this goal, several physical pieces or shapes were used as an initial starting point of the design process, such as a cube, a cylinder and a sphere. The design elements described above (see Subsection 7.2.1), such as integrating digital feedback into physical objects, were then incorporated into these pieces.

In a first instance, the spatial configuration of display screens that visualize the virtual world was taken into account. As no traditional display screens with a large pixel resolution were used, simple LED-lights were integrated that provide the players with simple, single-pixel feedback. As such, each interactive segment portrayed a single state at one particular time through one color. In order to combine the spatial configuration of these LEDs with the physical characteristics of the objects, they were distributed along the objects' shapes. As a result, the virtual feedback of the game is literally wrapped around the physical shape of the objects. Furthermore, the game's feedback was mixed with the material qualities of the objects in order to combine the virtual and the real. For example, while in many games the hardware of the display screens often needs to be forgotten or looked past during play, in this case the hardware was emphasized by the addition of an extra physical layer on top of the LEDs. The rays of light that transport the feedback of the game to the eyes of the players must travel through three layers (the outer pattern, a diffusing sheet, and a diffusing synthetic material) on the outside of the segments (see Figure 7.5). Accordingly, these rays and the physical material intermingle with one another, making it difficult to distinguish between the virtual and the real.

In a second instance, the setting of the rehabilitation therapy and the preferences of the therapists as described in section 7.3 were also taken into account. The game objects are relatively small, compact and portable. Consequently, they can easily be stored in the cupboards available in a rehabilitation space, and be taken out whenever necessary. Furthermore, turning the objects on and off only takes a few seconds as no large files need to be loaded into the game hardware, which may stimulate the flow of the therapy sessions where therapist often switch between devices. Additionally, the fact that the objects have different sizes and shapes, allows therapists to directly adapt the game to the capabilities of individual patients. For instance, patients with different handgrips may select objects that best suit their grip (e.g. large vs. small, round vs. cylindrical), without changing the core of a game.

7.2.5.2 Game concept

The game mechanics were a main concern during the design of this game. The main reason why players perform physical actions (e.g. moving and rotating the objects) is to reach the game's goal. No 'redundant' design elements such as visuals or narrative were included as central parts of the game play. Following the minimalist design approach, only one type or function was used for each object. Although different object forms (e.g. a cube or a sphere) have been included, conceptually these are

Figure 7.5: An open lighted segment of the cubical object of which the three outside layers (outer pattern, diffusing sheet, and diffusing synthetic material) are separated from one another.

utilized in the same fashion. As such, the players need to remember only a small amount of information, while the differences in shape provide variety.

In the virtual game presented in Chapter 6, the main goal of each level was to push a virtual square across a line in order to bring it to another square. This was a fairly straightforward assignment that was easy to present in an abstract visual style. One of the benefits of this abstract style was that within different levels the squares and lines could freely be repositioned in a variety of manners without breaking the logic of the game world. In the current physical game, a similar benefit is attained by the use of abstract game objects. Because the pieces have no specific orientation or 'right' meaning, they can be positioned and rotated in any conceivable manner without the logic of the game being broken. On the one hand, this provides a high degree of flexibility to adjust the game to the needs of individual patients. Objects can easily be placed closer to the patients if they cannot stretch their arms very far, or other shapes may be used to accommodate the handgrip of each individual patient. On the other hand, this also provides a wide range of options for patients to complete the game. Patients do not have to follow one predefined route of action to address the challenges, but can choose one that is suited to their abilities. To present these choices in a subtle manner, a simple rule of 'connect color x with color x' was implemented. As such the rehabilitation goal of the patients remains clear, while players have the ability to choose how they attain that goal.

7.2.5.3 Visual and material aesthetics

In the previous two sections the central objects of the game have been described in relation to the functionality of the physical rehabilitation therapy. In this section, the visual and material aesthetics are discussed that have been implemented on top of this functional layer. While it is important to provide functionality, the aesthetic qualities of a game may incite patients to enjoy the game more strongly. The results of the play tests discussed in Chapter 6 have indicated that the visual characteristics of the game were well-received by the patients. Our intention, then, was not to solely create a functional device, but one in which functional and aesthetic qualities are used to enforce one another.

The virtual game presented in Chapter 6 used compositional and expositional techniques to stimulate an easy start for patients. For this purpose, detailed shapes, colors and lights were used. In the current game the low-level visualizations with the LED-lights prevented us from integrating such details. Nevertheless, a number of steps were taken to ensure that patients could easily start the game. Naturally, physical objects encourage to be explored as they are designed in a visually attractive manner and are actually placed in front of the patient. Whereas in a virtual game world patients first need to decipher the meanings of the game, the pieces used in this game are recognizable and comparable to objects patients see and use in their everyday lives (e.g. the cylindrical game piece as a drinking glass). Specific materials were used to encourage patients to pick up objects. For example, the skeleton of the objects is made of a soft white plastic, while the segments are made from wood painted black. These materials and colors were meant to give the objects a non-technological look, as if objects they would pick up in their daily lives. Furthermore, the shapes of the objects are simple and relatively compact, yet, their unconventional appearances provide them with a mysterious look and feel, designed to incite players to explore them further out of curiosity.

In the game Collider discussed in Chapter 6, the virtual game world contained small cubes which players could interact with, and that indicated they were making progress. Additionally, these cubes provided an interesting visual display by adding subtle complexity and making the game world seem more interesting, without disrupting the play experience of patients. In a similar manner, in this game, we have added some complexity to the patterns of interactive segments (see Figure 7.4). These patterns, resulting from a relatively long process of experimentation (see Figure 7.6), add some visual complexity to an object, but do not hinder its usability. Additionally, these patterns, in combination with the light, provide an interesting light play (see Figure 7.5)

Finally, LED lights were visually designed in a manner to make the game feel more responsive. In the game Collider of Chapter 6, the virtual lines smoothly waved up and down, giving a relaxing atmosphere to the game. While such visual detail could not be achieved with LEDs, a rhythmical movement of fade in and out was programmed, which mimicked the movement of the virtual lines of Collider.

7.2.5.4 Technical design

A number of prototypes were constructed in order to technically produce the three dimensional game pieces and incorporate the necessary electronic components. In a first prototype, the overall viability of the game concept was explored by means of simple cardboard boxes (see Figure 7.7) integrated with an Arduino Uno microcontroller[3] powered through a USB wire. This microcontroller was connected to single color LED-lights and capacitive sensors[4] (made out of aluminum foil) attached to several sides of the boxes. As a result, physically connecting the sensors of different boxes allowed the Arduino devices to register the position of one another, and light the corresponding LEDs to provide visual feedback. This first prototype revealed that this setup could potentially support the development of the game concept if investigated further.

[3]http://arduino.cc/en/Main/ArduinoBoardUno

[4]http://playground.arduino.cc/Code/CapacitiveSensor

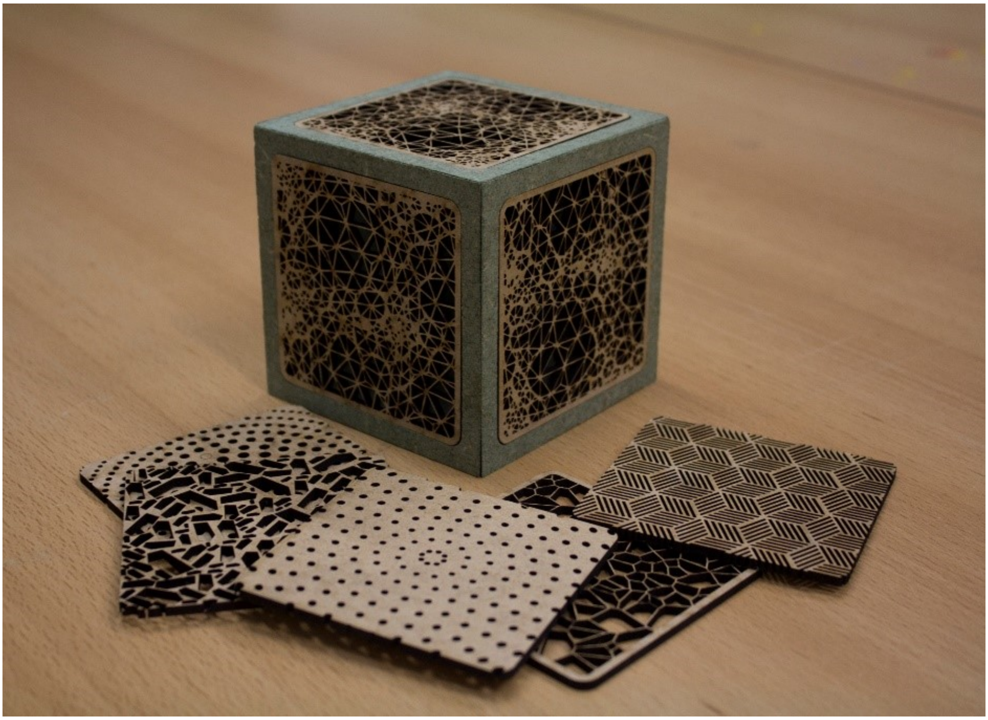

Figure 7.6: Different types of segment patterns on a prototype of the cubical game piece.

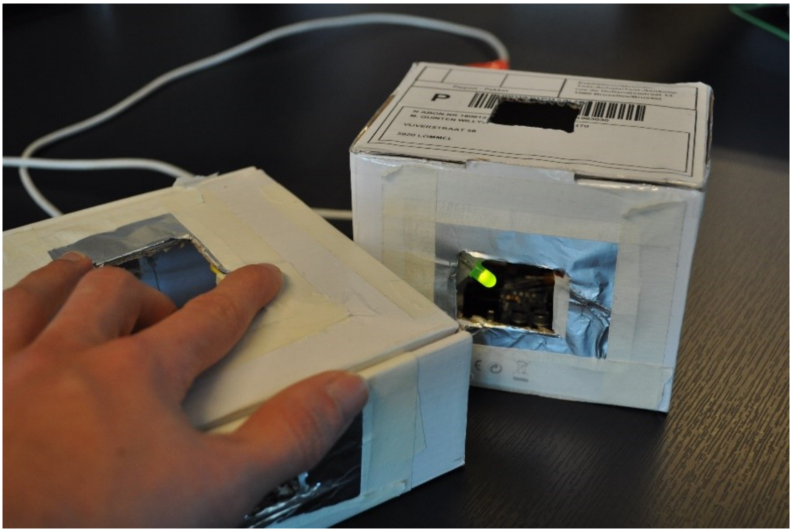

Figure 7.7: The first prototype of the game made with simple cardboard boxes and aluminum foil.

A second prototype was built to investigate how three-dimensional shapes could be used as carriers of multiple lights without these lights interfering with one another. A cubical game piece was therefore created out of paper sheets folded into numerous compartments joined together with paper clips (see Figure 7.9). The technique of using different compartments was adopted in subsequent prototypes in order to prevent visual interference between the different lights. However, the prototype simultaneously revealed that with this technique, the three dimensional shapes become large in size as each compartment required a minimal amount of depth to adequately spread the light. Additionally, it showed that the Arduino Uno would need to be replaced by a smaller alternative as it took too much space.

In the third prototype, the electronic components were examined more in depth in order to develop smaller objects that could emit a wide variety of colors . This resulted in the wooden version integrated with the technology shown in Figure 7.9 in which five aspects were of critical importance: the microprocessor, the lights, the touch sensors, the batteries, and the outside segments:

- The Arduino Uno microprocessor was replaced with the RFDuino microprocessor[5] which is much smaller (ca. 16 times, 15x15x2mm) and thus allowed for the development of smaller game pieces. The RFDuino was selected over other

[5] http://www.rfduino.com/

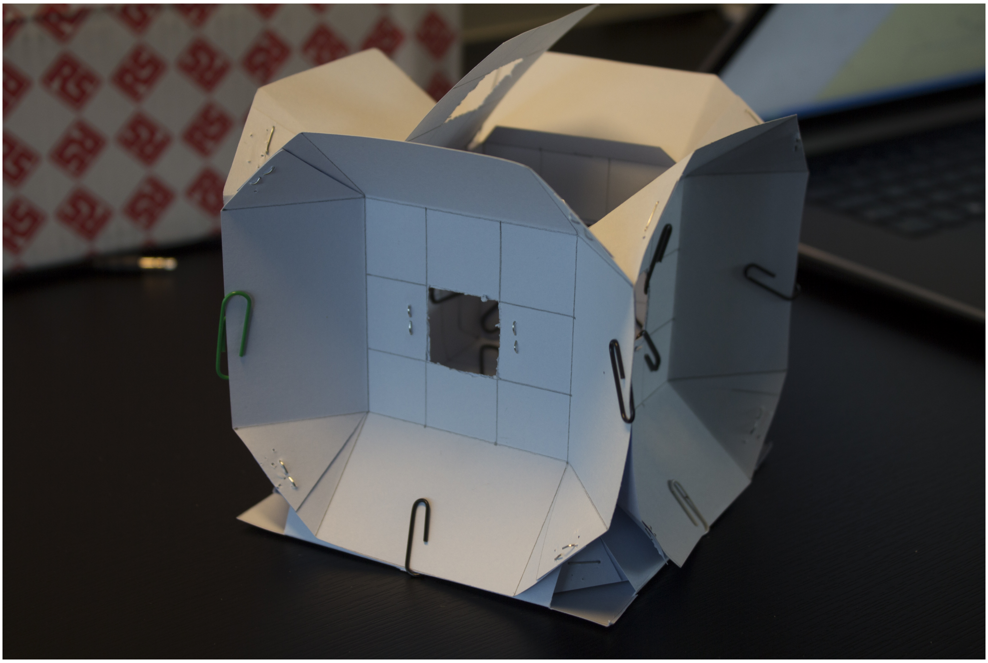

Figure 7.8: A second prototype made out of folded paper and paper clips to explore the three dimensional setup of the game pieces.

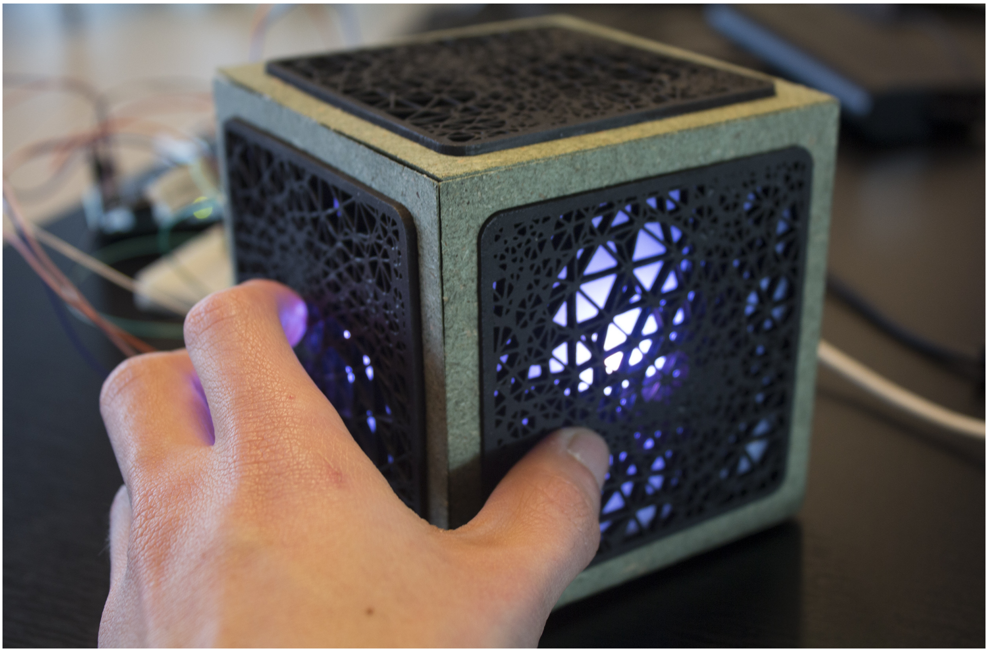

Figure 7.9: A wooden version of the paper prototype integrated with technology.

options such as the TinyDuino[6] and the MicroDuino[7] because it automatically integrates wireless Bluetooth communication between up to eight RFDuino's. This feature is discussed below in relation to subsequent prototypes.

- When using single colored LED-lights, a large quantity will be needed to provide a full color range: three LEDS: red, green and blue on each side of a three dimensional shapes (six sides on a cube, therefore 3 x 6 = 18 LED-lights). In order to control these lights, they each need an output/input pin on the microprocessor to supply the necessary signals. However, the RFDuino only has seven of such pins, and thus cannot directly power this amount of LED-lights. As a result, the 74HC595 shift register[8] was first incorporated to control each light with only three output pins. However, this shift register required a large amount of wiring, which would be difficult to connect in smaller game pieces. Therefore, in a second instance, the NeoPixel LEDs[9] were used because these require only one output/input pin and less overall wiring to control an almost

[6]https://tiny-circuits.com/
[7]https://www.microduino.cc/
[8]http://www.arduino.cc/en/Tutorial/ShiftOut
[9]https://www.adafruit.com/neopixel

endless string of LEDs.

- The capacitive sensors used in the first prototype, disposed of no additional hardware other than the aluminum foil, and required only one output/input pin per sensor (six for each side of a cube). In order to reduce the number of pins, the MPR121 Capacitive sensor breakout board[10] was integrated, which requires only three output/input pins to control up to twelve capacitive sensors, making a cubical shape, but also more complex shapes (e.g. the cylinder game piece) technically feasible with the RFDuino. Additionally, the aluminum foil was replaced with conductive paint, fulfilling the same technological role as the foil, but provided more flexibility in construction and a less technological look (see Subsection 7.2.5).

- Because the goal was to create wireless objects, the USB connector providing power to the first prototypes needed to be replaced with batteries. The main concern during the selection of these batteries was the trade-off between size and power capacity. While the RFDuino's current consumption is relatively low, the NeoPixel LEDs require maximum 60mA per light which is relatively high. Therefore, a wide range of batteries were compared (AAAA, AAA, 9V batteries split in two, and coin cell batteries). Eventually, coin cell batteries were selected as these are relatively small and at the same time provide enough power.

- The outer segments were created out of 3mm thick MDF wood formed with a Laser Cutter. Underneath this wood, a matte transparent paper and a low density foam sheet was placed to diffuse the light. A thin copper wire was then glued on each segment's backside which connects to the MPR121 Capacitive sensor breakout board.

In the fourth prototype, it was explored how the previous prototype could be applied to three dimensional shapes other than a cube. As such, the Open Source 3D computer graphics software product Blender3D[11] was used to virtually design a variety of objects (see Figure 7.12). Initially, less conventional shapes were designed. However, to keep the project practically manageable, simpler shapes such as a cube, a cylinder and a sphere were used, as these could just as well serve in a rehabilitation therapy context.

These virtual objects were then transformed into real-life objects. First, two game pieces were sliced in a large amount of slices using the Autodesk 123D Make software[12], cut with a laser cutter, and then glued together (see Figure 7.13). These initial

[10]http://bildr.org/2011/05/mpr121_arduino/
[11]http://www.blender.org/
[12]http://www.123dapp.com/make

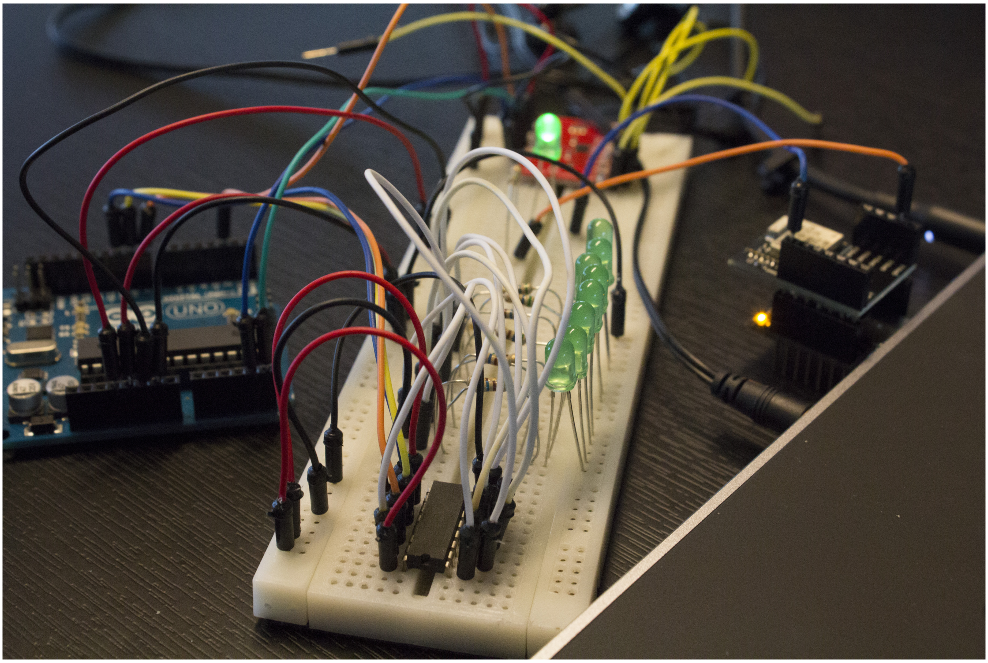

Figure 7.10: Controlling eight LED-lights with the 74HC595 shift register and registering capacitive touch with the MPR121 Capacitive sensor breakout board.

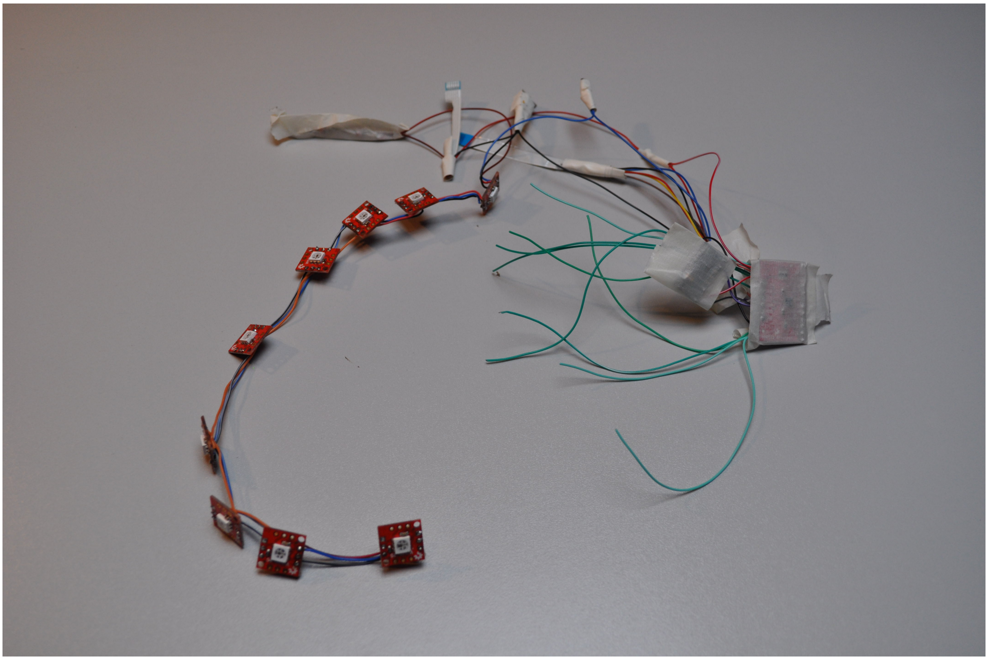

Figure 7.11: The electronic circuit with the NeoPixel LED's, RFduino, and the MPR121 Capacitive sensor breakout board.

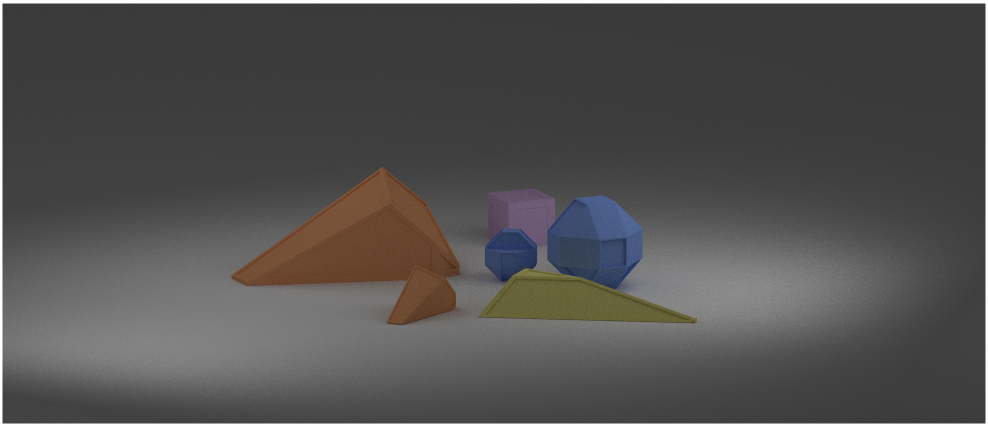

Figure 7.12: The virtual game pieces drawn in Blender.

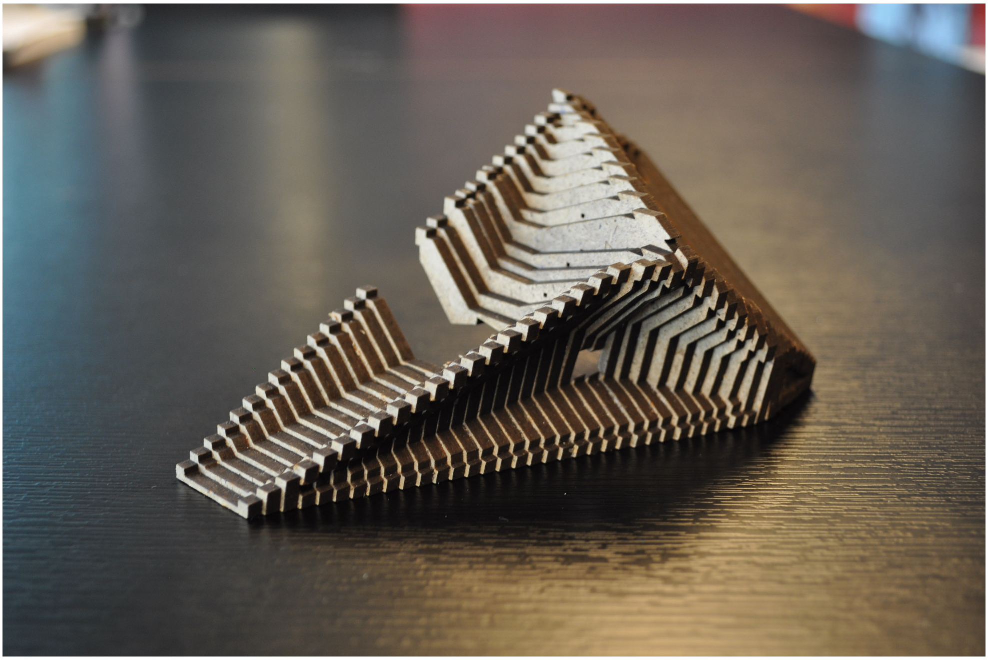

Figure 7.13: An initial game piece created out of multiple laser cut slices glued together.

objects gave a low-cost impression of the size of the objects in real-life, and showed that the batteries and other technologies could fit into the shapes. Afterwards, the eventual shapes were 3D-printed and integrated with the full technology.

7.2.6 Presenting a prototype to therapists

Before performing play tests with patients, the third prototype version of the game (see above) was presented to and discussed with seven rehabilitation therapists. This allowed us to determine if the game objects could be considered as relevant additions to a rehabilitation therapy. Furthermore, the pretests indicated if changes needed to be made in terms of usability. Overall, the therapists displayed a positive interest in the game objects, stating that they are simple and tacit objects and that they would be inclined to use them during their own therapy sessions. However, they did suggest that the use of additional shapes would support different handgrips of patients, such as a cylindrical and flat from. For this reason, a cylindrical form was eventually included.

7.3 Play test with patients following neurorehabilitation therapy

Play tests were performed in order to determine if patients could physically use the above presented game Shapes, and if they would be willing to play it in their own scheduled therapy commissioned by therapists. In a first instance, the tests addressed the physical and conceptual abilities of patients to manipulate the physical pieces. In a second instance, the tests targeted how the patients experienced playing with the game objects and how they perceived them visually. Two additional pilot tests were performed before the tests with patients took place, to check if the setup of tests was logical and if the objects functioned correctly. Small changes were made as a result of these pilot tests, most notably in terms of the affordances and colors of the lights (see below). Due to technological limitations, the colors blue and green appeared similar when more power was drawn (i.e. more lights were switched on). In an attempt to solve this, the color red instead of blue was used. However, the same difficulty of was distinguishing between the red color and green color was noticeable.

7.3.1 Participants

Four patients recovering from stroke were selected by rehabilitation therapists working in the MS and Rehabilitation Center (RMSC) in Overpelt, Belgium to be included in the play tests. The therapists were asked to select patients who were physically as well as cognitively sufficiently able to minimally control the above presented game objects. Consequently, three men and one woman were included in the study, ranging between the age of 70 and 84 years as indicated in Table 7.3.

Age	Gender	Impaired limb	Affliction	Neglect	Physical difficulties	Cognitive/visual difficulties
70	M	Right	CVA	-	Strength 2+ to 3-	-
81	F	Left	CVA	Left	Limited mobility and strength, difficulties with selective moving	Limited attention span and short term memory, Impulsive
84	M	Right	CVA	-	Limited strength, difficulties with selective moving	-
70	M	Left	CVA	-	Minor difficulties with hand-eye coordination	-

Table 7.3: The profiles of the participants included in the tests.

7.3.2 Procedure

The play tests were divided into three stages: (1) physically manipulating the objects without any use of digital feedback, (2) physically manipulating the objects in response to rudimentary digital feedback, and (3) physically manipulating the objects in response to more complex feedback. In the first stage, the aim was to investigate how the patients utilized and experienced the objects based on their physical characteristics (e.g. shape, size, weight and material). Patients were asked to perform three actions needed to complete one possible assignment. They first had to move each object to five marked locations on the table in front of them. Then, they were requested to rotate each object multiple times based on the directions of the instructor (e.g. rotate the object so that the top segment rests on the table's surface). Finally, the patients were asked to physically link two segments of different objects together by moving and rotating them. In this first stage, as well in the subsequent stages, the patients were told to complete the given tasks in their own manner, in order to reflect a real-case scenario. However, they were requested to only move one object at a time, preferably with their affected hand. All given assignments involved performing physical actions that had not been not explicitly stated, such as grabbing and picking up an object.

In the second and third stages, the objective was to establish how the patients handled the digital feedback of the game. The patients were also introduced to the visual qualities of the game (i.e. the light effects). At the beginning of the second stage, the algorithms within the objects were altered (through a wireless connection) so that one segment of the cube as well as one segment of the cylinder lit up with a blue color. The patients were then told to physically connect the segments that were lit blue. If successful, the lights and would be shortly dimmed, to light up again in new segments, thereby encouraging patients to move/rotate and connect the objects again. In the third stage, the principle of connecting two blue-lit segments was maintained. However, the lights would automatically change to different segments after a fixed time of around six seconds. Whenever two blue lights were correctly connected, the segments of the cubical and the cylindrical game piece would turn green and, conversely, when incorrectly connected, would turn red. The challenge for the patients was to obtain as many green lit segments as possible on the cylinder. The red and green lights on both objects would inevitably fade away so that in time all segments could be reused. During the third stage in one of the tests, the objects failed to provide the correct color of lights preventing the participant to complete the game at that stage. As a result, the associated results of this person test were omitted, as indicated.

A post-test interview and observations during the tasks were applied to investigate the manner in which the patients used and experienced playing with the game objects. The patients were introduced to the interview and observation through an oral and written explanation of the tests, explaining the design. It was made clear that the participants could stop at any time if they wished, and that not the user was tested, but the game. The interview was divided into three sections of questions, which related to: performing actions with the objects, the visual properties of the objects, and the experience of the interactions with the lights. The interview was conducted by a single instructor and contained a combination of open questions and rating scaled questions (see appendix F and G). The aim of the interview was to disclose the patients' perception of the performed tasks and game objects. The observations (see appendix H) were used to collect information from a perspective other than the patients'. Two instructors wrote down their observations during the play tests on. These observations were structured around four questions relating to how patients execute their movements, how do patients respond to the virtual feedback, how do patients respond while playing, and if they experience technological or hardware related issues, though other observations could also be noted.

7.3.3 Results

7.3.3.1 Performing actions with the objects

The results of the interviews and the observations indicate that all participants were able to perform the individual physical actions during the first stage, but that the quality of this ability depended on the properties of the objects. Though the participants were able to properly move, rotate and connect all objects, the spherical object tended to be more problematic to handle than other objects. Two persons could not get as good a grip on the sphere because of its smaller size, one of which also had difficulties stabilizing it after rotating it. Although less pertinent, the size and shape of the cubical and the cylindrical objects also caused minor issues. One participant stated that the cube was slightly too large to grab properly, and was also observed to have smaller problems rotating the cylindrical object on the correct segment. In spite of the above issues, all participants were able to complete the tasks.

The quality of performing the individual physical actions similarly depended on the abilities of the participants themselves too. This was apparent during the observations as the speed and smoothness of the actions were not always the same across participants. One participant needed to rest in between tasks to avoid spasms and needed to stand up to perform the exercises (this was also the case during his actual rehabilitation therapy). Furthermore, each of the participants had their own approach to perform the physical actions. For example, two participants rotated the objects segment by segment, while one other rotated the objects in a single fluent motion. Similarly, participants also grabbed the objects with different grips according to their

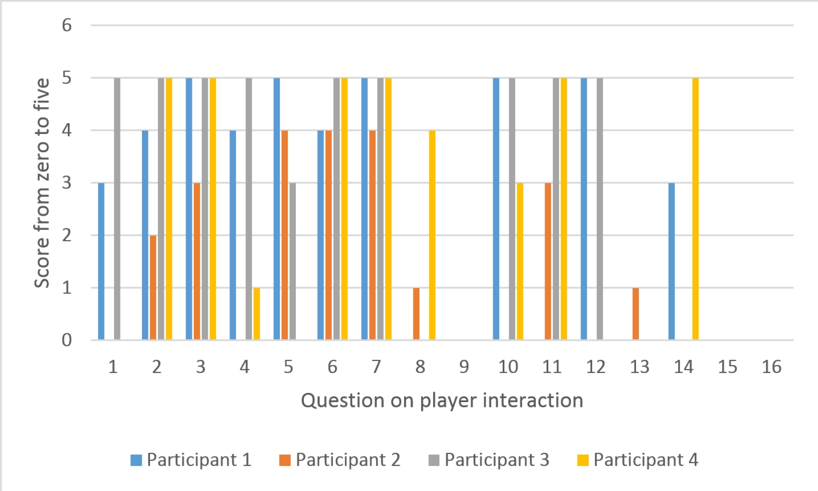

Table 7.4: The ratings of the patients on interacting with the objects according to the questions in appendix F.

capabilities. Which object was the overall easiest to handle and the most pleasant to use varied per participant.

The physical actions were generally experienced by all the participants as pleasant and natural to perform during all stages of the tests (see Table 7.4). This was corroborated during the observations where they appeared to be engaged while performing the actions. Additionally, all participants reported that the actions did not take too long, were not too repetitive, and that they did not need to wait too long in between the actions. While all participants stated that they found the actions relevant for their own rehabilitation in a medium to a high degree, one of them noted that he did not perceive an added value for use in his rehabilitation therapy. Finally, during the open questions in the interviews, the participants indicated that they did enjoy working with the objects because these were enjoyable to physically manipulate.

7.3.3.2 The experience of interacting with the game and the lights.

During the second and the third stage of the tests, the interactions with the lights were generally received well, although a minor issue was reported by one of the participants. All participants stated they instantly knew to a medium or high degree what to do. However, one participant indicated that she did not immediately understand what the results of the physical actions were. Nevertheless, she was able to correctly play the game during both stages. Furthermore, all of the participants did state that they knew which physical actions were available throughout these stages. One participant

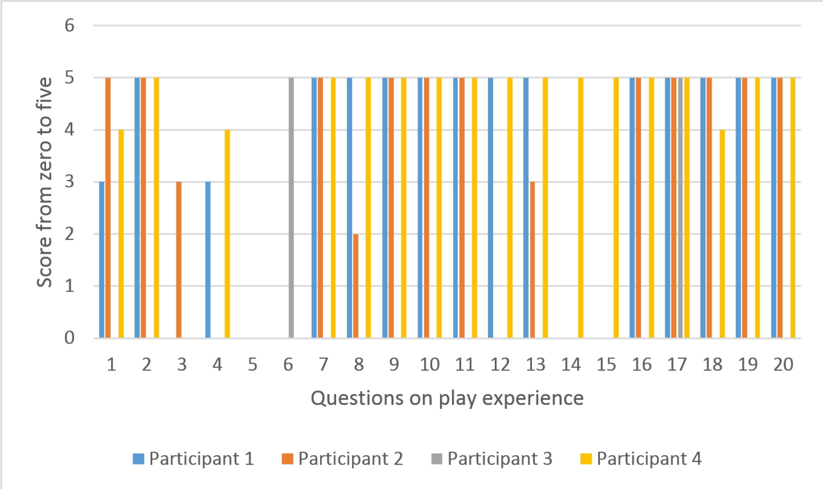

Table 7.5: The ratings of the patients on the play experience according to the questions in appendix G.

explicitly mentioned during an open question in the interviews that the lights guided and encouraged him to perform the related actions.

The three participants that could effectively play the challenges of the third stage found playing the game pleasurable to a high degree, but two were not able to light up all segments completely as the timing was too fast. All of these participants nevertheless did consider the game an added value to their training. In terms of challenge, the three participants indicated that they were challenged in a medium to a high degree. Related to this, the two participants who could not complete the game found the game too difficult, while the other indicated it was rather too easy than too difficult. Two participants also experienced difficulties distinguishing the blue and green lights from one another during the third stage.

Overall, the three participants reported they experienced the game as highly positive, motivating and informative (see Table 7.5). They also noted that the game highly incited them to start playing, whereas two of them also said it encouraged them to continue playing to a high degree, yet the other one only to a lesser degree. If they were given the choice, they would like to play the game with others, such as family members, therapists as well as other patients. Finally, they highly considered the game an added value to their training.

7.3.3.3 The visual properties of the objects and their forms

All of the participants noted that they visually enjoyed the objects and the game. The visual effects of the lights were considered as a strong addition to the visual perception of the game. In response to an interview question, three of the four participants noted that they would like to place the objects in their home as mood objects. Two of them explicitly stated that they would like to show these objects to their guests. The participants described the objects as “design” and “artistic”.

7.3.4 Discussion

In an attempt to expand on the developed ambient abstract minimalist style of Chapter 6 towards the physical space of the rehabilitation therapy setting, a novel game was developed containing a range of abstract minimalist physical objects. A range of qualities defined throughout this dissertation were incorporated into these objects. As a result, the developed game allows us to visualize new design possibilities for how a rehabilitation game can be created. In general, these possibilities relate to the physical qualities of the presented objects and can be seen as an extension of the research of Hondori, et al. [284] and Vandermaesen, et al. [285]. However, in contrast with this research, the presented prototype reveals a custom made game that was developed starting from a conceptual rather than technological perspective (though technology is an important part of the eventual design). Nevertheless, we believe the presented game can be considered as relevant to current rehabilitation game research. In a first instance, it is highly adjustable to the rehabilitation setting, as the physical shape of the objects can be altered without changing the game’s concept. Furthermore, the game’s concept in itself also remains simple as the display screens (used in previous prototypes) are replaced by a small amount of LED lights. By spreading these lights over the three dimensional forms of the game objects, an interesting interplay between the virtual and the physical world was shaped. Additionally, the visual and material qualities of the game were also taken into account, resulting in a unique rehabilitation game style.

Compared to the games presented in the previous chapters such as Collider, Shapes offers more possibilities to perform task-oriented exercises, which is an important part of rehabilitation therapy [50]. While the exercise goals are still rather abstract (e.g. connect two objects), manipulating real-life physical objects in a specific manner is a main part of the game play. As a result, important analogies with real-life tasks can be drawn. For example, lifting and rotating the cylinder may be compared to picking up a drinking glass and pouring water out of it. Of course, these analogies are not made explicit to the player, and it would therefore be interesting to explore with this system the degree to which task-oriented exercises can be abstracted in relation to rehabilitation effectiveness. Furthermore, in order to emphasize task-oriented training, it would be interesting to investigate the work of Jacobs, et al. [201] through the presented physical ambient abstract minimalist style. For example, the forms of a knife and fork (and a table, food, etc.) could be transformed into interactive segments such as in the presented game Shapes. With an extension of the game play, the exercises in the game Shapes could then be made more meaningful (e.g. cutting movement) without the need of a separate display screen.

Play tests were performed in order to investigate how the game and its objects were experienced and used by patients. Overall, they were received well. In a first instance, the patients were able to physically control the objects and play the game, although not all patients could handle all the objects equally well. What is interesting to note, is that the patients clearly had their own preferences in terms of what objects they could and liked to use. As such, a game that uses multiple, different physical objects that all relate to the same concept can be a relevant asset in a rehabilitation setting. It should be expected that some patients will likely experience some difficulties with handling these objects. As they are in need of rehabilitation therapy and thus still need to practice their dexterity, some failure is a logical ascendant of progression. Nevertheless, it is important that these difficulties are met with positive incentives to continue the rehabilitation exercises. Reflecting on the interviews and observations, it can be concluded that the games and objects can provide such incentives. While not all patients indicated that they would use the game in their own rehabilitation therapy, the game was generally described as pleasurable and motivating. Finally, the visual qualities and forms of the objects were received particularly well by the patients. Although, these will most likely not be a decisive factor for therapist and patients to adopt the game, it could provide an extra incentive to do so.

7.3.5 Limitations

There are two important types of limitations in the study: those relating to the game's design and those relating to the setup of the play tests. In the former, the number of different objects can be expanded on and the game concept can potentially also be broadened. In terms of the tests, these were realized with only a small group of patients, and one of these patients could not complete a small part of the tasks during the study as a result of a technological issue (i.e. the objects failed to provide the correct color of lights). These tests thus only serve as an initial contextualization of how the novel game introduced throughout this chapter is perceived and experienced by actual patients. As the results of these initial tests were moderately positive, more extensive testing in terms of how patients physically use the objects and how they experience them will be relevant for a further analysis of the game.

7.3.6 Contributions

The exploration of the physical or play space in rehabilitation games, and the subsequent development of the game Shapes contribute to the field of rehabilitation game research in two manners. First, the potential relevance of the physical space in a rehabilitation context is highlighted with a number of experimental rehabilitation games. Specifically, three elements were described that may be applied in order to combine the physical space in which rehabilitation exercises are preformed and digital games. Rehabilitation researchers can use these three elements to build their own rehabilitation game concepts. Secondly, the game Shapes demonstrates how these three elements can be combined with the ambient abstract minimalist style described in Chapter 6. The design rationale and the resulting design Shapes can furthermore be used as inspiration to the creation of rehabilitation games in rehabilitation research.

7.4 Conclusions

In this chapter, we have reported on the physical or play space of rehabilitation games. As such, the rehabilitation game Shapes was developed according to the physical ambient abstract minimalist style. This style highlights the physical and material properties of a rehabilitation game, but simultaneously also several style elements introduced in the ambient abstract minimalist style (see Chapter 6) such as abstraction and visual aesthetics. Small-scale tests with four patients following neurorehabilitation therapy showed a preliminary interest of the patients in terms of the experience of using Shapes, as well as its visual appearance.

In the next and final chapter, the physical ambient minimalist style presented in this chapter, as well as how previous chapters contributed to this style, will be summarized and described according to the research questions of this research.

Chapter 8

Conclusions, Limitations and Future Work

In this closing chapter, the presented dissertation is summarized and reflected upon in terms of the research questions described in Chapter 1. Additionally, directions for future research following from the answers to these questions are discussed.

8.1 Summary

The aim of this dissertation was to explore the concept of physical rehabilitation games primarily from the perspective of the game designer. More specifically, our goal was to explore how a rehabilitation game style could encompass the particular characteristics of physical rehabilitation exercises as well as patient disabilities in the medium of digital games.

In the first part of this dissertation, an investigation into the literature on physical rehabilitation games was performed. During this investigation, the claim was explored that physical rehabilitation games are too often developed from a rehabilitation-centered perspective only. Using a document analysis, twenty-one publications concerning games for physical rehabilitation were examined in relation to a number of parameters of general game design. It was concluded that the claim is true to a certain degree, and we extended the literature overview by providing a description of relevant general design parameters for rehabilitation games. This investigation permitted us to generate a comprehensive overview of the literature on rehabilitation games in terms of game design, and moreover gave us an insight into the rehabilitation games that had already been developed.

As the literature on physical rehabilitation game design was limited, we aimed to expand the design knowledge on the methods and practices appropriate for creating rehabilitation games. As a first step, preliminary design elements were defined that would guide the formation of a physical rehabilitation game style. A first rehabilitation game prototype – Flowers - was designed in which the inclusion of rehabilitation exercises and taking into consideration the patient disabilities were important features. Reflecting on this design, two initial game elements were identified as relevant to our rehabilitation game style: including game mechanics and avoiding unforeseen game conventions.

After having identified these two elements, we were able to design a novel experimental game in which the inclusion of game mechanics and the avoidance of game conventions served as important design elements. First, the artistic style of abstract minimalism found in established art forms such as painting and sculpture was identified as promising to stimulate this inclusion. This led us to define a practical abstract minimalist style for digital games, which was applied to reduce the existing game Quake Live's pictorial features as well as its number of game elements. After having performed play tests, four rehabilitation therapists concluded that the style could potentially be valuable, but had to be improved in terms of its adjustability to an individual patients' rehabilitation therapy, as well as in terms of its aesthetic and user experience features.

In response to these play tests, the game Collider was created by extending the abstract minimalist style, intending to improve the identified shortcomings. This resulted in the ambient abstract minimalist style, in which visual, expositional and compositional elements as well as a reduced reliance on an interface are emphasized. Play tests with eight patients who were following neurorehabilitation therapy revealed that the style is promising not only in terms of play experience, but also in relation to style and usability.

A design experiment with seven interdisciplinary groups of graduate design students from a variety of disciplines encouraged us to also explore an entirely different direction than thus far maintained. While we had predominantly explored the virtual or mediated space of digital games, the prototypes created during the design experiment identified elements relating to the physical or play space of digital games. Subsequent observations in an actual rehabilitation therapy setting led us to conclude that this space is also important in such a therapy. The identified elements, if further explored than in the experimental setup, could be relevant in the context of our own rehabilitation game style.

Finally, in response to this design experiment, a final rehabilitation game – Shapes - was developed in which a variety of the previously defined virtual features were merged with the physical play space. As a result, Shapes contained physical artefacts combined with virtual feedback. To contextualize the game in a real-life rehabilitation setting, play tests with four patients following neurorehabilitation were performed. These patients generally described the game as pleasurable and motivating, but also identified several possibilities for improving the physical artefacts and the game concept.

8.2 Research questions

In the introductory chapter, one main research question and four sub questions were posited. In this section, these questions shall be addressed one last time. As described in the methodological section (cfr. Chapter 2), the presented research positions itself within the constructivist view of design research. Therefore, the types of knowledge produced within this research should be considered in direct relation to the material qualities of the developed games and game styles. The main research question was stated as following:

RQ: What rehabilitation game style can be designed in order to stimulate the integration of rehabilitation therapy and digital games, specifically emphasizing the inclusion of physical rehabilitation exercises as well as patient disabilities?
This research question has been addressed with the following four sub questions:

1. **How can game elements contribute to the creative design of physical rehabilitation games?** Digital games are complex to develop as they contain diverse interrelated game layers. Each of these layers encompass a wide variety of elements that purposely need to be combined in order to generate a satisfying play experience. Rehabilitation game designers therefore need to comprehend these layers (and respective elements) and how they impact the overall game. For instance, an input device can be selected or developed to support an interaction method that reflects the physical exercises (e.g. pressing a button vs. employing gestures), while the visuals in a game can promote an aesthetic look and feel, but simultaneously explain the game world to players. However, these game layers and elements do not exist in a vacuum. As the layers and elements are tied to one another, together they comprise the totality of a game as experienced by players. Therefore, it is not only important to study how individual game elements can support rehabilitation therapy, but also how these elements offer support as a group. This is a critical point, since the grouping of elements impacts which and how individual elements are included. For example, if a game's underlying structure contains little communicable information (e.g. small number of objects or game mechanic attributes), the inclusion of an interface may become largely irrelevant. Consequently, the adaptation of the interface to patient abilities may become less necessary or

even obsolete. Therefore, it is argued that researchers and designers should first investigate the totality of game elements (game style), rather than the individual elements when adjusting to rehabilitation therapy.

2. **Which preliminary game elements can be identified to guide the practical formation of a game style that integrates digital games and rehabilitation therapy?**In order to create a physical rehabilitation game style, we first defined two preliminary game elements, which was necessary to steer the initial design of the game style. To adhere to the aim of the presented research, these elements needed to support the integration of the game world and the rehabilitation world. In this case, integration was defined as the connection of progression in the game world to progression in the rehabilitation world, specifically by creating a reciprocal relationship between elements of both worlds. Following this definition, two preliminary elements are proposed: game mechanics and (avoiding) unforeseen genre conventions.
   The first preliminary element, game mechanics, reflects the activities of patients in the rehabilitation world as well as in the game world. The connection of both worlds is contained within the various parts that constitute game mechanics: actions, attributes, space, rules, skills vs. chance and dynamics. For example, when patients perform a physical action to progress the rehabilitation, they simultaneously progresses in the game world through virtual actions. Rehabilitation parameters such as precision and accuracy of a motion thereby influence the amount of progression made in the game world. We do not posit that game mechanics should be included in rehabilitation games (which is self-evident), but more importantly that their quality of tying together the game and rehabilitation could be further exploited in the development of a rehabilitation style in order to integrate games with rehabilitation.
   The second preliminary element, avoiding unforeseen genre conventions, relates to the development of rehabilitation games from a predefined game concept, which may undermine the integration of games and rehabilitation. While a game concept can be altered to the rehabilitation context, it may still contain underlying genre conventions that conflict with patient disabilities. For example, the game Flowers presented in Chapter 4 was conceptually customized to patient disabilities in terms of elements and visuals. However as it is a tycoon genre game, an inventory system needed to be included in order to represent different flowers, even though an inventory contains small and detailed elements that may conflict with patient' physical and visual abilities. For this reason, (avoiding) unforeseen genre conventions during the design process of a game concept was selected as a preliminary element to take into account in the rehabilitation game style.

3. **Which digital game elements and qualities can serve as stylistic features in a physical rehabilitation game style?** The above two preliminary game elements were regarded as starting points for defining the stylistic features of a rehabilitation game style. Specifically, game mechanics were perceived as critical for stimulating the integration between the game world and the rehabilitation world - the main aim of the presented research -, while unforeseen genre conventions were considered as detrimental to that integration. To accommodate both elements, we stripped a fully formed and commercial game concept – Quake Live – of its genre conventions while retaining its basic game mechanics. In order to do this, a design process of abstraction and minimalization of the game concept was conceived and applied. This process resulted in the identification of a number of game style elements.
First, the abstraction process was applied to the pictorial and conceptual qualities of game objects, and the minimalization process on the quantity of objects. In this respect, the meaning and representation of game objects embedded in the game's fiction were largely removed. The game world as a result only consisted of basic shapes and colors and was formed by deconstructed spatial dimensions containing basic game challenges. Nevertheless, simple game mechanics were still present in order to accommodate the execution of physical exercises. We argue that abstracted and minimalized elements may be useful in a rehabilitation game style.
However, abstract minimalized elements as such may not be playable for patients or completely relevant for rehabilitation therapy. In the process of reducing the game to a rudimentary form, a variety of elements that make a game comprehensible (e.g. contextual structure) were inevitably removed. Furthermore, the player interactions had been narrowed due to the limitation of in-game choices, which in turn resulted in strict and highly constrained physical exercises. In order to remedy this, ambient elements were added to rebuild the playability, user experience and application for rehabilitation therapy. Important is that these ambient elements did not reconstruct the game as it was (e.g. restore the spatial dimensions), but shaped it further into a reworked form of abstract minimalism.
Ambient elements provide players with information about the game world through the presentation and atmosphere of the game world itself. In a first instance, this relates to the construction of the game world during play time. For example, the game Collider described in Chapter 6 starts with only one object on screen: a two-dimensional circle. Only after players interact with the circle, the rest of the game world gradually builds itself up. Players are thereby not overwhelmed by their initial unfamiliarity with the game world. Secondly,

ambient elements refer to visual elements that guide the gaze of players, for instance by using saturated colors, bright lights, shapes (e.g. triangles that point to a specific location), and the animation and positioning of game objects. This allows players to understand which game objects are important at a specific time in a specific location. Finally, providing more freedom in the game's spatial structure while simultaneously providing sufficient guidance (e.g. waving lines and a rotatable square in the game Collider), together with non-obtrusive decorative elements (e.g. small squares in the game Collider) was beneficial for player agency.
The process of abstracting, minimalizing, and rebuilding the game world was largely focused on digital elements. However, genre conventions can also be tied to the physical form of games, for example the separation between the physical and the virtual world through a display screen. By exploring this convention, three additional style elements were defined: multiple display screens positioned and rotated in 3D space, using the physical materials of the game's hardware to emphasize the visual aesthetics of the game, and integrating digital feedback into these physical materials of the game.

4. **How can these game elements be shaped into a single rehabilitation game style?**
Following the previous two questions and following the game Shapes developed in Chapter 7, we suggest that the novel physical ambient abstract minimalist style could serve as a relevant style for rehabilitation games in order to integrate game components and rehabilitation components. The game comprises three physical objects with simple geometric forms and minimal pictorial value. As a result, they can be rotated and positioned in any direction without conflicting with the meanings in the game In this respect, the style of Shapes can be described as both abstract and minimalist (SQ3).
As different object shapes and sizes are available, the game can be tailored to patients' individual capabilities (e.g. hand grip). The physical ambient abstract minimalist style also integrates digital feedback that stimulates patients to pick up the objects and physically connect them (or in extension, to touch the sides with their hand). As such, the game is similar to the game Collider presented in Chapter 6, where players need to push two squares together. Another similarity with the game Collider is the use of light. In both games light elements combine the virtual with the physical world, as they represent both the game's underlying algorithms and the physical objects.
One style element that was not included in Shapes, is the inclusion of detailed visuals to guide patients through the game, mainly because the simplicity of the lights did not allow such detailed elaboration. Additionally, as was the case

in the physical game experiments, the lights act as a sort of multiple display screen wrapped around the objects, thereby mapping the virtual world onto the 3D space in which the rehabilitation exercises happen.
Finally, the material aesthetics of the physical objects were also included in the style. Their textures show simple black and white colors, and are made of matte synthetic material and painted wood. This provides the objects with a soft-non technological look and feel.

8.3 Design heuristics

In design research, practical knowledge (designerly knowledge) is vital even though it is difficult to capture in a textual analytic form such as the presented text. While the answers above address the research questions in a textual form, the designerly knowledge is largely embedded in the games themselves We believe it is important to connect both types of knowledge by capturing the practical design process in a set of design heuristics. These heuristics link analysis (text) to generation (practice) and rehabilitation game researchers or designers may adopt these in order to create a similar rehabilitation game style. Five design heuristics are distilled from the presented research project:

1. **The selection of preliminary game elements is a starting point in the design process**
   Through the development of and reflection on an early playable prototype, preliminary game elements can be defined that embody the concept of integrating the game and the rehabilitation world. Essential is that this integration emerges out of specific rehabilitation characteristics such as the type of physical exercises, cognitive disabilities, and context. Depending on these characteristics, the preliminary elements may vary and delineate specific parts of the rehabilitation game design space for further investigation, without restricting creativity too much.

2. **Preliminary game elements catalyze the exploration of design possibilities.**
   Preliminary game elements may catalyze the exploration of the rehabilitation game design space. An overall goal - based on the preliminary elements - should be defined for this exploration (e.g. retain the element of game mechanics while removing as many genre conventions as possible). Starting from this goal, a method such as abstracting and minimalizing a commercial game can be conceived. This method can be approached in an experimental manner without being too constrained by the rehabilitation characteristics yet, though caution should be taken that the rehabilitation characteristics can come to the

foreground in subsequent design phases. This may be stimulated by incorporating simple physical exercises that are basic components of more complex exercises.

3. **Experimental games may progress the design process, even when they are not yet fully playable, pleasurable or relevant to the rehabilitation therapy.**
From a playability, user experience, and physical rehabilitation standpoint, an experimental game may appear unsuitable due to its unfinished and unconventional character. Important though is that the experimental game is only a phase in a larger design process. The game is specifically created to further delineate the design space and reveal an overall style direction (e.g. abstract minimalism) that can afterwards be adapted to specific constraints. Therefore, it is critical to reflect on the underlying potential of the experimental game to advance the further design process, and not only on how it measures to the concept of a fully functioning and effective rehabilitation game.

4. **Addressing the playability, the user experience and therapy relevance may stimulate not only the overall usability of the game, but also the refinement of the experimental style direction.**
Adding novel elements or adjusting present ones in the experimental game may transform it into a playable, pleasurable and useful game. The aim here is not to revert back to the original game concept, but to reimagine the rehabilitation style in a novel manner in relation to the physical exercises and patient disabilities defined in the first step. Qualitative player tests may be used to determine the playability and pleasure of the transformed game, and thereby adjust the game further.

5. **The developed rehabilitation game style may be extended.**
Having developed the game style, novel insights on the design space may have been gained with which to further integrate the game world and the rehabilitation world. In order to explore these insights, combine the style's elements with a not yet applied aspect of rehabilitation therapy. In this project, the abstract minimalist elements were adapted to the physical space in which patients perform rehabilitation exercises, resulting in the translation of the style into a new context. This step may be followed by step three and four again, and continue until the requirements of the specific project are met.

8.4 Discussion

This dissertation presents a novel game style that emphasizes the integration of digital games and the physical rehabilitation therapy of stroke survivors and persons with multiple sclerosis. Specifically, it illustrates how a digital game world can incorporate physical exercises while simultaneously being adapted to a number of patient disabilities. Previous research in the area of rehabilitation games has mainly focused on technological and therapeutic topics, as a result of which the integration of game design has only minimally been addressed in the literature. In particular, the notion of game style has not explicitly been investigated before, even though it is a critical element within game design.

The game style developed in this project opens up new opportunities for academic researchers and designers who want to create physical rehabilitation games. First, these opportunities are embodied within the novel rehabilitation games presented throughout the previous chapters. Researchers and designers can adopt or reinterpret these games or the game style they signify. Essential is that they reflect on how the rehabilitation demands are translated to elements in the game world. Second, the use of artistic methods presents a new perspective in the design of rehabilitation games. Within the artist community, such methods are commonly applied in order to explore artistic materials or to convey a certain concept or aesthetic. However, in this research project, these methods have been appropriated to achieve a purpose outside of the artistic realm: the integration of physical rehabilitation in digital games. This helped translate the qualities of the game world and the patient disabilities through the key characteristics of abstract minimalism. Through the heuristics and reflection on the process provided, we encourage others to adapt a similar design process.

However, the results of this research encompass more than practical examples and guidelines that researchers and designers can appropriate. On a higher level, the research reveals that rehabilitation games are flexible objects rather than fixed ones. These games do not contain a predetermined set of elements, and how elements are included varies widely across games. This is an important observation for two reasons. First, researchers and designers are not limited by examples of other types of games (e.g. commercial). Though these may serve as valuable inspiration, their conventions have evolved from an entirely different context than rehabilitation games. This research therefore invites researchers and designers to go beyond the initial limitations of their imagination, and apply an experimental design process to find novel rehabilitation game elements beyond the ones presented in this research. Second, it might be trivial to define individual rehabilitation game elements without context to a game style, as the inclusion of other elements may influence how the individual elements are shaped.

8.5 Limitations and future work

The presented research has been performed according to a design research philosophy as described in Chapter 2. This philosophy specifically emphasizes the practice and reflection of the design researcher in order to generate a contribution within the area of (rehabilitation game) design. However, practice and reflection bring with them several limitations that need to be considered when interpreting this contribution.

The proposed rehabilitation game style should not be considered as the only viable style, but rather as a possible style among many. Within the design space of rehabilitation games, many game and rehabilitation elements are still left unexplored. Constraints such as time, resources, and designer skill and knowledge only allow for a restricted portion of the design space to be explored within a research project such as the one presented.

Furthermore, the core process of exploring the design space relies on the designer's reflections. It can therefore be argued that these are not objective. While this is a valid concern, the goal of design research in the presented work is not to reveal an objective truth about the world, but rather to construct a novel perspective within that world. As such, a more relevant limitation is the absence of other rehabilitation game styles against which to contextualize the presented one. Without such contextualization, it is difficult to provide a qualitative comparison between the strengths and weaknesses of multiple developed styles.

Regardless that the main goal is not to provide an objective truth, the research is partially situated within the field of rehabilitation where objectivity is critical. It is essential that rehabilitation games are adapted to the needs of stroke survivors and persons with MS and are effective in training physical exercises. Player tests have been performed in terms of playability and user experience, yet only with small sample sizes. Furthermore, the effectivity of this game style has not yet been tested. Also, the potential differences of impairments between stroke survivors and persons with MS has not been addressed in detail during these tests, even though differences between these groups exist.

Though research on physical rehabilitation games has been growing steadily in recent years, many challenges still lie ahead. A main challenge is the further exploration, development and use of style for physical rehabilitation games in the context of stroke and MS. In this respect, several suggestions are given based on the novel game style presented in this dissertation.

Exploring the game design perspective In the presented research, only a limited amount of game elements have been included. In particular, the element of game mechanics has been emphasized throughout the design process. Nevertheless, games offer a much wider variety of elements which may also be relevant to explore in terms of a rehabilitation game style. Two specific approaches are envisioned. The first approach is to elaborate on the developed game style through the provided heuristics (see above), specifically with the fourth step of including novel elements. For example, it might be interesting to explore how narrative and background music can be abstracted and minimalized in order to fit the rehabilitation context and game style. The second approach entails the more detailed elaboration of elements already within the game style such as character development and the interest curve of the game.

Exploring the rehabilitation perspective Similar to game elements, there also are many more rehabilitation elements that have not been integrated in the game style. The main focus of the presented research project was to include physical exercises while taking into account specific disabilities. However, rehabilitation therapy spans a much boarder range of topics than exercising and disabilities, such as the emotional well-being of patients, their relation with family members and professional caretakers, their sense of independence, etc. The current game style may be augmented with these elements, or an entirely new game style may be developed to accommodate them. One could then envision different rehabilitation game styles for different purposes within the rehabilitation context.

Furthermore, the games Collider and Shapes create two concrete relevant paths for future research: (1) testing the play and user experience with larger user groups and including effectivity of the rehabilitation as a main concern in these tests and (2) expanding the inclusion of specific rehabilitation exercises. In this dissertation, the main objective was to explore the possibilities of digital games and rehabilitation therapy and construct a rehabilitation game style from a game design perspective. Now that this style and two concrete games have actually been developed, their effects on patients who are following a neurorehabilitation can be fully examined. Of course, in the second case, the games themselves could first also be expanded to include other specific rehabilitation exercises. For example, the game Shapes could be extended with different objects to encourage additional or more specific rehabilitation exercises.

Within the development of a rehabilitation game style, attention may be provided towards the specific impairments of patients, especially regarding the differences of impairment in stroke and MS. For instance, visual impairments may be further divided into a (partial) loss in vision, double vision, blurred vision, problems with processing visual information, etc. While the presented game style handles these in general, different strategies could be developed within the style to alleviate particular impairments. Of course, this would be a challenging endeavor as the individuality of each patient's impairments might require a wide range of different strategies.

Expanding on the design process and methods Additionally, at the beginning of the practical design of the presented style, the art style of abstract minimalism was identified as relevant to the overall goal of the style: including game mechanics and avoiding unforeseen genre conventions. However, there are many more art styles available that could be the foundation for a rehabilitation game style. In this respect, it would be interesting to explore sub art styles that can result in sub rehabilitation game styles. For example, the abstract expressionist style could potentially instill more energetic and lively game visuals. Whereas in the presented dissertation the abstraction still relies on concrete objects and forms (e.g. lines and triangles), within an abstract expressionist these objects could be dissolved, driving the game play more with the feeling of the objects. Naturally, caution should then be taken not to exceed the abilities of the patients. In a second instance, it would also be interesting to explore different art styles altogether. For instance, the impressionist style could potentially result in a rehabilitation game style where it is not relevant what the patient actually sees (thereby removing the need for detailed visuals), and focus instead on the experience of the colors and shapes in the game. Interestingly, perception is the core of the impressionist style, resulting in images that often seem crude and unfinished from a realistic viewpoint. The question could then be asked if, instead of simply minimalizing the game world, its visualization could be made more crude and unfinished, and if this would be easier to perceive by patients with vision problems.

We believe the consideration of the above suggestions can be strongly beneficial to the development of physical rehabilitation games in the future. In this manner, game style may become an important tool to improve the creative design of rehabilitation games and stimulate their eventual adoption in rehabilitation therapy. Logically, this should be done in cooperation with the wide variety of disciplines encompassing the field of rehabilitation games, including rehabilitation science and computer science. Only when all these disciplines contribute in a cross-disciplinary context, the field of physical rehabilitation game design can advance. The presented research provides, as such, a strong contribution from the perspective of game design.

8.6 Publications that contributed to this dissertation

This dissertation is based on the following publications and proceedings:

It was investigated to what degree game design concerns were included in the development of physical rehabilitation games in relevant literature, and was further expanded by discussing how such an inclusion could benefit rehabilitation games (Chapter 3).

> Niels Quinten and Steven Malliet. Considering Design Concerns in Games for Physical Rehabilitation. In Interactive Technologies and Games

2011 Conference Proceedings, pages 132–145, Nothingham, GB, 2011.

Niels Quinten, Steven Malliet, and Karin Coninx. Improving the Play Experience of Games for Physical Rehabilitation by Using Different Layers of Game Design. In David Brown, Eva Petersson Brooks, and Paul Sharkey, editors, Games for Rehabilitation, volume 3 of Virtual Reality Technologies for Health and Clinical Application. Springer. In press.

The design process of and the game Flowers have been presented in a poster (Chapter 4):

Niels Quinten, Steven Malliet, and Karin Coninx. Exploring Deep Content in Physical Rehabilitation Games [Poster]. In Konstantinos Chorianopoulos, Monica Divitini, Jannicke Baalsrud Hauge, Letizia Jaccheri, and Rainer Malaka, editors, Entertainment Computing - ICEC 2015: 14th International Conference, Proceedings, pages 433-38. Trondheim, Norway, 2015. Springer.

The experimental design process (Chapter 5) and the subsequent player oriented design of Collider (Chapter 6) was presented.

Niels Quinten, Steven Malliet, and Karin Coninx. The Creative Design of Physical Rehabilitation Games. In Amanda Ochsner, Jeremy Dietmeier, Caroline C. Williams, and Constance Steinkuehler, editors, Proceedings GLS 10 Games + Learning + Society, pages 353–359, Madison, Wisconsin, USA, 2014. ETC Press.

Additionally, the game Shapes (Chapter 7) has been presented during the Blank Arcade exhibit at the 2015 DiGRA conference, Lüneburg, Germany.

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Appendix A

Observations during the first play session

De testcoördinator observeert de speler en noteert voor elk punt zjin/haar bevindingen. De testcoördinator probeert zo weinig mogelijk tussen te komen (zie notities voor de testcoördinator, p. 8).

Ervaring
Toont interesse. Beweegt graag. Is uitgedaagd. Let weinig op de arm.
Functionaliteit
Start makkelijk. Heeft moeite met de uitdagingen. Kan de interface bedienen. Kan de cirkel en vierkanten besturen.
Concept
Weet altijd wat het doel is. Weet altijd wat hij/zij moet doen. Weet dat hij/zij verder geraakt in het spel door zijn/haar handelingen.

Appendix B

Evaluation of the first play session

Geef aan voor de volgende stellingen hoe je er tegenover staat van 0 (niet) tot 4 (heel erg):

Niet (0)	Een klein beetje (1)	Enigszins (2)	Behoorlijk (3)	Heel Erg (4)

Sensatie.

1. Het voelde aan als een karwei.
2. Ik vond het leuk om te bewegen.
3. Ik vond het zonde van de tijd.
4. Ik zag het als een overwinning.
5. Ik voelde met trots.
6. Ik had het gevoel nuttig bezig zijn te geweest.

Challenge

1. Ik vond het moeilijk.
2. Ik voelde me onder druk gezet.
3. Ik voelde me uitgedaagd.
4. Ik voelde tijdsdruk.

5. Ik moest er veel moeite insteken.

Algemeen

1. Ik zou nog verder willen spelen.
2. Ik vond het er mooi uitzien.

Appendix C

Evaluation of the second play session.

De testcoördinator bevraagt de speler aan de hand van de volgende vragen, telkens op het aangegeven speelmoment. Het spel stopt automatisch na elk level, de testcoördinator kan het spel verder zetten met de entertoets.

Na verbinding 1

- Vond je het moeilijk om te weten hoe je moest beginnen?
- Hoe vind je het om het cirkeltje rond te slepen?

Na verbinding 2

- Hoe vind je het om het vierkant voorwaarts naar het andere vierkant te duwen met de cirkel?

Na verbinding 3

- Vind je het spel beter wanneer de HapticMaster – het toestel dat voor je staat – je helpt?
- Denk je het cirkeltje beter te kunnen controleren wanneer je meer kan spelen?

Na verbinding 4

- Wat vind je ervan dat je het vierkant voorbij de rode driehoeken moet duwen?

Na verbinding 7

- Kon je goed volgen wat er gebeurt op het scherm, zoals de driehoekjes die bewegen over de lijntjes?
- Ten slotte, heb je nog opmerkingen of vragen over het spel die niet aan bod zijn gekomen in deze vragen?

Appendix D

User-related events

Error opportunity	Learning	Reflecting	Satisfied /excited	Frustrated	Confused	Annoyed	Unable to Continue	N/A	Suggestion /Comment	Other
Level 1										
Move the circle										
Move the circle to the square										
Push the square to the right over the line										
Connect the square with the other smaller square										
Level 2										
Move the circle										
Move the circle to the square										
Push the square to the right over the line										
Connect the square with the other smaller square										

Table D.1: Table of user-related events for the first two levels of Collider.

Appendix E

System-related events

Error opportunity	Functionality	Layout/UI	Game flow	Content	Technical	Non applicable	Other
Level 1							
Move the circle							
Move the circle to the square							
Push the square to the right over the line							
Connect the square with the other smaller square							
Level 2							
Move the circle							
Move the circle to the square							
Push the square to the right over the line							
Connect the square with the other smaller square							

Table E.1: Table of system related events for the first two levels of Collider.

Appendix F

Questionnaire - Interactions

1. Geef voor iedere stelling (zie F.1 onderaan) een score van 0 (helemaal niet van toepassing) tot 5 (sterk van toepassing):

2. Welke bewegingen had u moeilijkheden mee?
3. Wat vond u positief aan de objecten ?
4. Wat vond u negatief aan de objecten ?
5. Wat zou u veranderen aan de objecten?
6. Zijn er objecten die voor u missen in deze set ?
7. Zijn er bepaalde bewegingen die voor u missen in dit systeem?

Ik kan alle bewegingen goed uitvoeren.
Ik kan alle bewegingen stap voor stap uitleggen.
Ik kan alle bewegingen die ik moest uitvoeren goed herinneren.
Ik kan alle objecten correct gebruiken.
Ik vond de bewegingen belangrijk voor mijn revalidatie.
Ik vond de bewegingen aangenaam om te doen.
Ik vond de bewegingen heel natuurlijk.
Ik vond de bewegingen complex om uit te voeren.
Ik vond de bewegingen te lang duren.
Ik begreep onmiddellijk welke bewegingen ik moest doen.
Ik begreep onmiddellijk wat het resultaat was van een beweging.
Ik begreep onmiddellijk welke bewegingen mogelijk waren.
Ik moest te lang wachten tussen bewegingen in.
Ik moest veel moeite doen om mijn doel te bereiken.
Ik moest veel nadenken over de uit te voeren bewegingen.
Ik moest de bewegingen te veel herhalen.

Table F.1: Included statements on the player interactions.

Appendix G

Questionnaire - Play Experience

1. Geef voor iedere stelling (zie Table G.1 onderaan) een score van 0 (helemaal niet van toepassing) tot 5 (sterk van toepassing):

2. Zijn er bepaalde dingen die u miste aan dit spel?
3. Wat vond u goed / positief aan dit spel?
4. Wat vond u minder goed / negatief aan dit spel?
5. Wat vond u duidelijk of onduidelijk aan dit spel?
6. Wat vond u het meest aangename/ onaangename aan dit spel?
7. Wat heeft u geleerd van dit spel?
8. Wat is uw algemene ervaring met dit spel ?
9. In welke mate heb je het spelen met de objecten ervaren als revalidatietherapie, en in welke mate als spel?
   (a) Waarom komt dit meer voor u over als revalidatietherapie/spel?
   (b) Waarom komt dit minder voor u over als revalidatietherapie/spel?
10. Wat vind je van de vormgeving van de objecten?
11. Andere opmerkingen

Het spel is uitdagend.
Het spel is aangenaam/leuk.
Het spel is te gemakkelijk.
Het spel is te moeilijk.
Het spel is te druk.
Het spel is te simpel.
Het spel zet me aan te beginnen met spelen.
Het spel zet me aan om te blijven spelen.
Het spel is een meerwaarde voor het oefenen.
Ik zou het spel graag willen spelen met andere mensen met MS/ CVA.
Ik zou het spel graag willen spelen met mijn therapeut
Ik zou het spel graag willen spelen met familie of vrienden.
Ik zou graag anderen willen uitdagen met dit spel.
Ik zou het spel graag thuis willen hebben.
Ik zou het spel graag in het revalidatie centrum spelen.
ik vond het spel motiverend
Ik vond het spel vlot verlopen
Ik vond het spel leerrijk
Ik had verschillende keuzes ter beschikking gedurende het spel

Table G.1: Included statements on the play experience.

Appendix H

Observational guidelines

1. Hoe voeren de patiënten hun bewegingen uit?
2. Hoe voeren de patiënten aan de hand van de feedback van het spel (i.e. het opmerken van de lichtjes en effectief een actie ondernemen op basis daarvan)
3. Hoe reageren de patiënten tijdens het spelen van het spel?
4. Ondervinden patiënten problemen als een resultaat van technologische of hardware gerelateerde zaken?