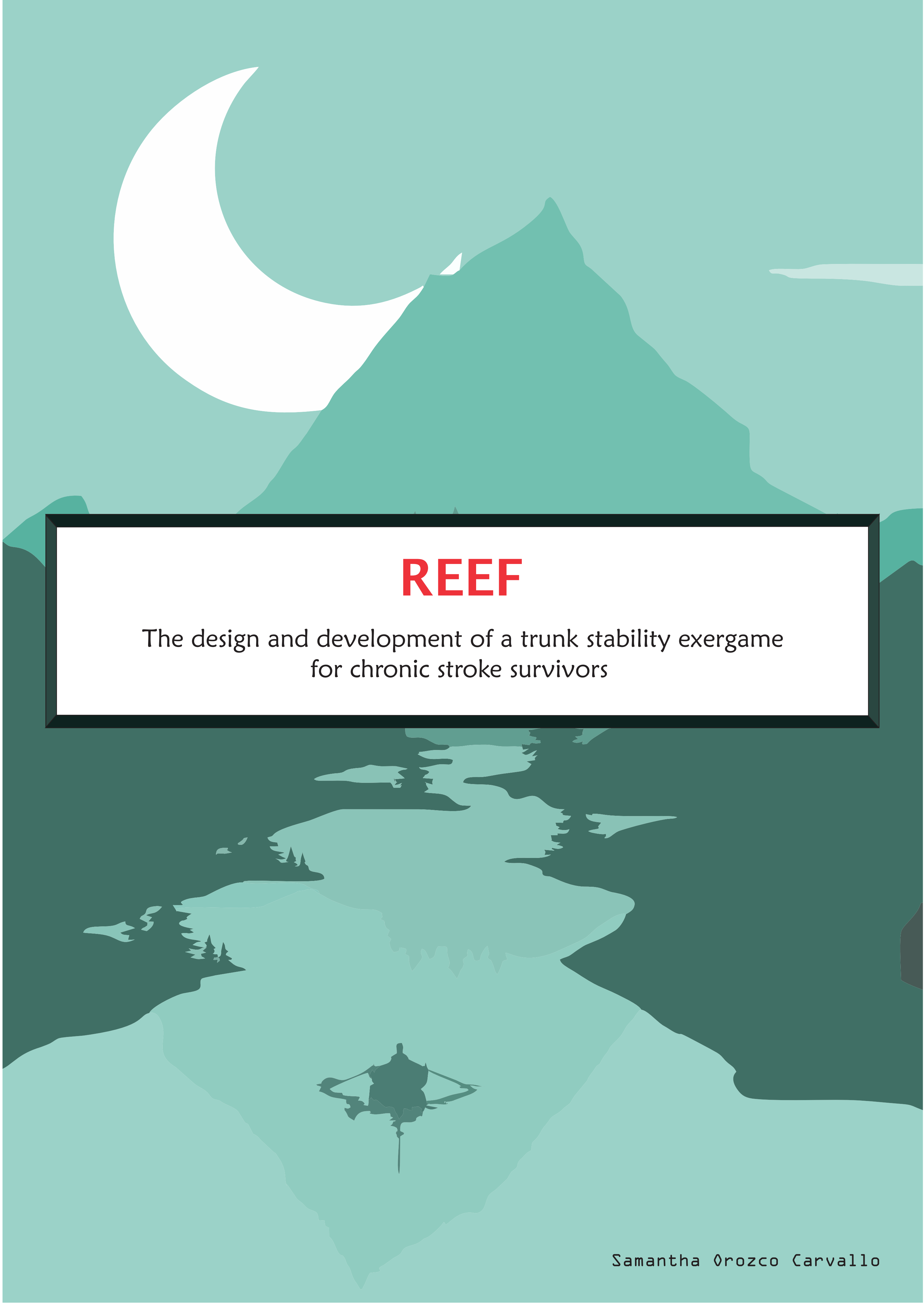

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The design and development of a trunk stability exergame for chronic stroke survivors

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UNIVERSITY OF TWENTE.

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As Gabriella Goddard said, we find strength when we connect to our core. When you act from your core, you will be able to move mountains.

Family, you are my core. Thank you for making me beautifully see the world and giving me the curiosity and hunger to explore the unknown, for always being there and supporting me even in my craziest ideas. Without you, I wouldn't be who I am. My mom, dad, Cesar, and Jean, this degree is both yours and mine. Thank you for complimenting my knowledge.

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.

We all have a starting point.
For me, it was in a desertic town in Sonora
where I learned how to use Kinect
to develop video games for fun, and later
had the idea to use them for rehabilitation.
That vision continues here.

Summary

Background Exergames are games that integrate that physical activity with gameplay elements. In the last years, exergames have shown to be an effective approach to promote e-home rehabilitation for stroke patients due to their low cost, accessibility, and motivational engagement. However, in most interventions, commercial games are used, they lack gameplay adjustments for tailoring the patient's capabilities, and lack therapeutic concepts. A common complication of stroke is the risk of falling, 73 percent of patients fall after their discharge from the hospital. Trunk control is a fundamental motor skill for performing functional tasks that are usually impaired after a stroke. Previous research has shown that trunk training helps to improve balance and the performance of daily living activities. Considering the need for a low-cost, easily accessible, and engaging trunk rehabilitation technologies, this research aims to design and develop a home rehabilitation exergame that improves trunk stability in chronic stroke survivors

Methods The procedure followed a User Center Design (UCD) approach. It was divided into four stages. At each stage, different methods were used to explore the needs, desires, behavior, and limitations in restoring trunk stability, define the requirements to develop such a system, design a solution with and for the end users, and evaluate whether the system met the established requirements in a home environment. The most important methods were semistructured interviews, brainstorming sessions, and usability tests evaluating user experience and user satisfaction through the questionnaires Satisfaction Questionnaire (QUIS) and Game Experience Questionnaire (GEQ).

Results A total of 11 stakeholders participated in the design and development process. The first three stages helped to identify the user, therapeutic, and game requirements for the exergame. With this, a final concept was created and used for the development of the game. For the evaluation of the user experience and user satisfaction, 10 healthy subjects were recruited. During the evaluation of the user experience and satisfaction, it was found that feedback, clear instructions, control tracking, and congruency between the icons and game objects are essential elements to provide an engaging and positive game experience. These elements must be improved in the developed exergame in the next iteration. Overall, the exergame Reef was evaluated with high satisfaction with the system interface and a greater feeling of enjoyment while playing.

Conclusions The procedure followed a UCD approach to integrate therapeutical, psychological, and game design concepts into the exergame to provide effective trunk rehabilitation. A strong aspect of the present research is that user classification was focused on adapting the gameplay to the user's capabilities and incorporating motor learning strategies. Additionally, each level adapts the virtualized exercises to the capabilities of the user. Based on quantitative and qualitative analysis of the user experience and user satisfaction performed, it is possible to confirm that the developed system can meet the needs and desires of the end users. The present study was able to reduce the gap between how to integrate therapeutical, psychological, and game design concepts into an exergame to provide effective trunk rehabilitation at home.

Contents

List of acronyms

CVA Cerebrovascular Accident

ADL Activities of Daily Living

UCD User Center Design

STS Sit-to-Stand

GEQ Game Experience Questionnaire

QUIS Satisfaction Questionnaire

FITT Frequency, Intensity, Time and Type

KNGF Koninklijk Nederlands Genootschap voor Fysiotherapie

FSS Fatigue Severity Scale

eHH eHealth House

SDT Self-Determination Theory

Chapter 1

Introduction

1.1 Motivation

Stroke is the second most prevalent cause of mortality and the first one of physical and mental disability in adults [1][2]. According to the Rijks Instituut voor Volksgezondheid en Milieu (RIVM), there were 356,400 persons living with the effects of stroke in the Dutch population in 2018. People with stroke usually exhibit poor balance, posture problems, poor trunk control, and asymmetrical weight distributions[2].

Trunk control is essential for balance, as it allows us to shift weight, stabilize our body against gravity, provide balancing reflexes and set a stable base for the upper and lower limbs[3, 4]. As a result of stroke-related motor impairments, quality of life and the performance of Activities of Daily Living (ADL) are directly compromised [1]. The most common complication of stroke is falling. The incidence is reported to be 73% for the chronic stroke phase, which is 6 months after discharge from the hospital [5]. An adverse outcome after a fall could increase the length of the rehabilitation process, increase the cost of healthcare, and result in severe injuries or even death[5][6][7].

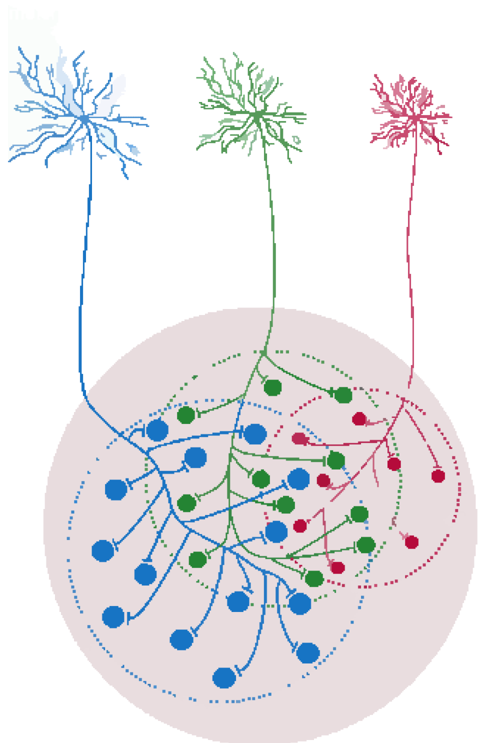
Several studies confirm that trunk training in chronic stroke survivors improves stability, gait, and dynamic and static balance. It is also a good strategy for rehabilitating trunk control and trunk performance [8]. Thus, intensive and continued rehabilitation is recommended for chronic stroke survivors [9].

As patients need to exert independent effort to maintain these practices and exercises, patient motivation is frequently used as a determinant of rehabilitation outcomes, and a lack of motivation is a perceived barrier to physical activity [10]. Previous research has reported that patients' adherence to rehabilitation therapy decreases between 30% and 50% in the first year [11]. Besides the lack of motivation, other contributors to the low adherence are the difficulty of finding a physiotherapist, the healthcare costs, and the distance the patient has to travel[10][12][1].

Technology-based interventions have been used to overcome some of these limitations [13]. Particularly video games have gained ground in the rehabilitation field as a result of low cost, large availability, and game engagement [14]. These video games, also known as ”Exergames”, are intended to achieve more than great entertainment by mixing therapeutic concepts with game elements such as rewards, narratives, and leaderboards. [13] [1].

Although the definition of exergames in rehabilitation implies the design of games that focus on treatment, in most of the interventions, commercial games such as WiiFit, Kinect on Xbox, and Wii Sports are often used as exergame [12]. In the absence of an integrated therapy program, commercial games fail to adapt the gameplay according to patients' rehabilitation requirements. This issue was observed in the study by Pedreira da Fonseca et al., where physiotherapists found it difficult to adapt the game parameters to specific intervention goals. Furthermore, only a few games targeted the trunk to improve balance.

In light of this context, it is essential to design and develop an exergame that complements the work of a physical therapist and that meets the needs and desires of chronic stroke survivors. This tool will enable end users to continue their recovery after discharge from a hospital and achieve effective trunk rehabilitation.



1.2 Goals of the assignment

Considering the need for low-cost, easily accessible, and engaging trunk rehabilitation technologies, this research aims to:

"Design and develop a home rehabilitation exergame that improves trunk stability in chronic stroke survivors"

To achieve this goal, the present study followed a UCD framework that addresses the patient's rehabilitation needs and conveys actionable steps to integrate therapeutical, psychological, and game design concepts.

Due to the characteristics of this methodology, the design and development process was divided into four main stages. At each stage, sub-research questions arise whose answers help to accomplish the main objective. Below they are described:

Stage	Aim	Sub-research question
Stage I. Understand the context of use	Identify who the users are, the environment of use, and the tasks they perform with the exergame	"What are the needs, desires, behavior, and limitations in restoring trunk stability during the chronic phase of stroke?"
Stage II. Specify requirements	Define usability criteria for the exergame in terms of user tasks and establish design guidelines and constraints according to the context of use	"What are the user, therapeutic, and conceptual requirements for the design and development of a trunk stability exergame?"
Stage III. Design solution	Produce a concept based on usability criteria defined in the previous stage	"How to incorporate the user, therapeutic and conceptual requirements on a novel solution?"
Stage IV. Exergame evaluation	Evaluate the developed exergame against user requirements in a home environment	"What elements affect the user experience and user satisfaction when using the system in a home environment?"

1.3 Thesis Outline

This thesis is structured chronologically. It is composed of seven chapters. Below there is a description of the content of each chapter.

Chapter 2, *Background*, provides the theoretical foundation of cerebrovascular accidents, as well as physiotherapy approaches and neurorehabilitation strategies for trunk rehabilitation following chronic stroke. Afterward, the UCD framework and its use in rehabilitation game design are explained in depth.

Chapter 3, *Stage I. Understanding the context of use*, identify the facilitators and limitations in restoring trunk stability during the chronic phase of stroke and the characteristics of the physical environment in which the system will be used.

Chapter 4, *Stage II. Specify Requirements*, and describes the selection criteria for the selection of requirements. Furthermore, the insights from the previous stage are used to inform the requirements of the user, therapeutic and conceptual requirements for the development of a trunk stability exergame according to the established criteria.

Chapter 5, *Stage III. Design Solution*, addresses the design and development of the exergame based on the requirements of stage II. This stage involved the main stakeholders with a participatory approach to come up with an innovative idea.

Chapter 6, *Stage IV. Exergame evaluation*, describes the evaluation of the system, as well as explains the identified factors concerning the home environment that negatively affect the user experience.

Chapter 7, *Discussion and Conclusion*, discusses this research's findings, implications, and limitations of this research. Additionally, offers recommendations for future work.

Chapter 2

Background

2.1 Cerebrovascular accident and Trunk control

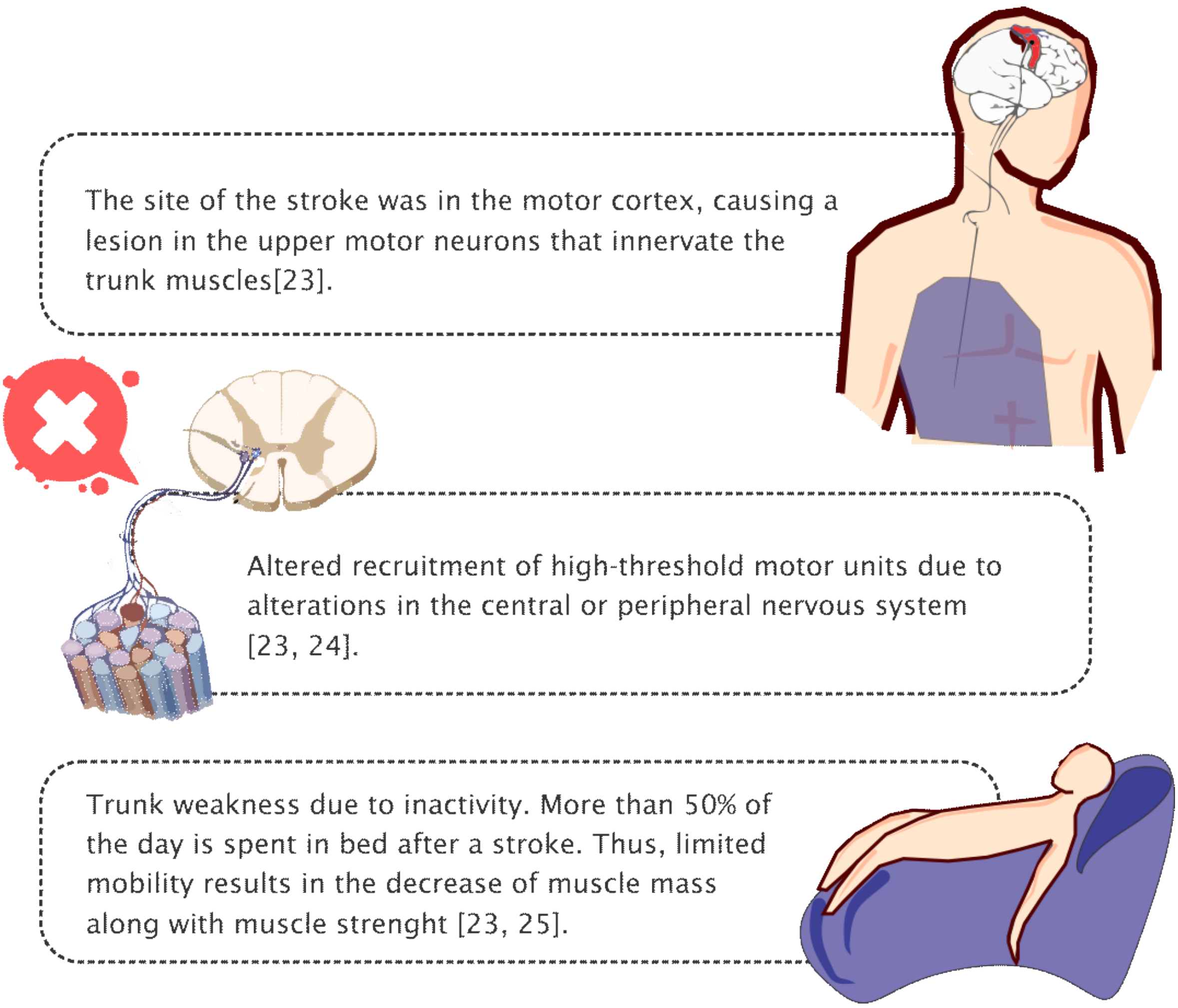
An Cerebrovascular Accident (CVA), also known as a stroke, occurs when blood flow to the brain is interrupted, causing the brain cells to die or suffer damage [16]. The brain is divided into different areas that are responsible for specific functions or abilities [17]. Thus, the stroke's location and size will determine the severity of its side effects. In this way, strokes are unique, and their effects differ from patient to patient[16].

Stroke survivors might present impairments in sensory, motor, or cognitive functions[1]. The most outwardly notable effects of a stroke are the ones that impact physical movement, especially when the trunk function is impaired [16, 18].

Composed of the core, the pelvic, and shoulder girdles, the trunk is the "center point" of the body. The contraction of the muscles that form part of it allows the alignment of the thoracic cage and the spine granting balance and stability by absorbing or dissipating external forces during static and dynamic postures [19] [4]. Because of its functions, trunk control is a fundamental motor skill for performing functional tasks such as sitting, transferring from the supine to the sitting position, and rolling[20, 18]. It is also a prerequisite for the control of more refined limb tasks such as walking and reaching tasks[21].

Trunk Control does not depend only on muscle strength. It is an integrated response that relies on sensory-motor skills that weigh the information coming from the visual, the vestibular, and the proprioceptive systems to predict and provide optimal motor commands for the task being performed in the specific en enviroment[19] [4] [22].

Several factors can lead to deterioration of trunk control after stroke, including the following:



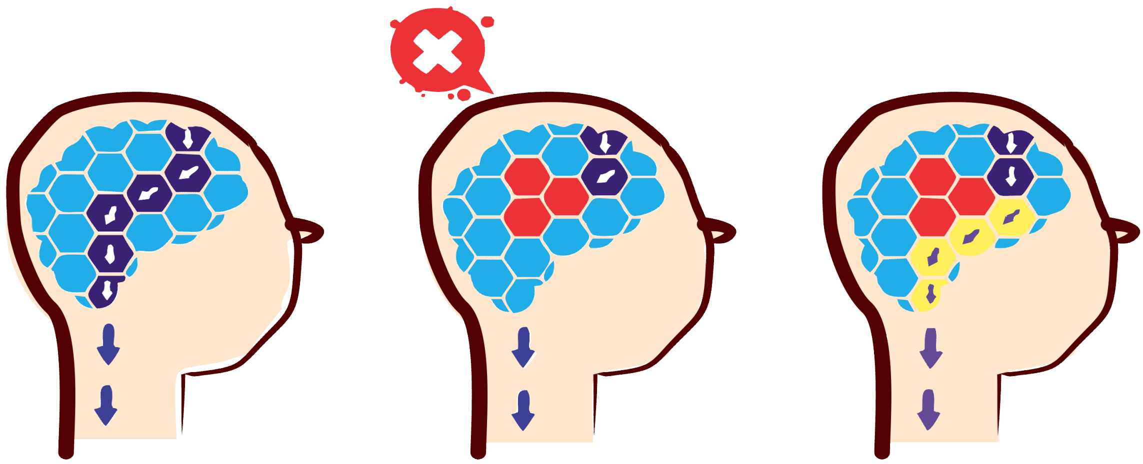
Regardless of the reasons, stroke survivors might present with different levels of poor balance, posture disorders, trunk misalignment, and asymmetry of weight distribution [5]. All of these factors increase the risk of falling [23]. After discharge from the hospital, 73 percent of patients fall, and from those, 30 percent sustain injuries [5]. Physical damage is not the only consequence that a fall can produce. Stroke survivors might also get affected psychologically, inducing depression and the fear of falling [5].

Those elements negatively impact stroke survivors' quality of life, their independence, and their ability to perform their daily activities [2, 24]. Evidence suggests that trunk control is an essential predictor of functional recovery following a stroke in 45 % to 71% of the cases [25]. Because of its importance and its relation with other functions, reestablishing trunk muscle function is essential for improving stability, facilitating the reeducation of limb muscles, and assisting the patient with the management of ADL [25].

2.2 The Art of rehabilitation

2.2.1 Brain reorganization

As mentioned before, a stroke affects different functions. Among its side effects are paralysis and weakness and the impairment of gross motor skills, fine motor skills, speech and language, cognition, vision, and emotions [26]. By itself, the brain can heal and reorganize its structure in response to stimuli and injuries[27]. This capability is called *Neuroplasticity*. After a stroke, some connections between the brain and the body get damaged [28]. Then, the plasticity process initiates to compensate for the lesion and the neural changes that had occurred[27].



Nonetheless, recovery after a stroke is not linear but in a curve shape. According to how the brain is reorganizing, the process can be divided into five phases. Table 2.1 describes the timeline of stroke recovery. During the first few days or months after a CVA progression of patients seems to be ”Fast” [29]. After all, a plateau may occur after six months[30]. For some, this means full recovery, but for the rest, recovery may slow down compared to the first three months [31]. Around 50% of stroke survivors become chronic patients and have to live with the consequences of stroke[8].

As opposed to what has been thought in the past, the regain of functions is still possible after reaching the plateau and even after years during the chronic stroke phase. The exposure to continuous stimuli can trigger the connections of new pathways, thus enhancing brain plasticity [30] [24]. Multiple strategies had been used for this purpose, such as the classification of functional tasks, motor learning strategies, and physical conditioning principles. It should be noted that during this stage, the rehabilitation process becomes tedious and slow, as well as the progression of the patient. Most of the dropouts from therapy occur during this stage[32].

Table 2.1: Timeline of stroke recovery

Phase and Time frame	Neural reorganization	Clinical goal
Hyperacute phase 0 hrs-24 hrs	Neural tissue dies or gets damage followed by swelling [33]	Prevention of progressive cerebral damage and secondary complications [29]
Acute phase 24 hrs-7 days	In the area surrounding dead tissue (called penumbra), the cells go into a shocking state, which prevents their functioning. They are still viable for recovery [33]	Encourage to perform basic movements (e.g. sitting, short walks) with low-intensity [29].
Early subacute phase 7 days-3 Mth	A rapid and significant improvement occurs by the own recovery mechanisms of the brain. This process is called spontaneous recovery. Now neuroplasticity mechanisms can be stimulated to promote the reorganization of the brain cells [33]	Rehabilitation focused on restoring motor and cognitive functions [29]
Late subacute phase 3 Mth-6 Mth	The neurons that were in shock become stable again. However, these neurons must adapt to the new organization of the brain and reroute pathways that were damaged. As a consequence, the individual might perform slow and inaccurate movements. The individual has to relearn again the skills she or he had acquired in the past [33]	Follow-up on the previous stage. The goal is to reduce limitations in Activities of Daily Living (ADL) and social participation [29].
Chronic Phase 6 Mth $>$	Neural repair has taken place. Surviving neurons are either working efficiently, lethargic, or somewhere in between. If the individual stops using the affected side, a detrimental effect can occur to their gained skills [33]	Optimize social functioning, teach coping with limitations, maintain fitness and manage quality of life [29]

Mth= months
hrs= hours

2.2.2 Physical conditioning: Is strength training enough?

The lack of physical activity that usually follows after stroke might be one of the factors influencing diminished muscle strength [34]. Stroke survivors spend 50% of the time in bed. Bed rest has been shown to cause muscle thinning within 7 to 10 days [35]. As a consequence, there is a reduction in muscle fiber size with an accelerated decline in muscle force generation capacity and alterations in muscle electromyography [36]. Within the first week of poor to null mobilization and due to the loss of muscle mass, up to 40% of muscle strength can be lost [37].

Lack of physical activity also affects other systems [36]. The cardiovascular system suffers from cardiac deconditioning, reducing the stroke volume by 30% within the first-month [38]. In the case of the respiratory system, there is an increased probability of developing respiratory complications such as pneumonia [39]. Other secondary consequences are the increase in cognitive processing impairments[36]. Exercise training is therefore a fundamental activity that must be performed to reduce secondary consequences of stroke and to improve functional capacity [40].

In the case of the trunk, a common contributor to impaired trunk control is the decreased strength and power of the anterior, lateral, and posterior trunk musculature [41][42]. Physiotherapy interventions that include trunk training can improve strength, stability, gait, and dynamic and static balance [41][8].

Due to the nature of stroke, every patient perceives different levels of trunk impairment. By focusing on the individual's needs, personalized therapy can be provided, this will maximize long-term adherence [42][43]. The Frequency, Intensity, Time and Type (FITT) factors allow the physiotherapist to personalize the training, ensuring that the dose and type of exercise are planned in such a way that benefits for the patient are maximized.

As of now, the selection of the FITT factors is based on trial and error since little to no evidence exists about how much training is beneficial. For chronic stroke survivors, the average training prescription is twice per week, 40 to 120 minutes per day, and with low-intensity [1]. Several systematic reviews and observational studies urge further research on examining which modalities concerning the FITT factors are optimal during stroke rehabilitation [20] [44].

In chronic stroke rehabilitation, physical conditioning plays a critical role, and on average strength improves by 50% of muscles that are specifically targeted [43]. However, an increase in strength does not necessarily reduce disability [45]. In the research of Sorinola et al., the physiotherapy intervention provided only core stability exercises to the participants. The results showed weak evidence for the effect of trunk exercises on functional recovery.

Thus, on its own, strength exercise is not enough to promote the rehabilitation of gross motor skills. It should be combined with other strategies that stimulate neurorehabilitation processes[44]. Research has strong support in the implementation of Motor learning strategies for the rehabilitation of chronic stroke patients[47].

2.2.3 Motor learning and recovery functions

The term *Recovery* has been defined as the reacquisition of motor skills lost through injury [30]. Similarly, *Motor learning* is the study of the processes involved in acquiring motor skills as well as the factors that contribute to or hinder their acquisition [48]. Both terms look for new solutions that promote the gain of skills concerning specific tasks and environments given the characteristics of the individual. Thus, it is possible to translate the processes that humans use to learn (motor learning strategies) into therapeutic actions for rehabilitation [30][49].

These strategies had been proposed as a model for stroke rehabilitation [47]. Their purpose is to aid a patient in retaining and transferring the learning achieved in therapy for a better performance in real life [44]. Based on the literature review, the following strategies proved to be essential for stroke rehabilitation [50]. (see table 2.2).

The most fundamental principle in motor learning is repetitive practice [30]. Despite its effectiveness in improving performance within a therapy session, this strategy is not optimal for long-term retention, and individuals are unable to transfer the motor skill to their daily lives [51]. Literature suggests that variable practice increases the generalization of learning new tasks leading to better retention and enhancing the performance of similar tasks or movements that have not been trained [50][51].

Based on this, the therapeutic effects that motor learning strategies provide are dependent on the characteristics of the stroke, the end goal of therapy, and the environment in which the task will be performed [52]. This dependency dictates the range of importance between them. Therefore, the selection of motor learning strategies applied to rehabilitation must take into account the elements described above.

Table 2.2: Motor learning strategies description

ML strategy	Description
Task-specific practice	The rehabilitation is oriented to practice context-specific motor tasks and receive feedback [53]
Repetitive practice	Repetition of motor tasks to allow the development of high skilled motor patterns [50].
Spaced practice	Increasing the time between sessions improves skill acquisition. However, the periods between sessions must not be too long [50]
Variable practice	Providing variability within the training [50]
Progression	Incrementation on the task difficulty to allow the increase in the error prediction and error processing [50]
Multisensory stimulation	Enhance perception and the recognition of sensory information through the exposure to multisensory stimulation [50]
Motor imagery	Mental visualization of future movements and mental plans [50]
Action- observation practice	The observation of the movement to perform activates the motor cortex and elicitates muscle activation [50]

2.2.4 The nature of movement and its classification

Movement arises from the interaction of three factors: the task, the environment, and the individual. In the face of sensory/perceptual, motor, and cognitive impairments, recovering functions from a CVA requires the development of movement patterns that meet the demands of the interacting functional tasks and the environment[30].

The nature of the task constrains the movement to be performed[30]. Thus, tasks regulate the neural organization of movement. An understanding of task attributes can provide a rehabilitation framework on which tasks can be classified according to different aspects. With this classification, therapeutic strategies can be developed to help the patient awake the muscles synergies to perform functional tasks [49].

The so-called Gentiles Motor Skill Taxonomy is a classification system that categorizes movement and motor skills into two dimensions of physical actions[54][55]: (1) the environment in which the skill is performed and (2) the function of the action. Each dimension has four sub-dimensions (see figure 2.1):

- (1) Stationary vs. In-motion conditions and Inter-trial variability vs. No intertrial variability.
- (2) Body stability vs. Body transport and Object manipulation vs. No object manipulation.

As has been highlighted before, it is essential to take into account the task that will be performed in a certain environment to provide an effective rehabilitation protocol [52]. The Gentiles taxonomy incorporates these factors[54]. Additionally, by its nature integrates motor learning strategies. These are listed below:

- Progression: Allows a systematic progression in difficulty of motor tasks.
- Variable practice: Each of the 16 categories is associated with unique features based on the two-dimensional approach
- Task-Oriented: Refers to the environmental conditions to which the performer has to react in order to successfully perform a task.

Thus, this taxonomy can be used as a template to guide the rehabilitation protocol [54]. By segmenting a functional task into the 16 skill categories of the taxonomy, the set of skills can serve as a progression for retraining functional movement in a patient with stroke [30].

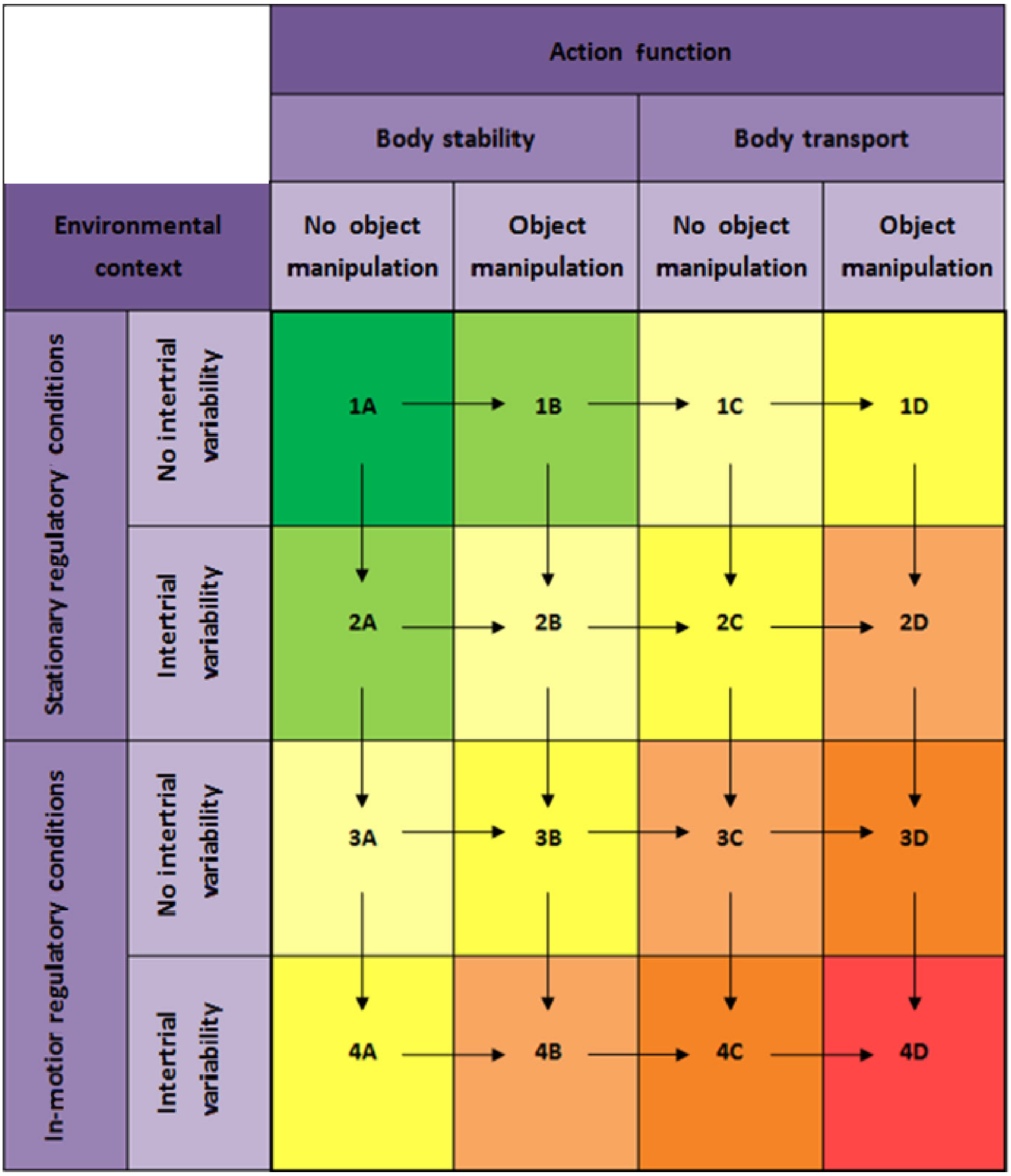


Figure 2.1: Gentile's taxonomy of motor skills. The taxonomy defines 16 different motor skill categories. The easiest skill category can be found at the top left position **1A**. Meanwhile, the hardest category is at the bottom left position **4D**. Thus, seven levels of difficulty, order diagonally, can be defined. [54]

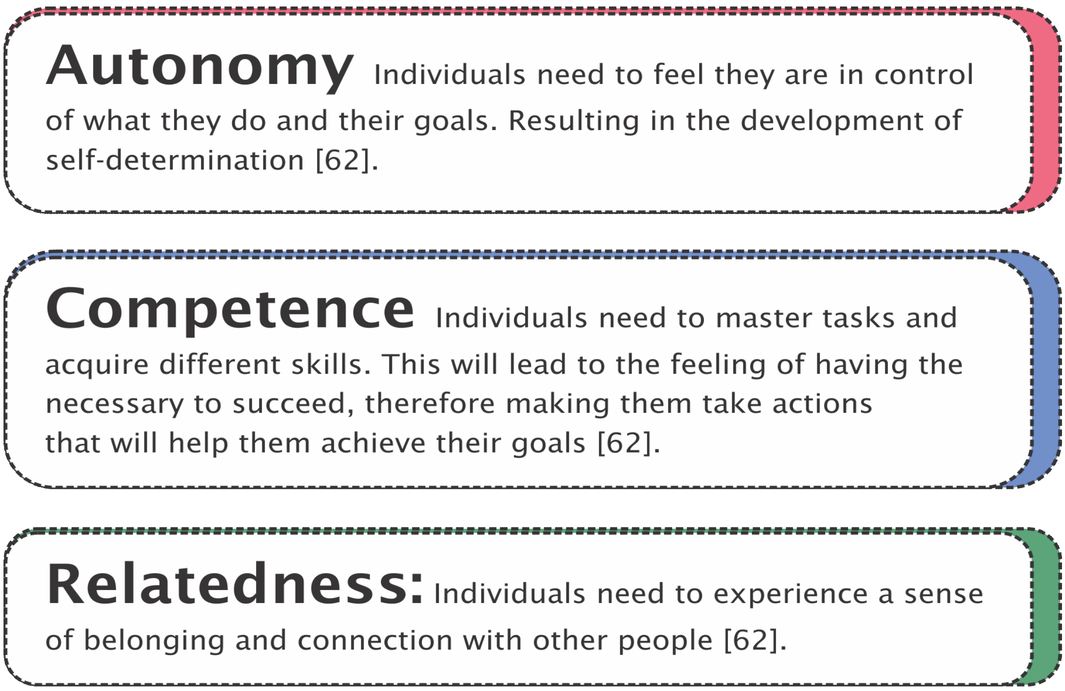
2.2.5 Motivation and its relation with therapy adherence

Although rehabilitation programs can improve functional capacity, the performance of ADL, and quality of life, the adherence to therapy decreases between 30% and 50% during the chronic stroke phase [56] [11].

During this phase, the rehabilitation process becomes tedious, repetitive, boring, and slow [32]. It requires willpower (motivation) to maintain adherence in the long-term [56]. In stroke survivors, motivation is associated with motor and functional outcomes [24]. Previous research has shown that high adherence to a prescribed rehabilitation program is associated with high motivation [56][24].

But what is motivation and where does it come from? There is a wide variety of theories regarding motivation that try to explain these questions[57][58]. In all of them, motivation is defined as an internal process that drives a person to achieve a goal [58]. Motivation is typically divided into intrinsic and extrinsic motivation. Extrinsic motivation refers to the behavior of doing something for a reward rather than for enjoyment [57]. In contrast, intrinsic motivation involves acting for the fun or challenge of an activity rather than because of incentives or demands [59]. This particular type of motivation is associated with high adherence to a task because it comes from the desire to satisfy human needs [60].

Self-Determination Theory (SDT) is a motivation theory that is highly related to intrinsic motivation [61]. The theory states that people can achieve self-determination when their capacities for competence, connection, and autonomy are met [62].



In clinical practice SDT is commonly applied to motivate chronic stroke patients [57]. The most used strategies that are applied are goal setting, active listening, praise, providing information regarding rehabilitation, enjoyable communication, and respect for self-determination [63] [60].

Gamification is another strategy that has been implemented in the rehabilitation field. This strategy has the power to enhance enjoyment because it fulfills the three basic psychological needs described by the SDT. Particularly video games can simulate engaging scenarios that attract users by setting aside the limitations of the ”real world” [54][60]. As a result, several researchers have suggested that video games can serve as motivational tools in health care [24][54][15].

2.3 Gamification in rehabilitation

Serious games are games intended to fulfill a purpose beyond entertainment[1]. One of the most used subcategories of serious games is Exergames. In them, physical activity is combined with gameplay elements [64] [1].

In the last years, exergames have shown to be an effective approach to promote e-home rehabilitation for stroke patients due to their low cost, accessibility, and motivational engagement [65]. Moreover, several studies have proved that exergames are an effective tool for motor impairment and cognitive rehabilitation for stroke patients [66][67][68].

However, there are limited exergames that target the rehabilitation of the trunk. The systematic review of Saeedi et al. shows that from the 60 exergames that were used to promote stroke patient’s rehabilitation, only 24 focused on training balance, and, within those, only 3 targeted the trunk. Additionally, none of these games were developed for stroke patients. Instead, researchers used commercial games such as WiiFit, Grid2 on Xbox, and Canoeing Wii Sports.

Using commercial games as tools of rehabilitation therapy presents multiple limitations. The most important ones are lack of gameplay adjustments for tailoring the patient capabilities, not generating data analysis, Inappropriate game design for the users, and lack of therapeutic concepts [1]. Therefore, there is a need to develop exergames specifically for rehabilitation purposes. This way, the goals established by the patients and the physiotherapist can be achieved.

2.3.1 Game design

The first concept that must be addressed for designing such a game is understanding the elements of game design. Game design is a process that dictates the form and shape of interactivity that the game includes [69]. This way of interaction receives the name of gameplay. It describes how the player interacts with the environment and how the environment reacts to the choices of the player [69]. Three key elements compose the gameplay: game mechanics, user interface, and storytelling and narratives [70]. Their characteristics are described below.

I. Game mechanics

A set of data and algorithms that define exactly the game's rules and internal operations, for instance, "The player will receive a reward if it lands in the blue circle" [70]. Its main functions according to Adams are:

- Detail how goods are created, distributed, and consumed. These goods can be health, skills, money, and experience.
- Present active challenges
- Accept player actions and implements their effects in the game world
- Detect victory or loss
- Operate the artificial non-player characters and opponents
- Transmit triggers to the storytelling.

II. User Interface

The user interface is in charge of translating the game mechanics into graphics and sounds, making the game visible to the player. But also triggering actions when the user makes use of the controller. Additionally, another function is to facilitate gameplay by providing intuitive instructions and screens. Figure 2.2 shows the relationship between the game mechanics, the user interface, and the player.

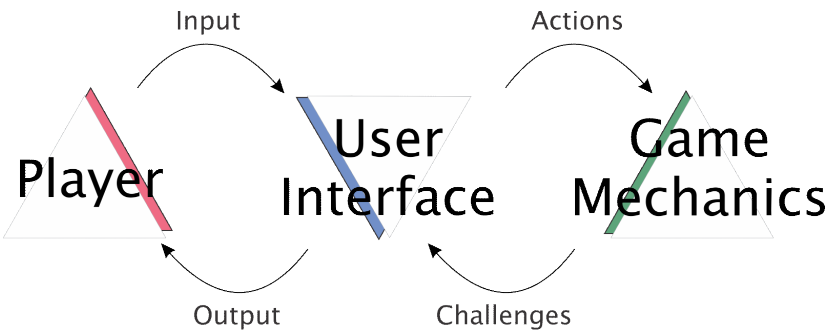


Figure 2.2: Relationship between game mechanics, user interface and the player [70]

User interfaces consist of three main components: interaction models, camera models, and art styles.

A. Interaction models

An interaction model determines how the inputs from the player's hardware will interact with the game world [70]. There are multiple standard interaction models used in videogames:

- Multipresence: The player can interact with the game world as an omnipresent being. Usually, these games are complex and they focus on making quick decisions[71]. Plants vs. Zombies is an example of a video game that uses this model.
- Avatar-based: The player controls a character in the game world [70]. The video game Mario bros use this model.
- Contestant-based: These games are multiple-choice quizzes on which the player has to select the correct answer [71].

B. Camera models

Refers to the point of view from which the game will be shown in the user interface [70]. Figure 2.3 depicts the different camera models used in video games.

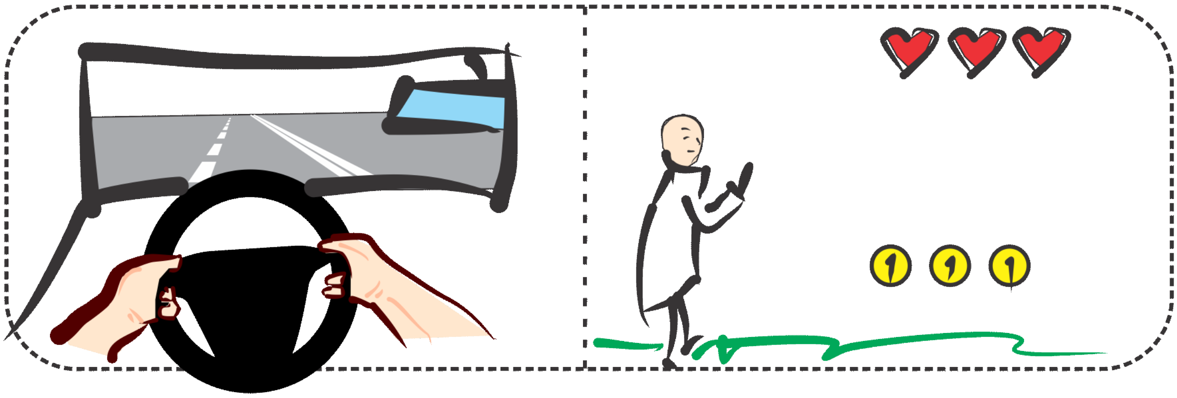


Figure 2.3: Camera models used in videogames. **Left.** Third-person perspective **Right.** First-person perspective

C. Art Style

The art style usually defines and creates the atmosphere of the video game [70]. In table 2.3 is possible to find a description of the tools used for creating the art style of a videogame.

Table 2.3: Common tools used for creating the art style of a video game according to Adams

Tool	Description
Lighting	Creation of illumination depending on the placement and orientation of the light
Color palette	Combination of colors that create the mood of the game
Music	This element helps to set the pace and the mood of the game
Ambient audio	Serves to amplify the immersion in the game, sometimes helping the player orient herself. It also helps to set the mood of the game

III. Storytelling and Narratives

Storytelling and narratives are often used to enhance the entertainment, engage the player emotionally, and therefore produce long-term interest [70].

There are multiple genres of video games. Among them is possible to find adventure games, action games, sports games, strategy games, and puzzle games, among others [69]. The type of game determines whether the gameplay needs or not a story [70]. For example, adventure games depend on the storytelling of game, without it the game might not have sense. In contrast, in sports games in which the player has to score points to win matches, the storyline is simpler because the gameplay does not depend on the narrative but on winning the events [70].

Design process

As it can be seen, game development involves multiple disciplines from engineering to art. Thus, the design and development process must follow a systematized procedure to ensure the effective integration of multidisciplinary concepts [72].

The game development life cycle methodology describes the steps that must be taken to create a video game [73]. The model of Ramadan et al. proposed a model of six phases: Initiation (fuzzy concept), Pre-production (game design ideation and prototyping), Production (game mechanics integration and refinement), Testing (bug refinement testing), Beta (third-party testers), and Release (public release).

Because of the nature of the exergames applied in rehabilitation, following a game development lifecycle methodology might not ensure the integration of the patient's characteristics. The process should take into account other steps to achieve this. As stated by Rouse, a satisfactory game design comes from considering several perspectives. Multiple research proposes the use of User-Center Design frameworks for the design and development of exergames [74][54]. Therefore, this limitation can be overcome by integrating game design elements into a User-Centered Design approach.

2.3.2 User-Center design

UCD is an iterative framework of the design process. It involves the major stakeholders from the beginning. This methodology aims to identify end-users needs, wants, and limitations in all stages of design and development [74].

According to Jokela et al., the UCD is divided into four stages. Each stage uses different approaches and methods, in which designers analyze and validate how users perceive the product in a real-world context [74][74][76]. Figure 2.4 depicts each of them.

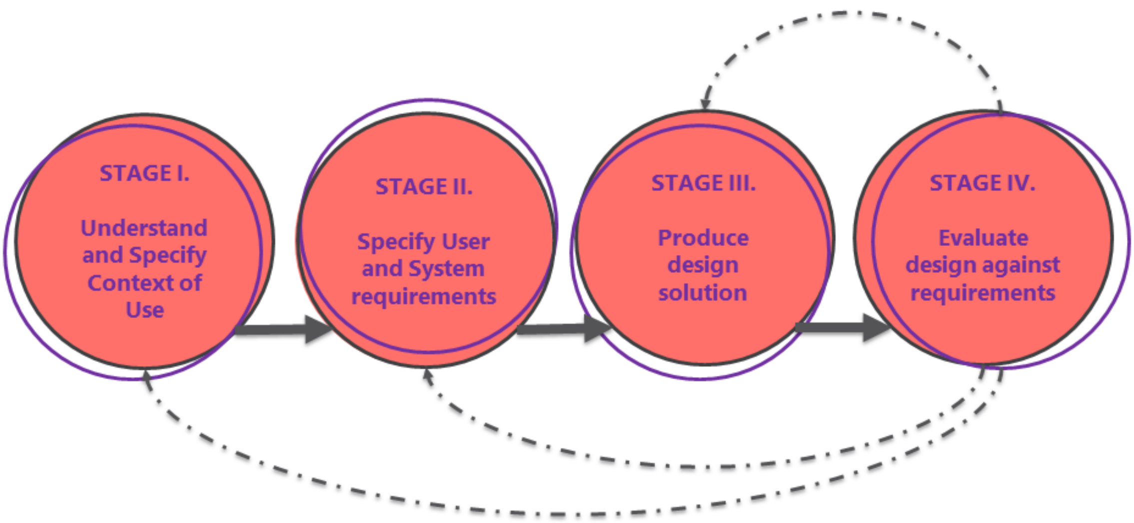


Figure 2.4: Stages of the UCD.

Stage I. Understand and Specify Context of Use

This stage aims to identify who the users are, the environment of use, and the tasks they perform with the product [75]. The researcher understands the context of use by collecting a broad range of information on the topic. Some of the research methods used in this stage are:

Interviews	Allow the collection of qualitative data and the exploration of unique points of view from the participants [77]. There are multiple methods for constructing interviews. One of the most used is the semi-structured approach. In this type of interview, the researcher prepares a few questions around the topic of interest while the rest of the questions are not planned. This allows the exploration of topics that are relevant to that particular individual [78][77]
Focus groups	Small groups of participants that share the characteristics of the phenomenon to study are recruited Schmidt2020. With this group, the researcher organizes a semi-structured interview where they share their thoughts, feelings, attitudes, and ideas on a certain subject [79]
Field observations	Nonobtrusive observations of the group of interest that allow the full understanding of the phenomenon in situ [77]

Data analysis

The data gathered from these studies can be analyzed using affinity diagrams, personas, scenarios, and other methods [80].

Affinity diagrams. Hierarchical diagram that organizes individual interpretations by grouping the data into key issues under labels that reveal the customer's needs [80]. The end diagram becomes the basis for user requirements [78].

Personas. A fictional profile is created by capturing the user's expectations, prior experience and expected behavior [80][81]. The information from affinity diagrams can be used to construct personas. Hence, fundamental needs are considered [80][82]. This profile is described in a narrative form so the persona seems like a real person [81]. By using personas, designers and stakeholders can prioritize the requirements and tasks of the system to be developed. In addition, it guides the focus on who the design is intended for [82].

Scenarios. Fictional descriptions that depict the daily life or events that the primary stakeholder has to live [78]. The persona that was created later is used as the main character of this story [81]. This tool also serves to elicit requirements and as a starting point for mutual understanding and collaboration. Scenarios must be concrete and be as close as possible to reality [78].

Stage II. Specify the User and System Requirements

This stage aims to define the usability criteria for the product in terms of user tasks and establish design guidelines and constraints [75]. Understanding the requirements is fundamental to the success of the interactive system [83]

Using the personas, scenarios, and/or affinity diagrams is possible to specify the requirements of the system. The following section describes the techniques and methods to support the requirements specification.

- **Evaluation of existing systems:** Help to extend the knowledge of what requirements have or have not worked for similar systems[83].
- **Requirements categorization :** Divides the requirements into different categories. These are user requirements, technology requirements, and organizational requirements [83].
- **Prioritization:** Arranging the requirements based on their importance to the stakeholders [83].
- **Criteria setting:** Establishment of criteria to evaluate if the system meets the requirements[83].

Stage III. Produce Design Solutions

This stage aims to generate ideas for the system to develop and from those ideas produce a concept based on usability criteria [75]. Participatory methods are used in stage III to involve the main stakeholders and produce innovative ideas from different perspectives [77]. The following list presents some of the techniques that are used to ideate solutions.

Brainstorming	Participants share their thoughts on a specific topic. All types of ideas are allowed [84]
Storyboarding	Participants draw a story of the process they try to solve on paper. The drawings are made on small squares, which represent steps of the process and the possible solutions are embodied in them [85].
Sketching	Participants draw their ideas on a piece of paper. Later, that drawing is passed to the next participant who continues further with the concept. In the end, participants discuss the drawing and try to find similarities [86]
Mind mapping	Is a visual tool that organizes information into a hierarchy using diagrams. It is based on individual preferences, starting with a central idea that branches out to other essential topics [87]
Brainwriting	Participants are sitting together in silence. Each of them writes their ideas on a piece of paper that later is passed to the next participant [84]

Stage IV. Evaluate design against requirements

The proposed design solution is evaluated against user requirements through usability testing with actual users [75]. The outputs of the evaluation provide direct information on how participants use and interact with the system as well as the issues they encounter[81].

The tasks that the participants will do in the evaluation must represent a realistic use of the system and the system should have the important parts of the user interface [81]. Other testing methods for evaluating satisfaction, user experience, and usability are questionnaires and interviews.

Through the use of these methods, an in-depth assessment of the user's point of view can be accomplished. The received feedback can be used to improve the system in the next iteration [81].

Chapter 3

Stage I. Understand Context of Use

3.1 Methodology

3.1.1 Study design

The aim is to understand the needs, desires, and behavior of chronic stroke survivors. Additionally, identify the limitations in restoring trunk stability during the chronic phase of stroke and the characteristics of the physical environment in which the system will be used. The gained knowledge will determine the criteria of the requirements for the design of the exergame. To achieve this a qualitative exploratory research approach is taken.

Data collection

The data collection was performed through semi-structured interviews tailored to physiotherapists and chronic stroke survivors. Four different protocols were developed according to the People-Activities-Context-Technology (PACT) framework [78] (See appendix A).This allows participants to raise issues that they feel are important, and the interviewer can follow up with questions to facilitate a better understanding [78].

In the following list is possible to find a description of each of the protocols.

- **Patients protocol:** Composed by 32 questions. The purpose of this protocol was to understand the situation of chronic stroke patients on four topics: follow-up rehabilitation, user requirements, motivation, and data.

- **Gamer Patients protocol:** Before conducting the interview, patients were asked if they were considered gamers; if yes, then this protocol was applied. The aim was to understand the user experience of playing commercial or rehabilitation games from a patient that has suffered from a stroke. The protocol contained 34 questions.

- **Physiotherapists protocol:** This protocol was designed to gather information on three topics: rehabilitation protocols, data, and neurorehabilitation concepts. The protocol contained 34 questions.

- **Specific type of exercise protocol:** This protocol of 15 questions aimed at physiotherapists was created to validate the information obtained from previous interviews and the literature review. It was divided into two topics: Rehabilitation topics and metrics.

3.1.2 Participants recruitment

The participants recruitment took place at the Rijndam revalidatie center, the rehabilitation center of Universidad Santander and the rehabilitation center of Instituto Mexicano del Seguro Social. A general invitation was made to physiotherapists and stroke survivors from these institutions to participate in the study. A total of four physiotherapists and two chronic stroke survivors were selected based on inclusion criteria and their willingness to participate. Table 3.1 shows the inclusion criteria.

Table 3.1: Elegibility criteria for the contextual study

Stakeholder	**Requirements**
Chronic Stroke Survivors	Stroke survivors who have suffered a stroke for more than six months, be from the Netherlands, medically stable, and able to speak English
Physiotherapists	Specialised in neurorehabilitation or have experience treating stroke patients in the Netherlands or Mexico, and can speak English or Spanish.

3.1.3 Procedure

The meetings were held via Microsoft Teams or Zoom and recorded for analysis. Participants' availability determined the duration of the session. The average duration of the interviews was 45 minutes. When the session ended, the researcher asked participants whether they were interested in participating in future stages of the project.

3.1.4 Ethical considerations

A brief explanation of the study's purpose and the procedure was given to participants. Those who agreed to participate signed an informed consent form and provided their permission to record the interviews (see appendix A). Anonymization was applied to all personal information.

3.1.5 Data analysis

Every interview was transcribed using the Microsoft stream auto-generator app and manually corrected if there were any errors. For the Spanish speaker participants, the researcher translated the transcripts.

The transcripts were analyzed for the identification of criteria for patient's requirements, chronic stroke rehabilitation, and game and engagement using affinity diagrams. The MOSCOW method was used to prioritize the collected information (see figure 3.1). This technique allows the management of requirements by classifying data into four categories: must-have, should-have, could-have, and won't-have [88]. Prioritization was determined based on recent neurorehabilitation findings, the researcher's critical thinking, and the guidelines of the Koninklijk Nederlands Genootschap voor Fysiotherapie (KNGF). For this research, only the data from the categories *must-have* and *should-have* were included for further analysis.

Finally, this information is presented as scenarios for the three topics. The scenarios were constructed using PACT framework for scenario development [78]. Additionally, two personas profiles were created following the methodology proposed by LeRouge et al. The profiles include a picture, descriptions of the individual mindset, daily living activities, motivation, concerns, and goals.

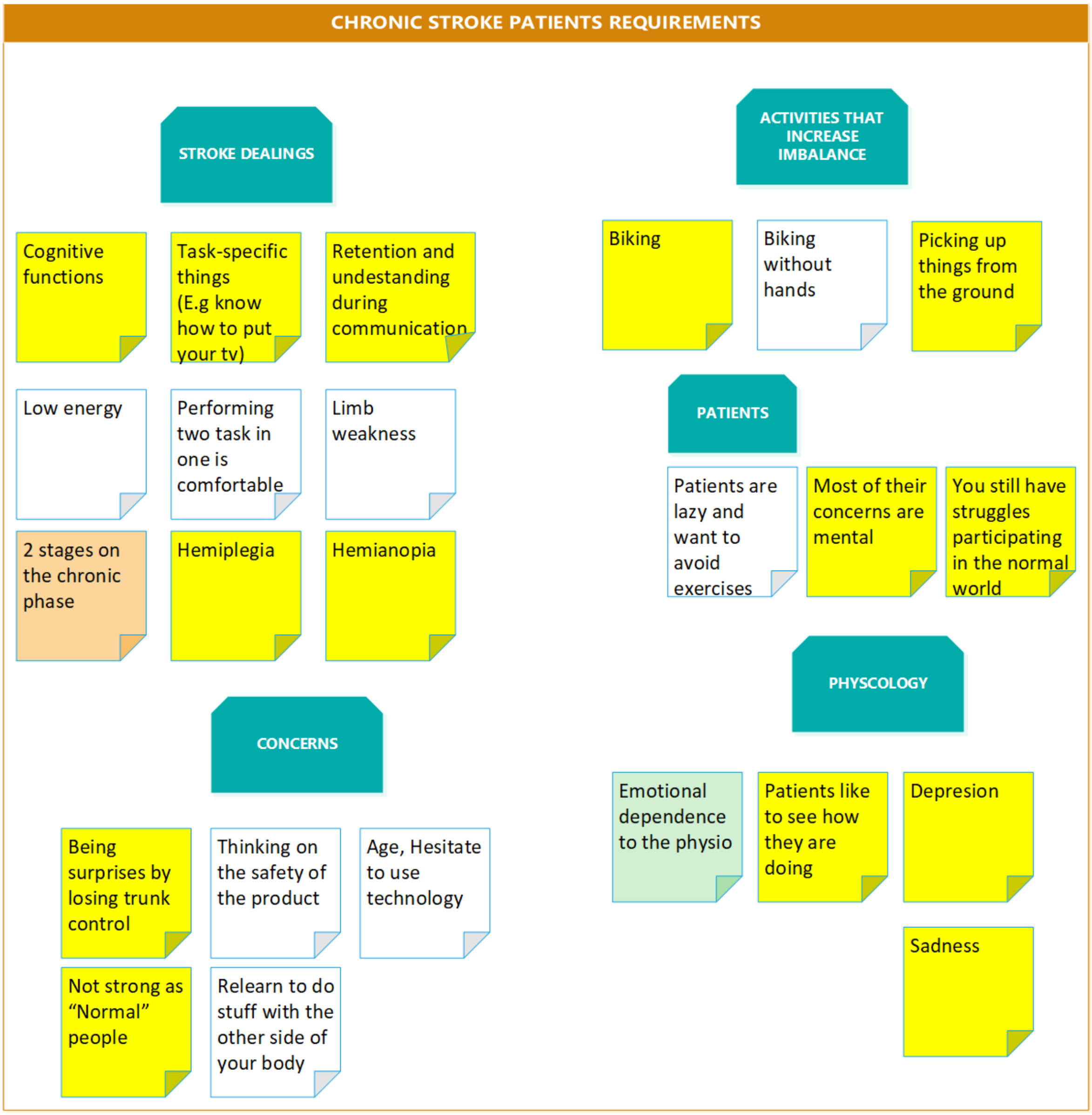


Figure 3.1: An affinity diagram segment containing the topic Chronic Stroke patient requirements. As per the MOSCOW method: (Yellow) Must-have, (Orange) Should-have, (Green) Could-have, and (White) Won't-have.

3.2 Results

Data from the exploratory study was analyzed and classified using affinity diagrams into three categories: Chronic stroke trunk control rehabilitation (10 subtopics), chronic stroke patient requirements (5 subtopics), and Game and engagement (9 subtopics). Below are presented the obtained scenarios and personas, followed by a description of the principal findings per category. Figure 3.1 shows a segment of the affinity diagrams (See appendix A for the complete diagrams).

3.2.1 Scenarios

Chronic Stroke Trunk Control Rehabilitation scenario
Valentijn is a physiotherapist who is specialized in neurorehabilitation. He treats chronic stroke survivors at home to improve balance. During the sessions, the first thing that he does is establish a primary goal with the patient. This goal is segmented into small goals, this way the patient's journey is progressive. Then the therapy program is adapted to train that particular skill that the goal involves (e.g. being able to stand up from bed). Thus, he uses task-oriented practices. He prescribes some exercises for the rest of the days that the patient will be on his/her own. The prescription follows the Frequency, Intensity, Type, and Time factors. Valentijn has established a base for these factors that adapts to the necessities of his patients. It goes as follows: F: 2 times a week, I: low, T: Strenght, Time: 3 series of 10 repetitions. If one of his patients has poor motor control, the repetitions increase by 5 with space timing between series. On the contrary, if the patient has good control, the series increases by 1. His years of experience had thought him that mirror feedback and making the patient aware of the movement he/she is doing have a great impact on the outcomes of the therapy.

3.2.2 Chronic stroke patient scenario

Chronic stroke patient requirements
Pepijn is a chronic stroke survivor. He suffered from a stroke 2 years ago, and still, he has to leave with some consequences of the stroke mainly when it comes to the performance of Daily Living Activities. Pepijn struggles when he has to go to the municipality or the bank because it takes a lot of effort to understand what the other people are trying to communicate. His cognitive functions are diminished. He has comprehensive aphasia, a condition in which a person has problems understanding during communication or reading. Additionally, oversaturated visual input overwhelms him and because of hemianopia his peripherical field of view is affected, so if he watches a movie he is not able to see the vertical borders of the screen's tv. Auditory input also affects him if it is sudden or if it has a lot of beats. Pepijn used to be a cyclist. However, he had to stop because his static sitting ability decreased after the stroke. Now he has problems walking and sometimes he loses control of the trunk when he pick-up things from the floor so now he is afraid of falling. Because of these issues and the great mental load of all the changes, Pepijn developed depression during the first year, he was demotivated and apathetic to treatment. However, this changed when he started to have some progress in the daily activities he performed. When he realized that there was a possibility to bike again Pepijn started to train constantly. Now he is very motivated, and even when he does not receives therapy from a professional he does exercises that he learned in the past. Of course not every day is bright, sometimes when he goes to the gym he cannot help to compare himself with "normal people" and not being strong enough as them. Some others, he is lazy and avoids exercising. He just wished that if there was an easy way to recover he would take it. His years of experience had thought him that mirror feedback and making the patient aware of the movement he/she is doing have a great impact on the outcomes of the therapy.

3.2.3 Game and engagement scenario

Game and engagement
Two years ago, Maaike suffered a stroke. Now that she is 65 years old tries to enjoy it as much as possible. Maike likes sharing experiences with others that have the same capabilities as her. So she joined a chronic stroke survivors group where some activities for rehabilitation are done. Maike enjoys the fact that the activities are so fun that she does not notice that she is rehabilitating. At the end of every session, participants receive some data coming from their performance within the session. Some measurements were the capability of starting and finishing a movement and the quality of movement. However, not even Maike seems to take the importance of those numbers. For stroke survivors is more important to see their progress in real life. One day, during daily activity, the physiotherapist brought a Wii video game so participants could have some physical activity while playing. The game was about an avalanche that the avatar has to avoid at all costs avoiding obstacles and other dangers. Participants had to stand on the board controller of the Wii and move to control the snowboard. The game was supposed to be engaging and fun. However, because of the visual input, and the sense of sliding made some participants almost felt or generate on them distressing feelings. After apologizing to the participants, the physiotherapist realized the importance of the adaptation of technology to the patient's characteristics.

3.2.4 Personas

The diagrams show the personas created with the information gathered from the affinity diagrams. The images were obtained from a free copy right website [1].

Marjolaine is a 62-year-old woman that lives with her nice Anne 30 in a house near the forest in Utrecht. She used to live alone and teach rowing at Uros association. Marjolaine enjoyed a lot sharing her knowledge with students. She was a very active person that liked outdoor activities. She is modest and even though when she is good at something and stands out, Marjolaine will not bring attention to herself.

However, 2 years ago she suffered from a stroke. Her activities had to decrease because the left side of her body got affected and had to move with her nice. She could recover walking, but she gets fatigued quickly. Besides that, she has difficulties with balance and cognition. The thing that affected Marjolaine the most was having to stop teaching because of the consequences of the stroke. Sudden turns or getting things from the bottom of the boat increase that imbalance. Now she is demotivated and depressed. She follows some exercises to continue rehabilitation, but she does not pay attention to the usefulness of them.

Thijs is a 46-year-old stroke survivor that has 3 kids and a dog. He is a gamer that enjoys FPS games (First Person Shooter) and shares his hobby with his kids. However, some days it's difficult for him to play because of the visual input that some of these games have. He also haves some problems with his sight and he can barely see objects that are in the lateral sides of his viewfield.

Sometimes when he is sitting or standing his body starts to fall to one side without noticing and he is scared that one day he will fall. He stopped cycling and even though that was sad for him because now he cannot go with his kids he is motivated to improve and get better. Thijs had tried different rehabilitation games, but he thinks they are not fun enough, so he continued with traditional rehabilitation. Now he trains 2 times a week by himself and one with a physiotherapist, however, he feels it is not enough. He also confessed that the homework that the physiotherapist gives him is tedious and sometimes he skips it.

[1] https://pixabay.com/

3.2.5 Principal findings

Chronic Stroke Trunk Rehabiliation

Guidelines: There is no straightforward guideline for recovery. Physiotherapists use their experience to create a program for each patient. Personalization was highlighted as a fundamental element.

Activities affected due to poor trunk control: Walking, static sitting, transfers from supine position to sitting, personal hygiene, dressing, showering, and sit-to-stand activities.

Therapy sessions: Involve strength training, coordination exercises, and improving balance. There is no isolation of trunk exercises. Instead, they train the trunk as a compound according to the activity that the patient wants to improve.

Therapy approaches: Task-oriented practice and goal setting. Physiotherapists also recommended segmenting functional tasks into smaller tasks.

Feedback: The techniques used by the physiotherapists to provide feedback were video recordings of the patient doing the activity and action-observation practice. They highlighted the importance of providing elements that allow self-awareness of the activity or movement that the patient is performing.

Devices used for trunk rehabilitation: There were no reported devices. The main reason was due to the cost of the devices.

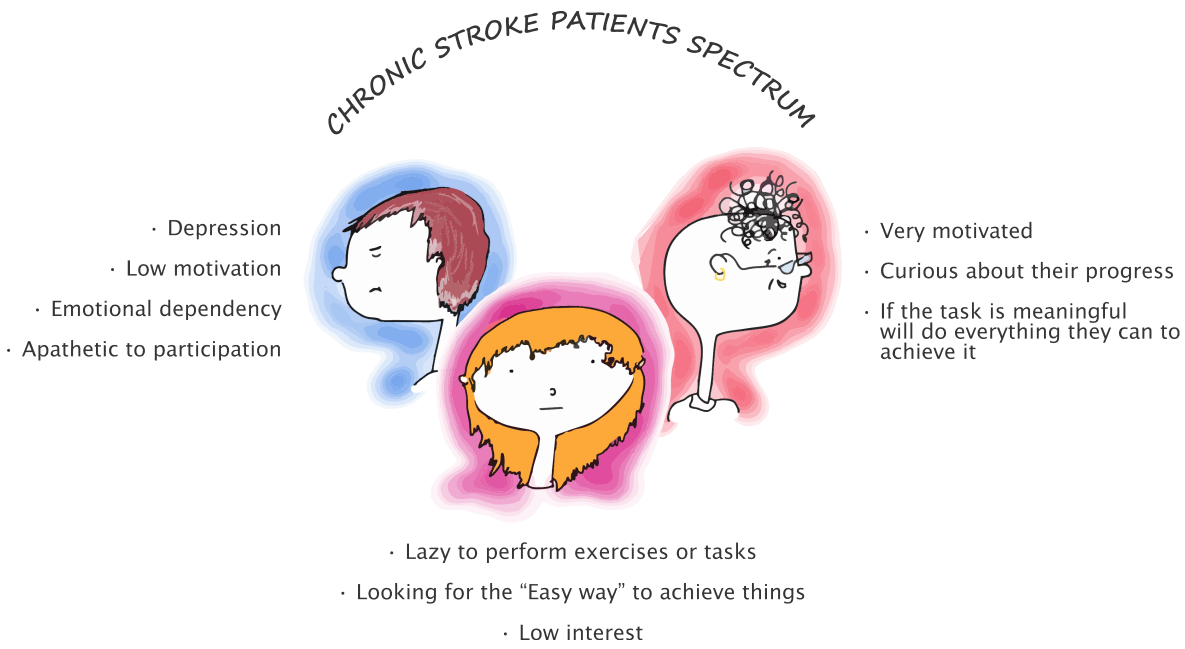
Chronic Stroke Patients Requirements

The collected information was grouped into main subtopics regarding the needs, desires, and concerns of the target group. Here are presented below.
Stroke dealings: Patients reported this as the most dealings of stroke: Impairment in cognitive functions, Hemiplegia, Hemianopia, Difficulty in performing task-specific activities, Fatigue, Processing visual input, and Muscle weakness.

Activities that increased imbalance: Static and dynamic sitting, walking, cycling, picking up things from the ground, and oversaturated visual input.

Concerns: Being surprised by losing balance control, the fear of falling, the feeling of not being capable enough, and the fear of losing independence.

Chronic stroke survivor's characteristics: Constantly confronting their new reality, learning to know themselves again, comparing their current capabilities with the ones they had before the stroke, and great emotional load.



Game and engagement

"A motivated patient will participate and improve faster than an unmotivated patient", was a common answer among physiotherapists. Here are described the elements that physiotherapists use to engage patients in rehabilitation and factors that stroke survivors find attractive about games and other leisure activities.

Motivation techniques: Setting goals, Sharing experiences and stories from other patients, Cheering the patient, and disguising the exercise as a game or by doing a functional task that is meaningful for the patient.

Game interests and Leisure activities: Long and engaging narratives, playing videogames, yoga, cycling, or gardening.

Commercial videogames and stroke dealings: Instructions can be hard to understand, game controllers are difficult to manipulate due to motor impairments, visual input is overstimulating and not everything can be processed.

Progress data: Patients did not find any use in information coming from functional tests such as the Berg Balance Scale or the Trunk Impairment Scale. Instead, they prefer to observe progress during their ADL or by accomplishing daily objectives.

Chapter 4

Stage II. Specify requirements

4.1 Methodology

4.1.1 Study design

After understanding the context of use, the next step is to determine the user requirements. Thus, the aim of this stage is to specify and determine the requirements for the design and development of a trunk stability exergame according to the needs of the end users. This will dictate the performance level of the exergame to be developed [75].

4.1.2 Procedure

First, the document analysis review method was used to validate and complement the scenarios from the previous stage 3. Using this method implementation is verified by reviewing existing guidelines, articles, or books relevant to the topic [89]. For this analysis a literature review on similar rehabilitation exergames, neurorehabilitation findings, and the Dutch guidelines for physical rehabilitation: "Koninklijk Nederlands Genootschap voor Fysiotherapie" was used [29].

Second, the criteria for writing the requirements were established. According to Mo et al., user requirements should follow the characteristics described in table 4.1 to be effective.

Third, for this research, the elicitation of requirements is proposed to be around three aspects: User requirements, therapeutic requirements, and game conceptual requirements. This decision is made based on the fact that therapies and games need their own requirements [91].

Table 4.1: Requirements characteristics according Mo et al.

Criteria	Description
Solution independent	Specify the goals to solve the problems
Complete	Cover all areas of concern
Clear	Understandable for everyone
Concise	Unnecessary requirements should be ommited
Testable	If applicable, ranges and values should be indicated
Traceable	Able to demonstrate the rationale behind a requirement

4.1.3 Requirements elicitation analysis

Requirements were obtained using the complemented and validated scenarios and grouped in one of the categories of the requirements. Following are the three categories and the elements and goals they seek to accomplish.

User requirements

The goal is to identify the constraints and elements regarding user characteristics, emphasizing the limitations of chronic stroke patients for the design of a trunk stability exergame. Table 4.2 outlines the requirements that need to be defined.

Table 4.2: User requirements

Requirements
1. Instruction delivery
2. Presentation of the information
3. Motivation requirements
4. Deliver of feedback
5. Level tailoring
6. Level progression
7. Modifiable parameters
8. Resting time
9. Interface requirements
10. Safety requirements
11. Type of controllers

Therapeutic requirements

Divided into two subtopics, the goal is to identify a functional task to rehabilitate and define a rehabilitation protocol to train trunk stability on the selected functional task.

a. Functional task identification

An analysis was performed to identify tasks related to trunk stability on which chronic stroke survivors had problems performing or causing imbalance. A functional category was assigned to each of the tasks outlined during the analysis [30]. One functional task was chosen based on its importance for trunk stability and ADL. Finally, an analysis of the biomechanics of the selected task was used to identify motion issues and muscles that contribute to the imbalance. Thus, the rehabilitation protocol can focus on training those muscles and skills.

b. Rehabilitation protocol

The approach of the rehabilitation protocol was chosen to provide functional recovery because it has been proven that the therapeutical effects ensure a long-term reduction in impairment and an improvement in quality of life [50]. Table 4.6shows the required information for defining the rehabilitation protocol for the rehabilitation of trunk stability on the selected functional task.

Table 4.3: Rehabilitation Protocol sections

Section	Description
Exercise prescription	Define the motor learning strategies to use, define the exercises to be included in the game and the FITT factors for each of them[43][92].
Feedback	The type of feedback was selected among the different motor learning strategies according to the user requirements and therapeutic effects.
Patient Tailoring	An important parameter that was defined with an evaluation of different approaches to tailor patients according to physiotherapists and the KNGF guidelines.

Game conceptual design

Conceptual aspects are elements that help to develop the ideal concept and design of the game. With them, it is possible to define the game objectives and determine what will be the fun factor that the game will provide[93]. During this stage, only the components of art style, music, color palette, game level progression, and motivation from videogame design were defined and constrained by user requirements, the aimed therapeutic effects, and the technical aspects [94]. The narrative of the game, game mechanics, rewards, and avatar construction were defined in the next stage with the participation of the main stakeholders.

4.2 Results

4.2.1 User Requirements

The scenarios from the previous stage (section 3.2) were complemented with the KNGF guidelines. With the new information using the criteria of Mo et al. the user requirements were selected. Table 4.4 shows these requirements.

Table 4.4: User requirements

Requirement	Description
1. Instruction delivery	Instructions shall be given verbally and written, clear and easy to follow. Avoiding complicated vocabulary.
2. Presentation of the information	The information shall be presented in a concise, congruent and clear way. Avoiding too much cognitive load.
3. Motivation requirements	Shall provide elements that engage the user in a positive way.
4. Feedback requirements	The system shall provide feedback that helps the user be aware of the movement that she/he is performing.
5. Level tailoring	The system shall be able to adapt to the capabilities of each patient.
6. Level progression	The game levels shall increase their difficulty according to the user's progression.
7. Modifiable parameters	User shall be able to: * Turn on or off the verbal or written instructions * Change the level of difficulty * Pause and quit the game
8. Resting time	There shall be a spaced resting time that allows recovery and avoids overloading the muscles, creating physical or mental fatigue.
9. Interface requirements	The perspective of the game shall be a frontal field of view and avoid over-saturated icons and information.
10. Safety requirements	The game shall be safe and avoid the falling of the users while playing. It should also deliver warning messages if the user performs dangerous movements.
11.Type of controllers	The system shall avoid the use of physical controllers that involve small buttons.

4.2.2 Therapeutic requirements

a. Functional task identification

The analysis of the functional tasks that cause an imbalance in chronic stroke survivors revealed that walking, static sitting, standing from a chair or bed, sitting on the toilet, and picking things off the floor are indispensable for quality of life and meaningful for the patients. A functional category was assigned to each of these. The following is the classification of the functional tasks [30].

A. **Mobilization:** dynamic balance, static sitting, moving from supine position to sitting, gait, static balance stand up.
B. **Transfers:** sit to stand, weight bearings.
C. **ADL:** Personal hygiene, dressing, undressing, bathing, urinating, defecating, feeding, cycling, sitting and standing on the toilet, moving between rooms and levels.

From these categories, both patients and physiotherapists indicated that C. Daily Living Activities were essential tasks with which stroke survivors struggle the most. The main problem, more than mobilization and transfer tasks, is that "patients cannot help themselves, daily living activities represent a struggle", as one of the physiotherapists stated.

The skills required for categories A and B are also essential during ADLs. One example is sitting and standing on the toilet. This action involves static balance, dynamic balance, and Sit-to-Stand (STS). Therefore, it is possible to make a correlation between the three categories. Figure 4.1 shows this correlation between functional tasks.

It can be seen that the transfer block is associated with blocks I and III of the ADLs. Within these blocks, tasks are based on both static and dynamic balance, as well as sit-to-stand motions. According to the literature, sit-to-stand is the most common movement and is crucial to perform activities of daily living independently[95]. It serves as the bridge between static position and dynamic body activity, allowing the shift of the center of mass from a sitting position to a standing position, in addition to being a prerequisite for gait[96]. Based on the results of this analysis, the exergame focuses on training the motor skills necessary to perform the sit-to-stand motion.

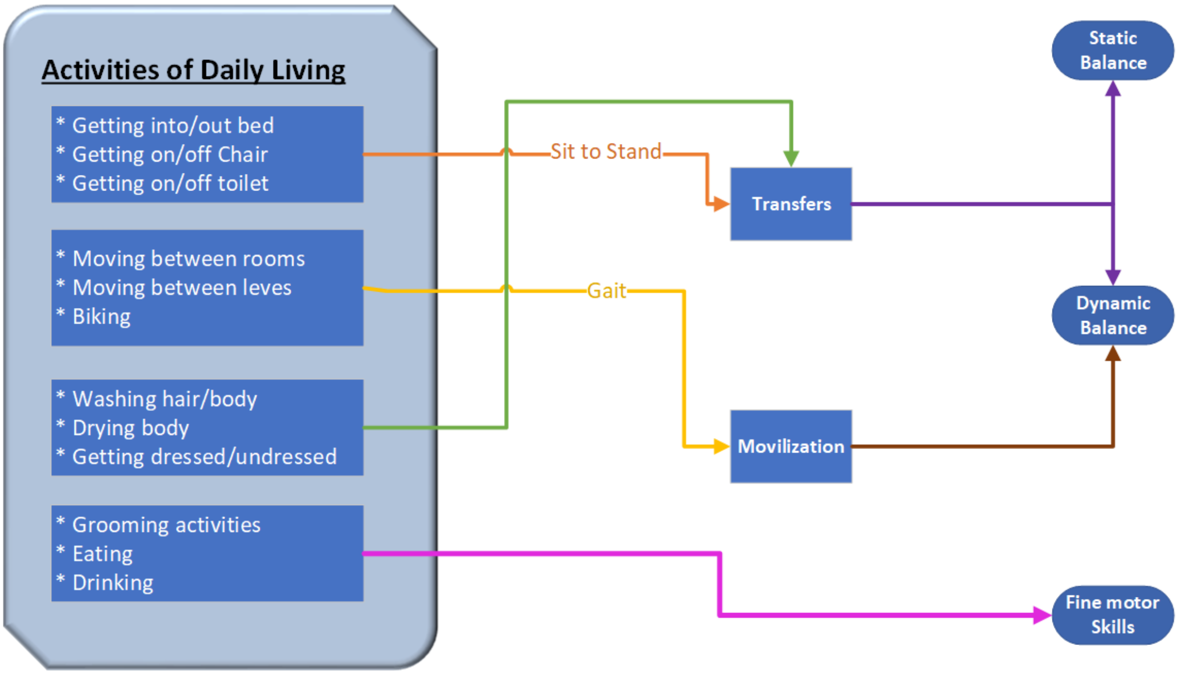


Figure 4.1: Correlation between functional tasks.

1. Biomechanics of the sit-to-stand motion in stroke survivors

The research of Mao et al. was used for the identification of issues during the STS motion and weak muscles that contribute to the imbalance in chronic stroke survivors. In figure 4.2 the STS movement cycle is depicted by phases.

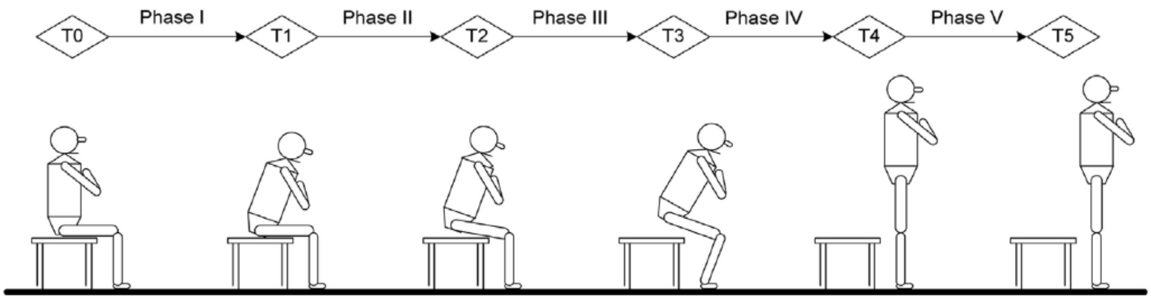


Figure 4.2: Biomechanics of STS in stroke survivors [95]

The results of the motion analysis revealed that there was an increased total time of sit-to-stand tasks in people with stroke when compared with the healthy controls. Especially in phase I, when trunk flexion occurs, and phase V, when hip and knee joints reach full extension, which contributes to the risk of falling, and according to previous research, stroke survivors fell 37.2% of the time when changing positions from sit-to-stand[97].

The increased time of the sit-to-stand motion might be related to the weakness of trunk flexion muscles, hip flexion muscles, and the gluteus maximus and quadriceps femoris[95]. Therefore, it is suggested that the rehabilitation protocol should target these muscles.

B. Rehabilitation protocol

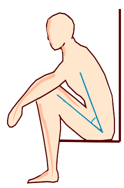
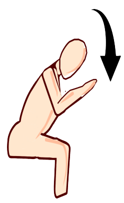
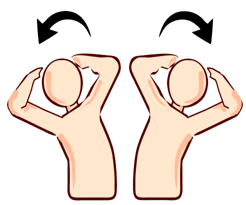
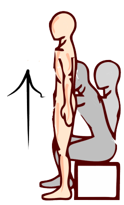
1. Exercise prescription

The aim is to define the requirements for the exercise prescription according to the functional task to train. This section is divided into three topics (1.1) Exercises, (1.2) Motor learning strategies, and (1.3) FITT factors.

1.1 Exercises

The prescription of the exercises for the STS motion targets the muscles that were identified as weak. These muscles are trunk flexion muscles, hip flexion muscles, quadriceps muscles, and gluteal muscles. Table 4.5 shows the exercises per muscle that were prescribed.

Table 4.5: Exercises that target weak muscles during the STS motion

Muscles	**Exercises**
Hip flexion muscles	
Trunk flexion muscles	
Lateral trunk flexion muscles	
Quadricep and Gluteal muscles	

1.2 Motor learning strategies and Feedback

The following six motor learning principles were selected based on their characteristics and therapeutic effects for inclusion in the exergame. From this Action-observation, mirror observation practice, and knowledge of performance were selected to provide feedback to the user.

- Task-specific Practice
- Action observation
- Mirror observation practice
- Variable practice
- Increasing Difficulty
- Repetitive practice
- Knowledge of Performance

1.3 FITT factors

According to the contextual study and the KNGF guidelines, these are the selected parameters for the FITT principle:

- F: 10 sessions
- I: Low intensity with a standard base of 3 series of 10 repetitions
- T: 30 minutes maximum to avoid fatigue
- T: Strength and coordination

2. Patient tailoring

The contextual study revealed two important factors that affect the FITT principles: the individual's perception of fatigue and trunk control. Both factors affect every patient uniquely, therefore the FITT factors described above might not work for everyone.

First, fatigue can considerably affect the performance of chronic stroke individuals by reducing physical or mental energy, limiting their activities [98]. A protocol that contains a lot of repetitions is not suitable for a user with high levels of fatigue. To solve this issue, fatigue could be measured so the FITT factors can be adapted. One of the most commonly used self-report questionnaires to measure fatigue severity is the Fatigue Severity Scale (FSS) [99]. This questionnaire classifies patients into four categories: Normal (2.3-3 points), Low fatigue (3.01-3.99 points), Mild fatigue (4-5 points), and Severe($>$5 points).

Second, individuals with poor trunk control will need to undergo a more extensive intervention than those with greater trunk control [29]. Then, it is necessary to adapt the FITT factors too.

Trunk control is associated with the strength provided by trunk muscles [100]. Poor strength in the core leads to small trunk flexion angles [95]. Therefore, trunk flexion angle may be an indicator of the trunk control ability of an individual. Thus, it is possible to classify users by determining their trunk flexion angle threshold and comparing it with the average healthy individual's trunk flexion angle.

Three categories were defined for the classification of users based on the percentage of the range of motion of the flexion of the trunk. The categorization occurs by comparing the flexion angle of the user with the ”normal” average values of healthy subjects and obtaining a percentage of the movement deficit. The average trunk flexion angle, right lateral trunk flexion angle, and left lateral trunk flexion for healthy subjects are 36.39 ± 3.39, 22.8 ± 6.6 and 21.7± 7, respectively [95]. Listed below are the categories and their ranges.

- **Poor trunk control:** when the patient's trunk flexion angle is less than 50% of the healthy subject's trunk flexion angle.
- **Mild trunk control:** when the patient's trunk flexion angle is between the 50% and 70% of the healthy subject's trunk flexion angle
- **Good trunk control:** when the patient's trunk flexion angle is greater than 70% of the healthy subject's trunk flexion angle

Finally, using both classifications, the FSS and the user's trunk flexion angle threshold, it is possible to prescribe personalized training to users. Figure 4.3 shows the protocols.

	Patient Threshold < 50%	
FATIGUE	Normal	3*25
	Low	3*15
	Mild	3*10
	Severe	3*5

(a)

	50%<Patient Threshold <70%	
FATIGUE	Normal	3*20
	Low	3*10
	Mild	3*5
	Severe	3*2

(b)

	Patient Threshold >70%	
FATIGUE	Normal	3*30
	Low	3*15
	Mild	3*10
	Severe	3*5

(c)

Figure 4.3: (a) Poor trunk control (b) Mild trunk control (c) Good trunk control.
*** Right column indicates the number of series by number of repetitions e.g 3 series of 25 repetitions (3*25)*

The rehabilitation protocol aforementioned works as follow: Patients flexion angle threshold is compared to the average flexion angle and is classified into one of three categories (poor control, mild control, or normal control). Once a table has been selected, users are classified by FSS into one of four categories of fatigue severity (normal, low, mild, or severe). Then, the prescription for exercises can be delivered.

Overview of the therapeutic requirements

Table 4.6: Rehabilitation Protocol sections

Section	Description
Exercise prescription	Motor learning strategies to use • Task-specific Practice • Action observation • Mirror observation practice • Variable practice • Increasing Difficulty • Repetitive practice • Knowledge of Performance FITT factors • F: 10 sessions • I: Low intensity with a standard base of 3 series of 10 repetitions • T: 30 minutes maximum to avoid fatigue • T: Strength and coordination Exercies • Sitting Lateral trunk flexion, right and left • Sitting trunk flexion • Sitting hip flexion • Squads sitting and raising from a chair or couch
Feedback	Action-observation and knowledge of performance
Patient Tailoring	Patients trunk control capability is classified into one of the three categories proposed in this research: Poor control, Mild control, and good control. The classification is based on the FSS and the patient's trunk flexion angle threshold. (See 4.2.2)

4.2.3 Conceptual Design

Conceptual aspects were based on user requirements (table 4.4), and the results from the analysis made on Stage I (Section 4.1.1). Table 4.7 shows a description of these requirements.

Table 4.7: Conceptual aspects requirements.

Conceptual aspect	Requirement
Art style	Simple, minimalist and avoiding excessive ornamentation
Music	Peaceful without abrupt changes.
Colors	Pastel colours
Motivation	* Allowing conditions for exchange depending on user progress. * Praise. * Feedback regarding the results.

Game level progression

The rehabilitation protocol requirements indicate that is desirable to implement task-specific, progressive and variable training. To achieve the integration of these elements, the game level progression was constructed using the Gentiles motor skill taxonomy [54].

Following Gentile's framework, the STS motion was segmented on the 16 skill categories of the taxonomy. Giving a total of 7 levels of difficulty ordered diagonally (See figure 4.4). To progress to the next level, the user must complete all the skills within one level, this means that to be able to go to skill 3A, the user must have completed skills 2A and 1B.

Now that the requirements had been set. The design and development of the exergame will be focused on developing level 1 (1A) with all the characteristics described in this chapter.

		Action Function			
		Body Stability		Body Transport	
Environmental Function		No Object Manipulation	Object Manipulation	No Object Manipulation	Object Manipulation
Stationary Regulatory Conditions	No Intertrial Variability	• Trunk flexion • Hip flexion • Lateral trunk flexion 1A	• Hip flexion • Lateral trunk flexion Holding a virtual object with arm 1B	• Crossed arms Sit-to-Stand 1C	• Arms in front the chest holding virtual object, Sit-to-Stand 1D
	Intertrial Variability	• Trunk flexion • Hip flexion • Lateral trunk flexion Random variations 2A	• Trunk flexion • Hip flexion • Lateral trunk flexion Random variations Holding Virtual object 2B	• Random variations with arms Sit-to-Stand 2B	• Random variations with arms Sit-to-Stand Holding virtual object depending on arm variation 2D
In-Motion Regulatory Conditions (PILLOW)	No Intertrial Variability	• Trunk flexion • Hip flexion • Lateral trunk flexion 3A	• Hip flexion • Lateral trunk flexion Holding a virtual object with arm variations 3B	• Crossed arms Sit-to-Stand 3C	• Arms in front the chest holding virtual object, Sit-to-Stand 3D
	Intertrial Variability	• Trunk flexion • Hip flexion • Lateral trunk flexion Random variations 4A	• Trunk flexion • Hip flexion • Lateral trunk flexion Random variations holding virtual object 4B	• Random variations with arms Sit-to-Stand 4C	• Random variations with arms Sit-to-Stand Holding virtual object depending on arm variation 4D

Figure 4.4: STS motion segmented and categorized according to the Gentiles motor skill taxonomy. The framework provides seven levels of difficulty (ordered diagonally), being the green color the easiest level and the red color the hardest level.

Chapter 5

Stage III. Produce Design Solution

5.1 Methodology

With the user, therapeutic, and conceptual requirements already established, it is time to turn all into an innovative idea for the STS rehabilitation exergame. This chapter describes the steps that were taken to ideate a novel idea regarding the design and development of a STS rehabilitation exergame. The chapter is divided into three sections, starting with the concept ideation, followed by the concept validation, and finally, the game development.

5.1.1 Concept Ideation

A. Study Design

The approach adopted in this study is a participatory design that involved the main stakeholders. The aim is to define the game objectives and determine what will be the fun factor that the game will provide. Consequently, a brainstorming session was proposed around three topics, the type of game, the metrics of success, and the feedback received. Table 5.1 shows the topics and their expected requirements.

To support the topics, aid questions were formulated using the "How might we" (HMW) method from design thinking. This approach has proven to explore further aspects of a given problem[101]. Figure 5.1 shows an excerpt from the workspace.

Table 5.1: Addressed topics and their expected outputs

Topic	Expected output
Type of game	* The mission/goal * Characteristics of the avatar * The intensity of the exercises per level
Success measure	* Scoring system * Motion parameters that can affect the score * Elements to avoid frustration
Feedback	* Ways of giving feedback * Progress presentation

Workspace set-up

Because of participants' availability and geographic location, the session was held online. The workspace for the brainstorming session was prepared on the online interactive whiteboard of Mural.

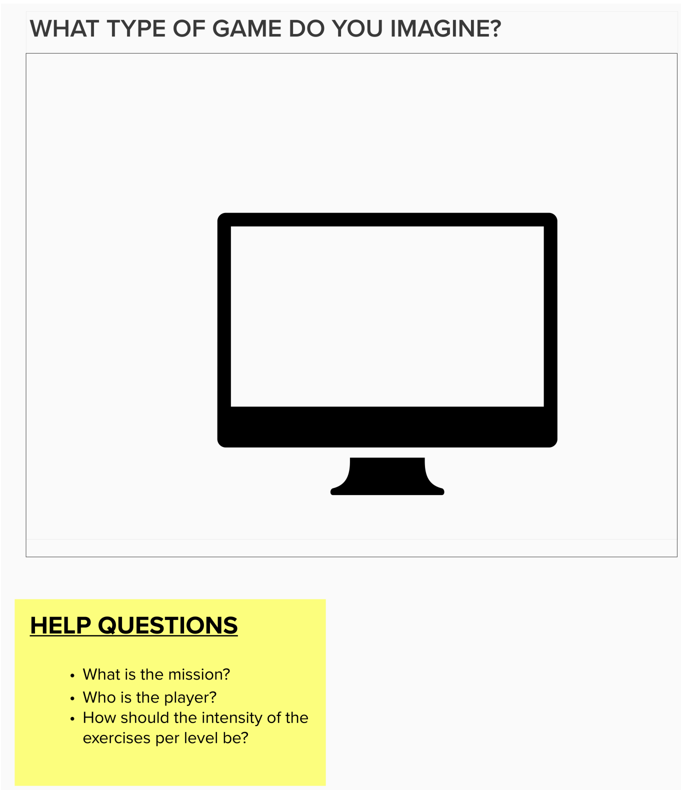


Figure 5.1: Excerpt from the workspace of the session. Square containing a monitor and a small box with aid questions that the participants could use as guides for brainstorming around them.

B. Participants recruitment

The recruitment took place at the University of Twente, the Revalidatiecentrum Roessingh, the Topvorm Twente physioterapeuten and the Rijndam revalidatie center. The eligibility criteria for participation in the participatory study are described in table 5.2. Participants from the contextual study 3 that matched the eligibility criteria and that agreed to participate in further stages of the project were invited. In addition, researchers in these institutions were also invited to participate.

C. Procedure

Before the session, participants received an instruction brochure with all the necessary indications(see appendix C). At the beginning of the session, a brief explanation of the study's purpose and the procedure was given to participants. The researcher acted as the moderator, guiding the participants to brainstorm around the three topics. Participants had to take into account: the persona's profile, exercises, level description and system description for proposing ideas. The session lasted one hour and was conducted using Microsoft Teams.

D. Ethical considerations

A brief explanation of the study's purpose and the procedure was given to participants. Those who agreed to participate and had not participated in previous stages of this project signed an informed consent form (see appendix A). Anonymization was applied to all personal information.

E. Data analysis

The results of the three topics were analyzed using the MOSCOW method of prioritization [88]. The prioritization was done taking into account the established requirements of 4.2. The analysis led to the development of an additional set of conceptual design requirements, resulting in the development of a pre-concept for the exergame.

Table 5.2: Elegibility criteria for the participatory study

Stakeholder	Requirements
Chronic Stroke Survivors	Stroke survivors who have suffered a stroke for more than six months, be from the Netherlands, medically stable, and able to speak English
Physiotherapists	Specialization in neurorehabilitation or have experience treating stroke patients in the Netherlands and Mexico and can speak English
Game developers	Experience in the design and development of video games and can speak English
Biomechanics engineers	Specialization in balance control or have experience working with balance control data analysis and can speak English
E-health technologists	Experience in the creation of user-centered health technology and can speak English

5.1.2 Concept validation

A. Study design

The aim of this study is to validate the pre-concept by the main stakeholders to determine if it meets the needs and desires of the end user, as well as the therapeutic requirements for trunk rehabilitation.

The evaluation was performed with semi-structured interviews. Two protocols were created to validate the concept from the point of view of the chronic stroke survivor and the physiotherapist (See appendix C). The physiotherapist's protocol included a specific set of questions to validate the proposed rehabilitation protocol to be virtualized in the exergame. For the chronic stroke survivor, the protocol incorporated questions regarding the proposed game mechanics, characters, and type of game.

B. Participants Recruitment

An open invitation was made to the physiotherapists and chronic stroke survivors that participated in the brainstorming session. A total of one physiotherapist and one chronic stroke survivor accepted to take part in the assessment.

C. Procedure

The meetings were conducted separately via Microsoft Teams and recorded for analysis. All personal data was anonymized. Participants were given a brief explanation of the study's purpose and procedures before the concept validation began. The validation included the presentation of the pre-concept regarding the narrative of the story, the game mechanics, the controllers and some sketches of the aesthetics of the game. After presenting the pre-concept, the protocols were applied for the evaluation.

D. Data analysis

All suggestions and answers from the participants were documented and categorized on a digital file. Using the MOSCOW method data in the categories was prioritized and selected based on the requirements that were established previously. Below it is possible to find the topics for the categorization:

Physiotherapist protocol

- FITT
- Rewards
- Kinematics analysis

Chronic stroke survivor protocol

- Intuition
- Game mechanics
  - Goals
  - Controllers
  - Interactive elements
  - Open world features

A final concept was created based on the gathered information from the concept validation session. This concept contains a detailed description of the design and was used as a guide for the development of the exergame.

5.1.3 Game development

A. Procedure and materials

The final concept was used as a guide for developing the exergame. Table 5.3 describes the tools that were used to achieve this.

Table 5.3: Material used for the game development

Element	Description
Game requirements	Final concept
Development platform	Unity 3D Engine 2021.1.19f1. Selected due to its availability, large assets libraries and support
Graphic design	Two [1], [2] 3D assets from the unity library were used The software CorelDraw X7 was used to create the rest.
Controllers	The depth camera Intel® RealSense™ D435i
SDKs for skeleton tracking	Nuitrack SDKs

5.2 Results

5.2.1 Concept ideation

The design session led to the definition of a pre-concept for the development of the exergame. Here two important aspects were defined and are presented below. Figure 5.3 shows a segment of the obtained results from the design session.

[29]

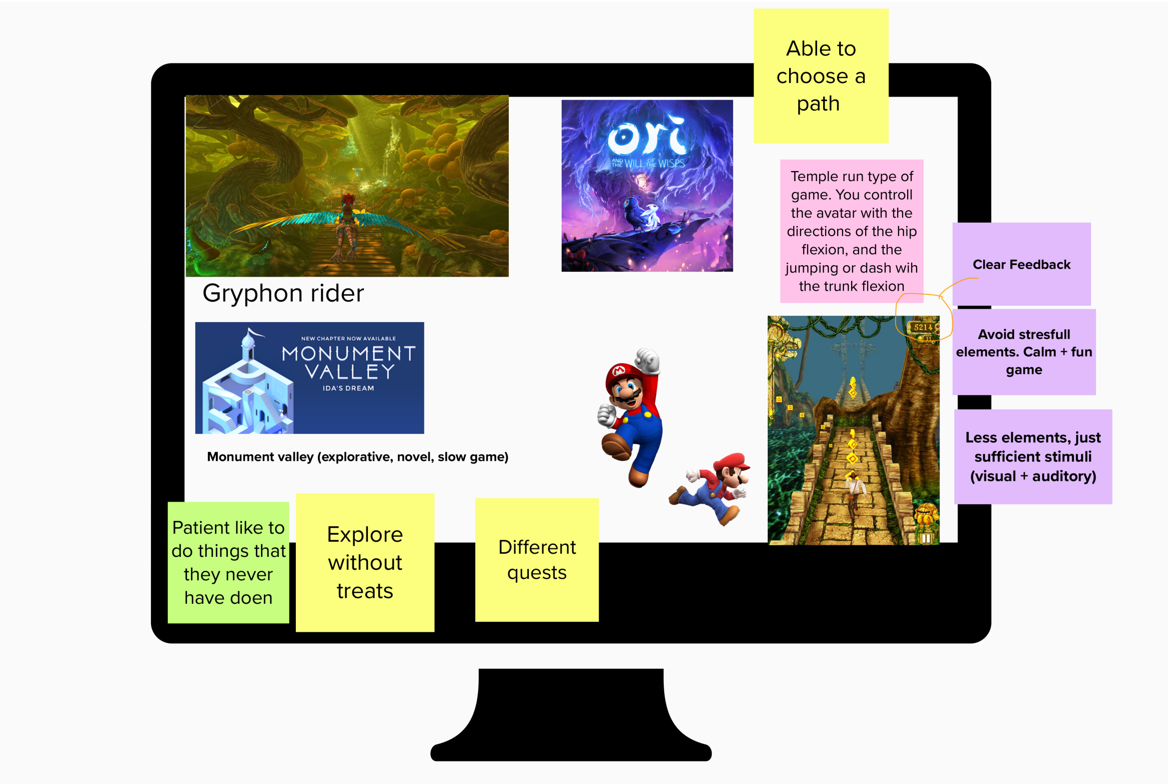


Figure 5.2: Segment of the results from the design session

A. Game requirements

- There is no real failure while playing the exergame
- Should be simple and easy to understand
- The user should not feel frustrated
- The exergame should stimulate the following emotions: Joy, curiosity and the feeling of being capable
- The exergame graphics should not be oversaturated.
- The game should avoid the sensation of danger

B. Type of game

The majority of the participants of the design session proposed an adventure/exploration game alike. The pre-concept took as references the following indie and adventure games that had some similarities with the established game requirements: Gris, the old man's journey, Flower, Monumental valley, and Journey. A more detailed description of the references named above can be found in appendix C.

C. Pre-concept game narrative description

The following pre-concept was created using the information above:

1. Story Reef is an explorer that wants to discover the wonders of a faraway land that his ancestors once visited, and is described as a magical place with creatures and landscapes that no one has ever seen.

2. Challenge Complete the tasks to continue the journey.

3. Rewards In the beginning, the "arena" is a plain blank space with basic props. Every time the user completes a series of exercises the environment changes: More creatures appear, and the color of the sky changes. Little by little everything becomes more alive.

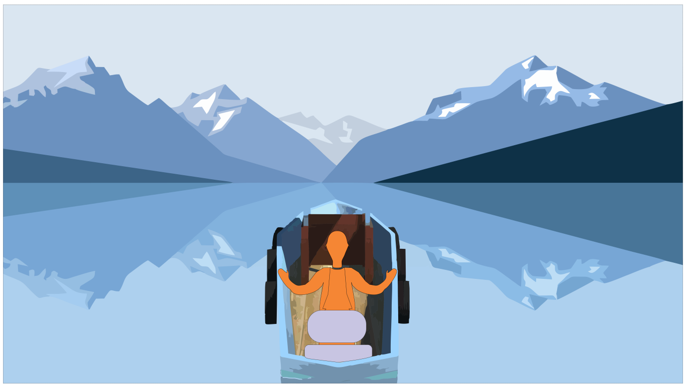


Figure 5.3: Segment of the results from the design session

5.2.2 Concept validation

This pre-concept was presented and validated by one physiotherapist and one chronic stroke survivor. Presented in table 5.4 and table 5.5 are the updates requirements that were discussed with the main stakeholders.

Table 5.4: Physiotherapist validation

Requirements	
F.	10 sessions
I.	Low intensity
T.	30 minutes maximum
T	Strength and Coordination
Rewards	
***.**	The player must have a goal to work through it
***.**	Gain gear besides the changes in the environment
Kinematic analysis	
*	Feedback on avoiding dangerous positions

** F: Frequency, I: Intensity, T: Time, T: Type of exercise.

Table 5.5: Chronic Stroke survivor validation

Objects to interact with	
Fish	Depending on what fish you trap then that gives you more strength
Intuitive design	
*	Activities in the game should match movements in the real world so patients “know” how to move.
*	Do not lose the focus on that is a therapeutic game.
Game mechanics	
Goal	The user must collect 20 fish and bring them to the guardian in 10 moons.
Controllers	
TF	Enables the rowing action
TLF	Enables fishing
Open world characteristics	
*	Choosing paths
*	Different types of fish
*	Acquisition of gear for the avatar

** TF: Trunk flexion, TLF: Trunk Lateral Flexion.

5.2.3 Final concept

Below is a description of the narrative of the game, the characters, the game mechanics, and the interface and screens for level one of the pilot prototype.

5.2.3.1 Narrative of the game

A finding-yourself adventure, "Reef" is free of frustration and danger. Despite losing the ability to walk, players control Reef, an avatar searching for the landscapes and creatures described by its ancestors in a faraway land.

The journey of Reef is manifested in the landscapes and creatures by interacting with items and solving pressure-free puzzles. The story unfolds as Reef's ability to stand up increases, presenting new challenges and paths.

5.2.3.2 Assets

a. Avatar

Reef is a non-binary human avatar. It was selected and customized from the unity asset Character Pack - Lowpoly FREE [102]. See figure 5.4.

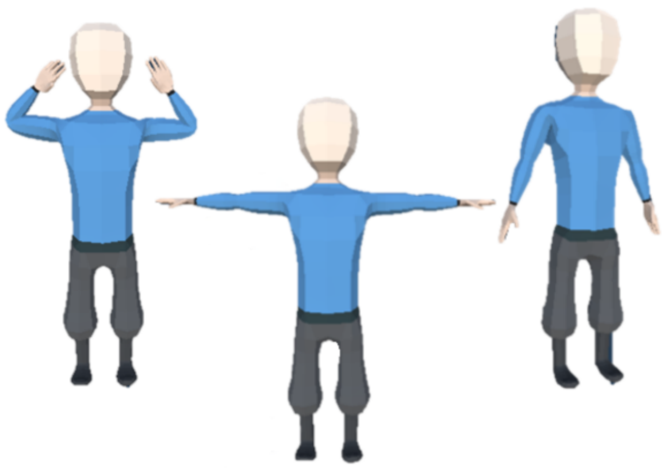


Figure 5.4: Avatar used for the exergame in different positions.

b. Collectables

For level 1, three items were created for the interaction with the user. Their design was based according to the requirements. Figure 5.5 show the created items with their corresponding icons.

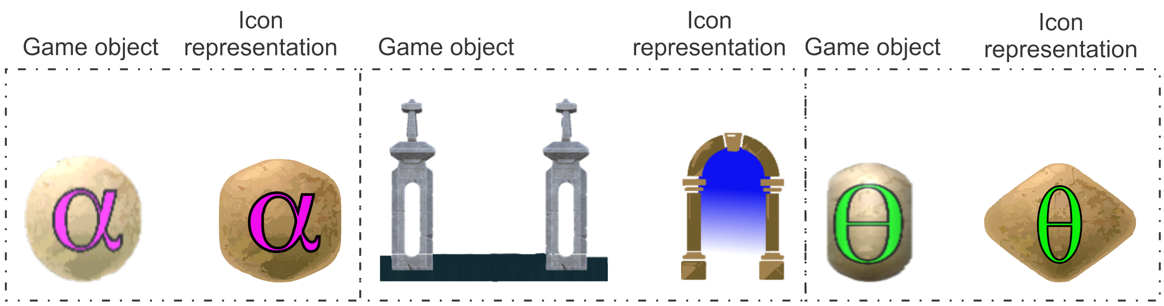


Figure 5.5: (Left) Left rune, (Center) Portal and (Right) Right rune

5.2.3.3 Game mechanics

Here the game rules and design aspects that guide the player's actions to produce enjoyable gameplay are described. The design decisions of the game mechanics were based on the user, therapeutic, and game requirements.

a. Game genre

The selected gameplay for the video game is a modified version of an endless runner. When playing a conventional endless runner, the player is forced to move forward for an infinite amount of time. The goal is to survive by avoiding obstacles for as long as possible [103].

In the present study, this genre was chosen due to the repetitive nature of the prescribed exercises. This type of gameplay allows bringing challenges to the user at a certain pace that can be modified depending on the progression of the same user.

To comply with the user and game requirements the gameplay was modified by adding checkpoints and allowing the player to explore old paths of the land, Reef disguises the sense of moving forward for an infinite amount of time. To avoid the feeling of danger, obstacles were replaced by pressure-free challenges.

b. Challenge

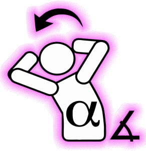
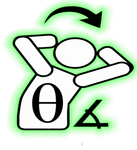
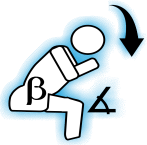
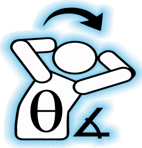
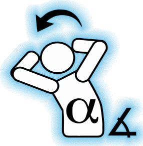
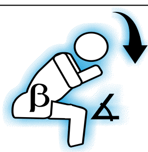
The exercise prescription of level 1 can be found in figure 4.4. Level 1 focuses on strengthening the trunk. During this level, the user must collect two types of items and activate portals by performing lateral trunk flexion and trunk flexion. Table 5.6 shows a description of the controllers of the exergame.

c. Level design

The rehabilitation protocol of each level is suggested by the system depending on the classification made. Since the exergame was evaluated with healthy subjects the chosen rehabilitation protocol was c/normal from figure 4.3. For a first-time player, the game starts with a tutorial of the game controls and a description of the ultimate goal. Then, as the avatar moves forward the items to be collected appear.

The exercises were divided into blocks of four repetitions each. After completing the 2 exercises (total 8 repetitions), a decision platform appears and the user must choose a path from three options. Then the same mechanics repeats until the player has accomplished 30 repetitions of each exercise. The block of exercises is generated randomly to avoid the boredom of repetition. Figure 5.6 shows a flowchart of the generation of the challenges.

Table 5.6: Controllers of the exergame.

Game challenge	Motion required	Graphic representation
Collect pink rune	Left lateral trunk flexion	
Collect green rune	Right lateral trunk flexion	
Activate portal	Trunk flexion	
Choosing path right	Right lateral flexion	
Choosing path left	Left lateral flexion	
Choosing path straight	trunk flexion	

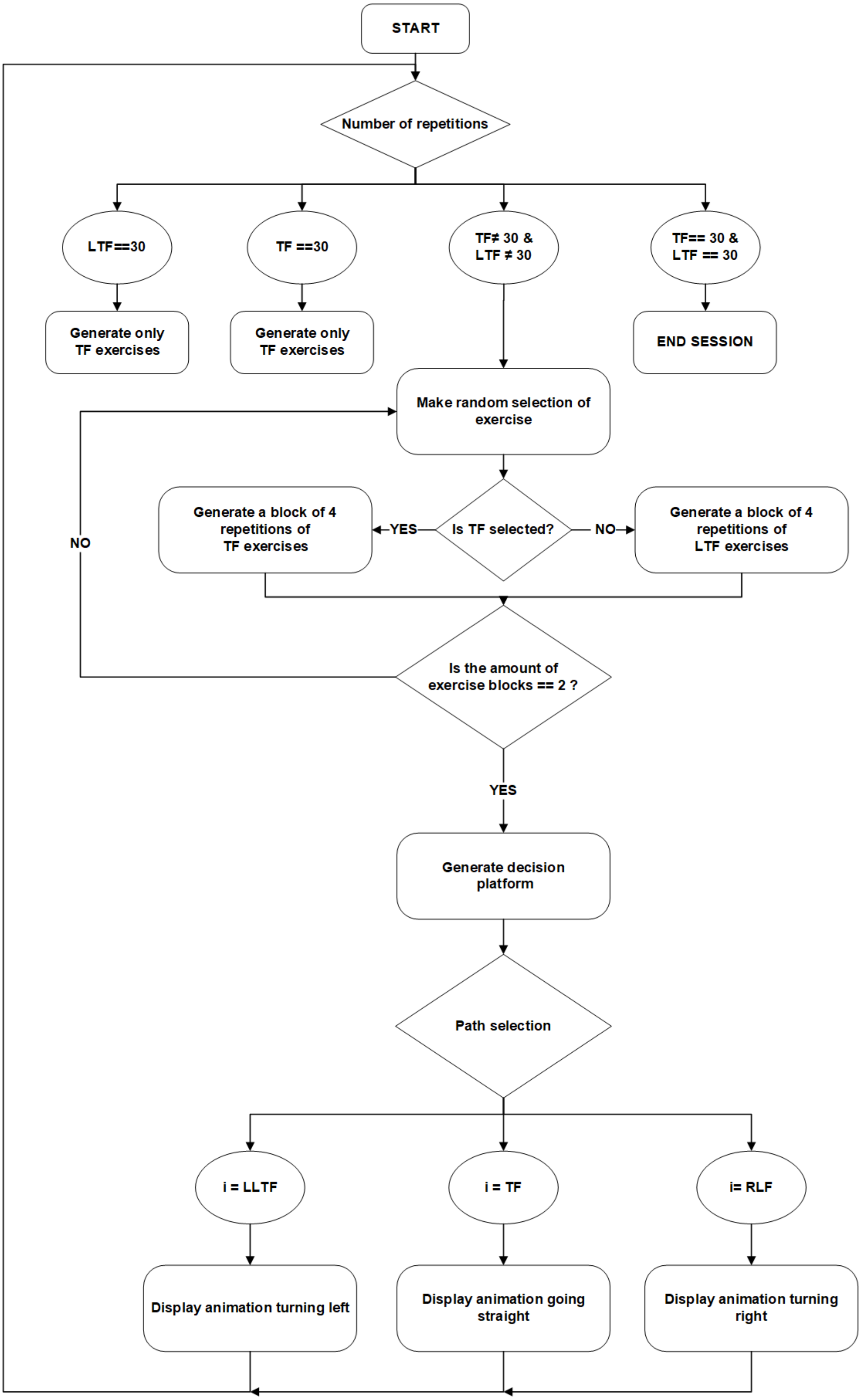


Figure 5.6: Flowchart describing the level design.

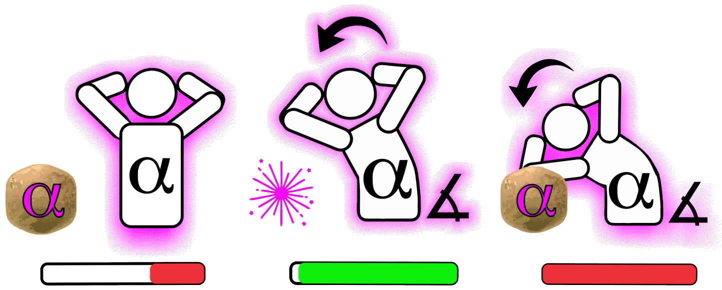
*TF: Trunk Flexion, LLTF: Left Lateral Trunk Flexion, RLTF: Right Lateral Trunk Flexion

d. Feedback

i. Visual feedback Two types of visual feedback were developed:

a. Slider

A slider with an image of the required exercise is displayed every time the user has to collect or activate an item. The slider has a red color at the beginning and fills or decreases depending on the angle of the trunk or lateral trunk flexion. When the optimal value is reached then the slider turns green. See figure 5.7.



(a) (b) (c)

Figure 5.7: (a) User sitting still (b) User performing the movement within the range (c) User performing the movement out of the range.

b. Control instruction screen

When missing 5 points the game paused automatically. Then, a Control instruction screen appeared. This screen provided a reminder of the controllers of the game. See figure 5.8.

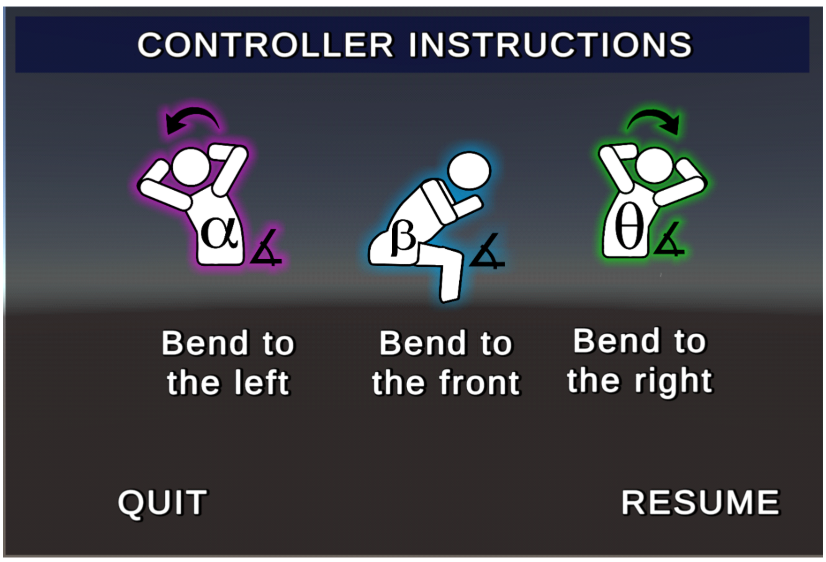


Figure 5.8: Control instruction screen

ii. Auditory feedback

Auditory feedback was given depending on three conditions. Table 5.7 shows the given auditory feedback. The phrases that are recorded, were elaborated following the requirements.

Table 5.7: Auditory feedback given depending on three conditions

Trigger	**Audio script**
Performing the exercises above the angle limit	• ”I can see your commitment. But careful, don’t lean too much you could fall” • ”Seriously I don’t want you to fall, don’t go beyond the limit”
Five not successful item collection	”You have missed some items there. Let’s take a break. Here is a small reminder of the game controls. If you are ready to continue please raise you hand. Remember small progress is still progress”
Every 3rd random collection of items	• ”Not gonna lie, that was an amazing move” • ”You are dancing. I’m impressed”

5.2.3.4 Interface

The interface and different screens were created based on the established requirements. Below the main interface and the end session screen are described. The other screens can be found in the appendix.

a. Game screen

There is a table at the top right of the game screen displaying the number of items collected. Initially, these tables have zero numbers, but as the player collects items, they fill up. An instruction slider pops up when the avatar's boat is close to an item indicating what the user should do. Figure 5.9 shows the screen that the user sees while playing.

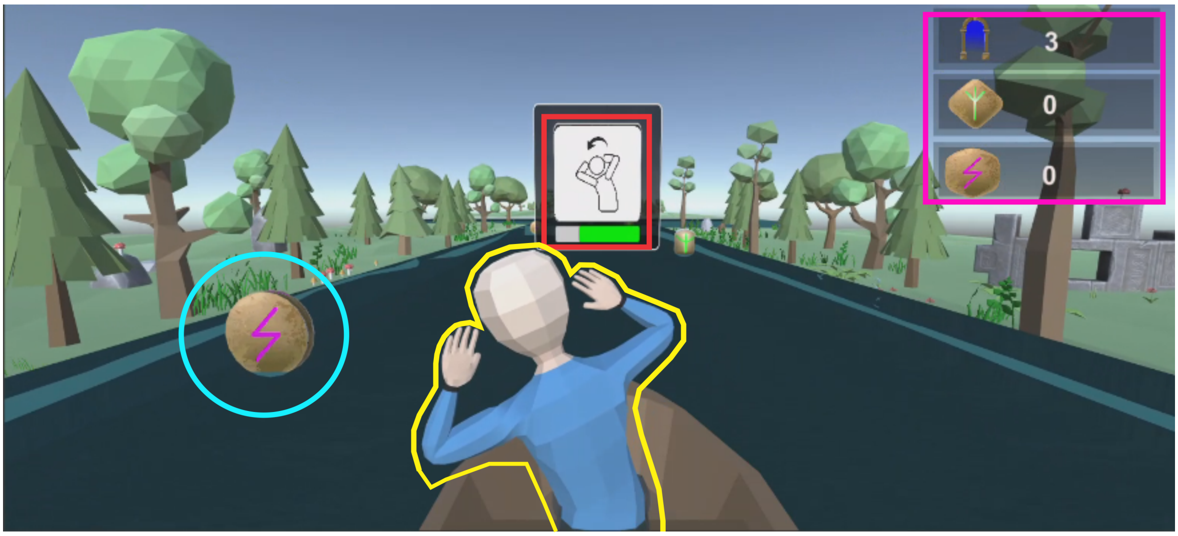


Figure 5.9: (Cyan) Item that has to be collected, (Yellow) Avatar that the user controls, (Red) Slider with instructions, and (Fuchsia) Item counter board

b. End session screen

User progress can be viewed on an end-screen at the end of the session. The end-screen displays information in the form of 5.10

Figure 5.10: (Cyan) Each icon displays the percentage of items collected out of 30 on a circular slider, (Yellow) Shows the total items that were not collected, and (Fuchsia) Shows the average angle that the user made per movement.

Chapter 6

Stage IV. Exergame evaluation

6.1 Methodology

A. Study design

This stage evaluates whether the system meets the requirements established in previous sections, along with identifying any factors concerning the home environment that may negatively affect the user experience.

Experiment set-up

The exergame was developed for home rehabilitation. To emulate these conditions, the experiment was performed in the living room of the eHealth House (eHH) at the University of Twente. Figure 6.1 depicts the arrangement of the elements used.

B. Participants Recruitment

Participants were recruited from the University of Twente. An open invitation was done to students and employees from the institution. A total of 10 participants were selected according to the inclusion criteria. Table 6.1 describes the inclusion and exclusion criteria.

C. Procedure

The experiment consisted of one session of 3 minutes. The participants were instructed to sit in front of the depth camera. A calibration check was performed using the NUITRACK 3D Sensor app to ensure proper skeleton tracking. Then, an instruction video was shown to the participants on how to play the game. After the preparation, the participants were able to start playing the "Reef" exergame whenever they felt ready to start. Once the game started, the assigned task of the researcher was to observe the performance of the user and the system. The

Figure 6.1: Experiment set-up. (Blue)The laptop with the developed exergame was connected to the television in the living room. (Pop-out)The depth camera d435i was placed at a height of 70 cm from the ground and 2 meters from the couch. The height of the couch was 53 centimeters from the ground. (Yellow)The researcher was sitting next to the laptop, observing both the game and the participant

Table 6.1: User requirements

Inclusion criteria
1. Any gender or ethnicity
2. Age must be 18 years old or over
Exclusion criteria
3. Have any injury or problem that does not allow the performance of Lateral trunk flexion and trunk flexion movements
4. Suffering from a movement impairment due to physical trauma
5. Had suffered a stroke in the past

researcher did not interfere in any aspect unless a safety situation arose. During the game, the participant had to collect three different items that appeared on the screen. To do so, the subject had to perform the correct trunk flexion movement.

At the end of the three minutes, the end screen with the total score per item, the average flexion angle of each movement, and the total missing items were presented to the player. Just right after finishing the game, participants had to fill in a standardized questionnaire.

D. Ethical considerations

The study protocol was reviewed and approved by the ethics committee of the University of Twente. The potential risks and benefits of participation in this study were explained to the participants in advance. All participants gave written informed consent before the start of the experiment. See appendix A.

E. Data evaluation

The developed system was evaluated in two ways:

1) Participants filled out a modified standardized questionnaire composed of the QUIS and the GEQ. These questionnaires measure user satisfaction with the system and user experience while playing, respectively. For more information regarding the QUIS and the GEQ items and reliability please refer to the appendix B.

2) The researcher observed the participants while playing as well as filling out a quality form of total points per game, errors made and any other observations regarding the safety, complaints, and comfort of the participants. (See appendix B).

1. Primary outcomes

User Satisfaction

The QUIS questionnaire is a ten-point Likert-type scale that measures user satisfaction with the system [104]. A higher score indicates higher user satisfaction. The acceptance levels are divided like the following: Poor acceptance: $x<5$, Moderate satisfaction $5< x <7$, High satisfaction ≥ 7 [104], [105].

Therefore, to investigate if an improvement is required in the different categories, an average acceptance level will be considered to be equal to or greater than 7. Scores lower than 7 indicate that improvement is needed.

User game experience

The GEQ questionnaire is a reliable, valid, and sensitive tool for evaluating user game experience while playing(In-game) and after playing (Post-game)[106]. The In-game section assesses the game experience in seven dimensions: Competence, Flow, Negative Affect, Positive Affect, Challenge, Tension, and Immersion. Meanwhile, the post-game section evaluates the Positive Affects, Negative affects, Tiredness and Returning to reality [106].

It uses a five-point Likert scale going from 0 to 4. However, to maintain consistency the scale was modified to a scale from zero to nine (same as the QUIS questionnaire). The acceptance levels from the GEQ were translated to the acceptance levels from the QUIS by relating the scales between them. The acceptance levels for the dimensions Competence, Flow, Challenge, Returning to reality, Tiredness and Positive Affect, are divided into the following: Poor experience: $x<5$, Moderate experience $5< x <7$, High experience ≥ 7 [104], [105]. The acceptance levels. For the modules Tension/Annoyance and Negative Affect low scores are seek. The acceptance level was established as $x<6$ [107].

For this research, two sections were added to the questionnaire to identify therapeutical and safety aspects considered important for the users regarding the developed exergame. The questions were obtained from the patient satisfaction in physiotherapy questionnaire and adapted to the purpose of the game[108]. Refer to appendix B to learn more about the added items per category.

2. Secondary outcomes

Usability metrics

Table 6.2 shows the data that was collected by the researcher while the subject was playing the game as well as, the gameplay data collected by the system.

The game play data of each subject included the following: the total points per item, the total score, the total missed points and the average angle per movement. It was directly stored from the game and saved on individual CSV files per subject.

The research observations were then compared with the gameplay data to evaluate the system performance, user performance, and factors influencing the experiences of the users.

F. Statistical analysis

QUIS developers suggest that a sample size of 20 is needed to do a with-in-subject comparison. Because the sample size was less than 20, descriptive statistical analysis was used to assess the overall scores obtained from the standardized questionnaire. The scores of the standardized questionnaire are presented by mean and standard deviation [104].

Additionally, Kendall's tau correlation was used to investigate whether there was an influence on the errors made and the perceived frustration. The software GraphPad Prism 9 was used to perform the analysis. Data were tested for normal distribution using a Shapiro-Wilk test and Q-Q plots. A statistical significance level of 0.05 was used in all measurements.

Table 6.2: Description of the data collected by the researcher and the system.

RESEARCHER OBSERVATIONS	
Element	Description
Factors influencing the experiences of the participants	External factors of a home environment such as furniture and lighting that could affect the experience of each user while playing were written down
Subject performance * Comments * Movements	Any comment regarding the game was written down on the specific section of the level where it was said. As well as, the movements and posture of the subjects while controlling the character.
System performance * Total points * Performance	Each point that the user had to make was checked. Once a movement was performed sensitivity of the tracker, and any delay perceived by the researcher were written down.
Errors * User mistake * The system fails to track * Angle limit not reached * The user does not understand	Four types of making an error were identified. If a user lost a point, one of the 4 mistakes was marked in the template.
GAMEPLAY DATA	
Element	Description
Average angles per movement	Average angles of trunk flexion, Right lateral trunk flexion and Left lateral trunk flexion were stored
Total points per item	The total points per collected item were stored
Total misses	The overall missed points of the total points to make.
Total score	The total score that each user had to make
Instruction screens	The number of times during the game an instruction screen appeared.

6.2 Results

6.2.1 User Satisfaction

The average user satisfaction for the five categories of the QUIS is presented in table 6.4. The overall subjective user satisfaction for the "Reef" Trunk stability exergame was above the average of >7 for all five categories. The average total rating was 7.45 ± 0.547. This indicates a High overall satisfaction with the system interface. However, it can be seen in table 6.4 that some items scored below the average acceptance level of 7, suggesting low satisfaction issues.

6.2.2 User Experience

A. In-game category

Table 6.3 shows the obtained results for the GEQ. Overall, the positive Affect category showed a high overall experience effect. Meanwhile, the categories of competence and Sensory and Imaginative immersion were below the acceptance level of 7. Indicating moderate user experience in those categories. For the categories Tension/Annoyance, challenge and Negative Affect, the overall rates were relatively low <6.

B. Post-game category

The average post-game user experience is presented in table 6.3. Overall, the categories Negative Affect, Tiredness and Returning scored with the acceptance level of <6. Indicating that the negative effects on the user experience post-game are low. Meanwhile, the category Positive Affect rating is below the average acceptance level of 7. Suggesting moderate user experience.

C. Safety and Therapeutical categories

Results from these sections are described in table 6.3

Safety

Overall, users felt safe while playing and controlling the avatar with their movements. However, in terms of comfort, the average score is below the acceptance value of 7.

To investigate this item the information was complemented with the open question: " Any further comment regarding any complaints caused while playing ". Four out of ten participants complained about the position in which the arms must be held while playing. These subjects felt fatigued after the second round of exercises.

Therapeutical aspects

The item Continuity of care shows a high score above the acceptance level of 7. This suggests that users are engaged with the game and would like to play it again. However, there was some low dissatisfaction regarding the information provided by the game and the physical intervention.

Table 6.3: GEQ Questionnaire results

Category	Mean	SD
In-Game section		
Competence	6.5**	1.66
SII	6.8 **	1.51
Tension/Annoyance	3.1	2.44
Challenge	3.72	1.33
Negative Affect	2.56	1.26
Positive Affect	7.6	0.74
Post-Game section		
Tiredness	3.05	2.49
Returning to reality	3.26	1.20
Negative Affect	2.9	0.98
Positive Affect	5.97**	1.33
Safety Aspects section		
Comfort	5.9**	2.02
Feeling unsafe	1.4	1.7
Therapeutic Aspects section		
Continuity of care	8.35	0.59
Informativeness	6**	1.77
Expectations	6.5 **	1.28

SD = Standard deviation, SII= Sensory and Imaginative Immersion
** $<$7 ; * Equal to 7

Table 6.4: QUIS Questionnaire results analysis

Item	Mean	SD
I. OVERALL REACTION OF THE SYSTEM		
1.1 Terrible-Wonderful	7.5	1.1118
1.2 Difficult-Easy	6.8 **	1.778
1.3 Frustrating-Satisfying	6.5**	2.012
1.4 Boring-Engaging	7.6	1.685
Total	7.1	0.329
II. SCREEN		
2.1 Characters on the computer screen	8.3	1.187
2.2 Information displayed on screen	7.4	1.96
Total	7.85	0.386
III. TERMINOLOGY AND SYSTEM INFORMATION		
3.1 Use of terms throughout the system	8.3	0.640
3.2 Position of messages on screen	8	0.894
3.3 Images on screen	7.8	0.748
3.4 The video game keeps you informed about your progress	6.8 **	1.661
3.5 Audio feedback information	7.3	1.847
3.6 Slider visual feedback information	6.8**	2.088
3.7 The end screen menu information	6.4**	2.375
Total	7.3428	0.6465
IV. LEARNING		
4.1 Learning to operate the system	7.9	0.943
4.2 Remembering movements and use of commands	8.2	1.166
4.3 The task can be performed in a straight-forward manner	8.5	0.5
4.4 Help messages on the screen	7*	1.764
4.5 Supplemental animations	7.6	2.107
Total	7.84	0.575
V. USABILITY AND UI		
5.1 Use of colors and sounds	7.7	1.1
5.2 System feedback	6.9**	2.071
5.3 Audio feedback messages	7.8	1.4
5.4 System messages and reports	6.8**	2.182
Total	7.3	0.453

SD = Standard deviation

** $<$7 ; * Equal to 7

6.2.3 Usability Metrics

Gameplay data

According to the results obtained by the system, the average trunk flexion angle, the lateral right trunk flexion and lateral left trunk flexion angles were 20.94°, 20.06°, and 19.31°, respectively.

The summary of the gameplay data per user collected from the game and the observations of the researcher can be found in table 6.5. The table shows the total points that the user had to collect, the generated series per exercise, the total errors made, the percentage of success, the number of errors that occurred per exercise, the type of errors for which the user did not get a point and the times the instruction screen appeared.

Table 6.5: Summary of the gameplay data

Subject	Exercises		Total points	Total errors	Success rate	Instruction screen
	Trunk Flexion	Lateral T. Flexion				
1	2	3	23	6	73.9%	1
2	5	1	24	2	91.7%	NA
3	2	2	16	6	62.5%	1
4	3	2	21	2	90.5%	NA
5	3	2	19	3	84.2%	0
6	1	3	13	6	53.8%	1
7	2	3	18	4	77.8%	0
8	3	1	14	8	42.9%	1
9	2	2	16	10	37.5%	2
10	0	5	20	6	70%	1
			TOTAL	53	68%	

NA = Not Applicable

Overall, the success rate to collect the items of the game was 68% with an average of 5.3 errors made per user. Most of the mistakes were caused by the system not being able to track the user's movements. Figure 6.2, shows the error division percentages.

In the exercise Lateral trunk flexion, most of the mistakes happened during right lateral flexion. The system showed low sensitivity to track this movement. In the case of trunk flexion, subjects 9 and 8 were confused about identifying the portals. Only subject 9 lost all the points because of this confusion. The subject expressed the following "I was expecting kind of a tunnel for the portals and felt confused with the slider". Even when the instruction screen appeared 2 times for subject 9, this did not have any effect further than informing the type of movement that was needed for the portals. In the case of subject 8, the slider was the indication to know when to perform trunk flexion, however, the subject did not identify the shape or figure of the portal. Nonetheless, most of the errors for this subject were caused due to poor tracking of the system.

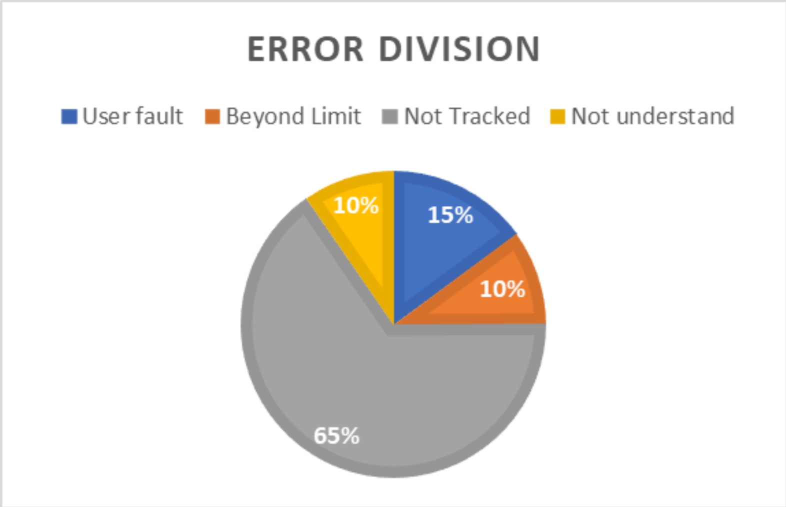


Figure 6.2: Error division. Four types of errors for which the user could lose a point. When the user made a mistake (User fault), the User performed the movement beyond the limit (Beyond Limit), The system did not track the motion of the user (Not tracked), and when the user did not understand instructions on what to do (Not Understand)

6.2.4 Relation between frustration and tracking errors

From the results obtained by the Shapiro-Wilk test and the Q-Q plots is possible to conclude that the data has a normal distribution. (See figure 6.3).

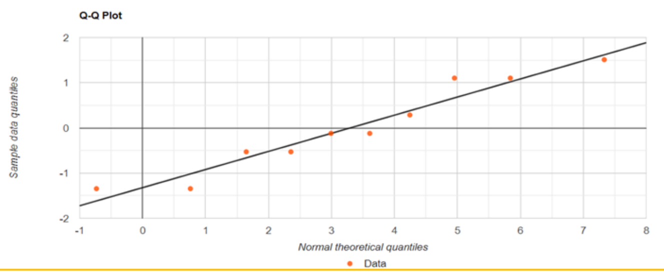
The Kendall's tau correlation results are shown in table 6.6. There is enough statistical evidence that indicates that there is a correlation between the errors caused due to poor tracking and the perceived frustration of the subjects.

Table 6.6: Kendall's tau correlation.

Statistics	**Value**
Kendall's Tau	0.1797
Z score	4.977
p-value	0.00000032
95% Confidence interval	[0.1090, 0.2505]

(1)

Parameter	Value
P-value	0.499
W	0.93
Sample Size (n)	10
Average	3.3
Median	3
Standard deviation	2.4518
Skewness	0.1323



(2)

Parameter	Value
P-value	0.1763
W	0.8909
Sample Size (n)	10
Average	6.5
Median	6
Standard deviation	2.1213
Skewness	-0.8293

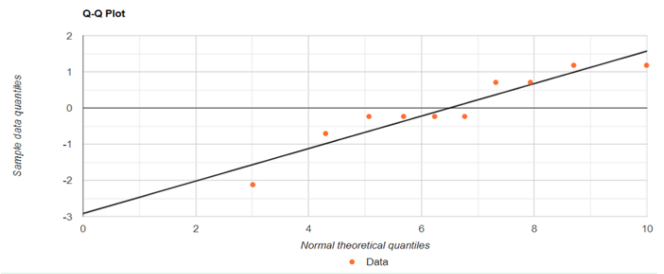


Figure 6.3: Shapiro-wilk test and Q-Q plots. (1) Variable Errors. (2) Variable Stress scores

6.2.5 Observations

System performance

The system showed delays in tracking and responsiveness due to the low processing capacity of the computer used. Subjects 1, 8 and 10 presented these problems. Only with subject 10, the experiment had to be paused because the system was not responding adequately.

Environment

The height of the couch in the eHH was 53 cm from the ground. The height of the subjects was not measured, among the participants, subjects 6, 7, 8 and 10 had a higher height. It was observed that the angle of the legs and the trunk was less than 90° and their sitting position was as depicted in figure 6.4.

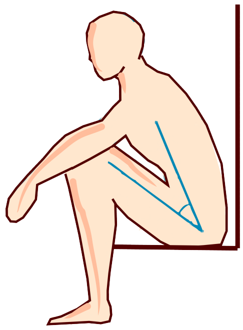


Figure 6.4: Leg posture of tall subjects

Subject performance (behavior) during gameplay

Subjects were observed to detect safety issues while playing, and their reactions to the game. Regarding the movements that the participants had to perform it was observed that during trunk flexion all subjects kept looking forward to the screen. Figure 6.5 shows the average position that subjects held while playing.

Figure 6.5: Average position that subjects held while performing trunk flexion

For the movement of right lateral flexion, some issues regarding sensitiveness were observed. In most cases, the obtained angle from the system and the one made by the user were perceived to be less than the true angle. Consequently, users tend to exaggerate the movement to get the point increasing the risk of falling. Subject 6 leaned too much and his elbows touched the couch, Subject 10 lost balance on 1 point and Subject 9 also leaned further than expected.

The system was programmed to send an alarm to avoid risky movements. However, the discrepancy of the detected angle with the actual movement of the user prevented avoiding those actions. In some cases, when the user made the exaggeration the system delivered the alarm, the user received the message and comprehend that it was not necessary to go beyond the limit.

Concerning the game mechanics, three subjects found a bug while playing. To get the points of the portal subjects had to flex the trunk and come back to an up straight position. However, if the subjects held the trunk flexion position without coming back, subjects were able to collect points for the portals. Despite recognizing this while playing, subjects 1 and 5 only collected one portal point each. It was only subject 7 who collected all the portal points using this method. For the crossroads, users had to choose between three options:

- Turning left (Left lateral flexion)
- Go straight (Trunk flexion)
- Turning right (Right lateral flexion)

Similar to the right rune collection, the right movements were not very sensitive to the system. For subjects 1 and 2, turning right did not result in a successful result, so they had to choose either to turn left or to continue straight. With subject 10, the participant turned left, while the animation displayed a right turn.

Chapter 7

Discussion

Over the past years, exergames have gained popularity in the rehabilitation field because of their engaging elements. In most interventions, commercial games from Nintendo Wii or Microsoft Xbox Kinect are used instead of exergames specially developed for rehabilitation [12]. The reason is that this technology is affordable and has large accessibility. However, using commercial games as tools of rehabilitation therapy presents multiple limitations. The most important ones are the lack of gameplay adjustments for tailoring the patient capabilities, inappropriate game design for the users, and lack of therapeutic concepts [1]. This could negatively affect patient motivation and progress.

7.0.1 Tailoring

Most rehabilitation exergames fail to integrate user tailoring into their parameters. Personalization has shown to be a fundamental element in both therapy design and game design. The first is for the prescription of exercises depending on the needs of the patient. The second one is to engage and entertain a target group. Thus, user classification is needed as a tool to tailor content.

This research aimed to design and develop a home rehabilitation exergame that improves trunk stability in chronic stroke survivors. The procedure followed a UCD approach, which helped to explore the needs, desires, behavior, and limitations in restoring trunk stability, define the requirements to develop such a system, design a solution with and for the end users, and evaluate whether the system met the established requirements in a home environment.

However, some challenges were faced during the implementation of the UCD framework. Although the exergame was developed taking into account the requirements of chronic stroke survivors, the methods applied during the stages of the UCD did not consider the limitations of chronic stroke survivors. Especially during the brainstorming session. During this session, participants had to learn to use the online whiteboard Mural and make drawings or notes using the mouse and keyboard. For a chronic stroke survivor, this might be challenging and can hinder participation or lead to wrong outputs.

In the study of Brox et al. the need for specific UCD protocol for exergames targeting seniors is highlighted. They proposed a framework on which the methods from UCD were adjusted to the limitation of the participants. Additionally, De Vette et al. also raises the urge to design a taxonomy for game design that classifies users and that is based on solid foundations.

In this research, user tailoring was strongly focused on adapting the gameplay to the user's capabilities and incorporating motor learning strategies. To achieve this Gentile's motor skill taxonomy was used as a template to guide the level design according to the functional task to train. The researchers Wüest et al. proposed to use Gentile's Motor Skill Taxonomy to facilitate the incorporation of multiple concepts that help to tailor patient rehabilitation into the exergame design. In their research, they developed six exergames to improve gait. The exercises increased in difficulty depending on the category they were in the taxonomy.

In contrast, the approach taken in the present study was to segment the functional task to train, in this case, the STS motion, and target weak muscles that contribute to the imbalance in this movement. This means starting from sitting exercises and progressing until performing the STS motion.

This study proposed to adapt the progression of the patient's journey using Gentile's motor taxonomy by segmenting the functional task to train, in this case, the STS motion, and target weak muscles that contribute to the imbalance in this movement. This means starting from sitting exercises and progressing until performing the STS motion. Which proved to adapt to the requirements of the exercise prescription and the game design requirements. Additionally, each level adapts the virtualized exercises to the capabilities of the user regarding the perceived fatigue and their threshold angle to perform trunk flexion movements. To the knowledge of the researcher, this is one of the few exergames that address the rehabilitation of trunk stability, focused on the STS motion, using this approach.

As a result of this approach, the present study was able to reduce the gap between how to integrate therapeutical, psychological, and game design concepts into an exergame to provide effective trunk rehabilitation. Based on quantitative and qualitative analysis of the user experience and user satisfaction performed in 6.1, it is possible to confirm the above affirmation that the developed system can meet the needs and desires of the end users. However, the following recommendations should be taken into account when using this methodology in patients: Make sure information and instructions are understood, make all methods to be intuitive, be flexible regarding timing in trials, be able to reschedule studies, and be aware of difficulties in the recruitment of participants [110].

7.0.2 User experience and User satisfaction

Overall, ”Reef” was evaluated with high satisfaction with the system interface and a greater feeling of enjoyment while playing. In accordance with Kooij et al. research, gamification can increase the enjoyment of a task. The researchers found that gamification stimulates intrinsic motivation. This type of motivation is associated with high adherence to an activity. Thus, the elements implemented in the exergame prove to provide an engaging intervention. Further research must be done to determine the effects of adherence in long term.

However, the game requirements *”avoid the frustration of the user”*, *”The game should be simple and easy to understand”*, and *”stimulate the feeling of being capable”* were not fulfilled.

The exergame overall reaction was rated to be slightly frustrating and difficult. Further insight into where this frustration came from was obtained with Kendall’s tau correlation analysis and the comments made by the users. Results showed a statistically significant correlation between the level of frustration and the system’s ability to track the player’s motion. Following prior research, slow and less responsive systems are frustrating, and the perceived level of frustration scales with the length of system response delays regardless of the application context [111].

The exergame was developed using Nuitrack SDKs. A disadvantage of using this skeleton tracker is that it is affected by a noisy background, clothing, and light [112]. Despite this, the decision to use Nuitrack was made based on the fact that it offers a three-minute trial, is well supported, and runs on Unity.

The obtained results concerning the correlation between perceived frustration and tracking user movements highlight the importance of developing a system that is capable of responding to user actions in the moment and with the least possible delay. Based on the study of [112], the researcher recommends the use of Cubemos or a higher-level skeleton tracker.

Regarding the capabilities of the exergame to provide instructions and feedback, the subject rated Reef as confusing. Before the game started users had to watch a video tutorial. In this tutorial visual and auditory step-by-step instructions on how to collect the different items were given. However, only icons showing drawings of the movement to perform were shown and there was not any visual representation of that movement in the 3D environment (see figure 5.7). Additionally, the icon for the portal does not match the game object (see figure 5.5). This can add confusion to identifying this object in the game.

Instructions and feedback

The feeling of confusion affects other states of mind, such as competence and the sense of immersion in the game, then later can transform into frustration or anger[70]. Subjects felt less capable and less immerse while playing the game. Possibly, this was caused by delays in the tracking system and unclear instructions.

Each element from the game evokes experiences in the user. There is an interconnected nature to all of them, the failure of one will affect the whole. Thus, all game elements should be taken into account during the design of exergames for patients even if they seem too obvious. These elements include movements, instructions, colors, game icons, and sounds among other elements [74]. According to Harrington et al., competence can be provided by providing the user with intuitive controls and useful feedback. Sailer et al. evaluated the use of performance graphs, badges, or leaderboards to increase the sense of competence. The results of their research showed that these elements positively affect competence by acting as a feedback element. They also found that an increase in the sense of competence contributes to an increase in perceived task meaningfulness. It is consistent with SDT, which states that the feeling of having the necessary to succeed can lead to intrinsic motivation and adherence to a task.

7.0.3 Factors affecting user experience

Comfort

The experienced comfort of the user while playing was rated to be moderate. During the whole game, subjects had to elevate their arms to their head and held the position. This arm's position was decided due to the limitations of the chosen skeleton tracker. Most Nuitrack errors are a result of incomplete skeletons [112]. Thus, occlusion of the joints should be avoided to decrease inaccuracy.

During conventional therapy, the usual position is with arms crossed on the chest [29]. The design of the "Reef" had to be modified to a more neutral position of the arms. This way, tiredness can be reduced.

Home environment and safety aspects

The experiment was carried out in a space that simulated an average living room of a house. During the game, subjects had to perform trunk flexion to collect the portals. All of the subjects kept looking forward to the screen when the trunk was flexed (see figure 6.5). They were maintaining a non-neutral position of the spine. This posture puts pressure on the lower neck as it is forced into flexion [115]. In long term, this can cause neck pain and/or an injury. Neck pain is a common occurrence in commercial gaming caused by poor posture [116]. Usually is addressed by limiting the gameplay and positioning the screen at the height of the eyes [117].

No other solutions were found to this problem in the literature review. However, the researchers suggest avoiding visual input when this move needs to be performed and instead using rhythmic cues that do not draw the attention of the eyes to the screen. This finding is important and a new requirement regarding ergonomics of the movements performed should be addressed in the next iteration.

7.0.4 Limitations

First, the participants in the contextual and participatory study were limited to two chronic stroke survivors who had an average age of 35 years and were both highly motivated. As a result, the design might not contain enough elements that can persuade or engage older users or those who are not motivated.

Second, after the participatory study, several ideas are usually presented to stakeholders to identify the best solution. Nevertheless, only one idea was created and validated in this study. The opportunity to conceive novel ideas may have been reduced as a result. Additionally, the participatory study took place online over the course of one hour. This was due to the availability of the participants and their locations. Remote meetings limit participants' ability to understand the dynamics, it reduces engagement and motivation.

Third, due to the license type, the use of the skeleton tracking SDKs was limited to three minutes. So the game finished abruptly when the available time was over. It is believed that the results of the positive affect in the Post-game evaluation were influenced. This assumption is made due to the general reaction of the participants and by comparing the positive affect obtained in the in-game and post-game experience evañuation.

Fourth, the researcher was the only person observing errors and other behaviors from the participants while also being in charge of checking the system. Despite careful planning that included several rules to identify errors and behaviors, the researcher may have missed some observations due to the number of tasks. A three-person observer system is necessary to prevent this: one observing the participant, another observing the game performance, and the third ensuring that the equipment is operating properly.

7.0.5 Conclusion

When it comes to the development of personalized technology for health, understanding user needs is fundamental for providing effective tools.

This research aimed to design and develop a home rehabilitation exergame that improves trunk stability in chronic stroke survivors. The procedure followed a UCD approach to understanding the patient's characteristics and the current situation of trunk rehabilitation in chronic stroke survivors. As a result of the involvement of the main stakeholders throughout the study, the design process of the trunk stability exergame remained true to the needs of the end-users. It also served to identify points for improvement.

A strong aspect of the present research is that user classification was focused on adapting the gameplay to the user's capabilities and incorporating motor learning strategies. This study adapted the progression of the patient's journey using Gentile's motor taxonomy. Which proved to adapt to the requirements of the exercise prescription and the game design requirements. Additionally, each level adapts the virtualized exercises to the capabilities of the user. To the knowledge of the researcher, this is one of the few exergames that address the rehabilitation of trunk stability, focused on the STS motion, using this approach.

Based on quantitative and qualitative analysis of the user experience and user satisfaction performed, it is possible to confirm that the developed system can meet the needs and desires of the end users. However, special attention should be drawn to two aspects. First, the methods used in the different stages of the UCD approach. These need to also adapt to the capabilities of the main stakeholders participating to obtain valuable results. A second recommendation is that all elements of the game should be as intuitive as possible, regardless of how obvious they may seem. During the evaluation of the user experience and satisfaction, it was found that feedback, clear instructions, control tracking, and congruency between the icons and game objects are essential elements to provide an engaging and positive game experience.

Overall, the exergame Reef was evaluated with high satisfaction with the system interface and a greater feeling of enjoyment while playing. Further research must be done to evaluate the therapeutic effect of the exergame in long term.

Bibliography

[1] F. Noveletto et al. "Biomedical serious game system for balance rehabilitation of hemiparetic stroke patients". In: *IEEE Transactions on Neural Systems and Rehabilitation Engineering* 26.11 (2018), pp. 2179–2188. ISSN: 15344320. DOI: 10.1109/TNSRE.2018.2876670.

[2] Metin Karatas et al. "Trunk Muscle Strength in Relation to Balance and Functional Disability in Unihemispheric Stroke Patients". In: *American Journal of Physical Medicine and Rehabilitation* 83.2 (2004), pp. 81–87. ISSN: 08949115. DOI: 10.1097/01.PHM.0000107486.99756.C7.

[3] Hyun Young Kim et al. "Investigating the Dose-Related Effects of Video Game Trunk Control Training in Chronic Stroke Patients With Poor Sitting Balance". In: *Annals of Rehabilitation Medicine* 42.4 (Aug. 2018), pp. 514–520. ISSN: 2234-0645. DOI: 10.5535/arm.2018.42.4.514. URL: http://www.e-arm.org/journal/view.php?doi=10.5535/arm.2018.42.4.514.

[4] John W. Reza, Shadmehr; Krakauer. "A COMPUTATIONAL NEUROANATOMY FOR MOTOR CONTROL". In: *Bone* 23.1 (2008), pp. 1–7. ISSN: 15378276. DOI: 10.1007/s00221-008-1280-5.A. arXiv: NIHMS150003.

[5] Olivera Djurovic et al. "Risk factors related to falling in patients after stroke". In: *Iranian Journal of Public Health* 50.9 (2021), pp. 1832–1841. ISSN: 22516093. DOI: 10.18502/ijph.v50i9.7056.

[6] Anna Ramnemark et al. "Stroke, a major and increasing risk factor for femoral neck fracture". In: *Stroke* 31.7 (2000), pp. 1572–1577. ISSN: 0039-2499. DOI: 10.1161/01.STR.31.7.1572. URL: https://pubmed.ncbi.nlm.nih.gov/10884456/.

[7] A. Ramnemark et al. "Fractures after stroke". In: *Osteoporosis international : a journal established as result of cooperation between the European Foundation for Osteoporosis and the National Osteoporosis Foundation of the USA* 8.1 (1998), pp. 92–95. ISSN: 0937-941X. DOI:

10 . 1007 / S001980050053. URL: https://pubmed.ncbi.nlm.nih.gov/9692083/.

[8] Rosa Cabanas-Valdés et al. "The effectiveness of additional core stability exercises in improving dynamic sitting balance, gait and functional rehabilitation for subacute stroke patients (Core-trial): Study protocol for a randomized controlled trial". In: *International Journal of Environmental Research and Public Health* 18.12 (2021), pp. 1–17. ISSN: 16604601. DOI: 10.3390/ijerph18126615.

[9] Francesco Ferrarello et al. "Efficacy of physiotherapy interventions late after stroke: A meta-analysis". In: *Journal of Neurology, Neurosurgery and Psychiatry* 82.2 (2011), pp. 136–143. ISSN: 1468330X. DOI: 10.1136/jnnp.2009.196428.

[10] Kazuaki Oyake et al. "Motivational Strategies for Stroke Rehabilitation: A Descriptive Cross-Sectional Study". In: *Frontiers in Neurology* 11.June (2020), pp. 1–11. ISSN: 16642295. DOI: 10.3389/fneur.2020.00553.

[11] Tamina Levy et al. "A systematic review of measures of adherence to physical exercise recommendations in people with stroke". In: (2019). DOI: 10.1177/0269215518811903.

[12] Soheila Saeedi, Marjan Ghazisaeedi, and Sorayya Rezayi. "Applying Game-Based Approaches for Physical Rehabilitation of Poststroke Patients: A Systematic Review". In: *Journal of Healthcare Engineering* 2021 (2021). ISSN: 20402309. DOI: 10.1155/2021/9928509.

[13] Marika Demers et al. "Integration of motor learning principles into virtual reality interventions for individuals with cerebral palsy: Systematic review". In: *JMIR Serious Games* 9.2 (2021). ISSN: 22919279. DOI: 10.2196/23822.

[14] Benoit Bossavit. *Serious Games in Physical Rehabilitation*. Vol. 13. 4. 2019, pp. 251–252. ISBN: 9783319661216. DOI: 10.1108/JET-12-2019-076.

[15] Erika Pedreira da Fonseca, Nildo Manoel Ribeiro da Silva, and Elen Beatriz Pinto. "Therapeutic Effect of Virtual Reality on Post-Stroke Patients: Randomized Clinical Trial". In: *Journal of Stroke and Cerebrovascular Diseases* 26.1 (2017), pp. 94–100. ISSN: 15328511. DOI: 10.1016/j.jstrokecerebrovasdis.2016.08.035.

[16] Flint Rehab. *Areas of the Brain Affected by Stroke: Location Matters*. 2021. URL: https://www.flintrehab.com/areas-of-the-brain-affected-by-stroke/ (visited on 09/09/2022).

[17] *Effects of Stroke — Johns Hopkins Medicine.* URL: https://www.hopkinsmedicine.org/health/conditions-and-diseases/stroke/effects-of-stroke (visited on 09/09/2022).

[18] Masahiro Ishiwatari et al. "Trunk Impairment as a Predictor of Activities of Daily Living in Acute Stroke". In: *Frontiers in Neurology* 12.June (2021). ISSN: 16642295. DOI: 10.3389/fneur.2021.665592.

[19] John J. Dougherty. "The anatomical "core": A definition and functional classification". In: *Osteopathic Family Physician* 3.6 (2011), pp. 239–245. ISSN: 1877573X. DOI: 10.1016/j.osfp.2011.07.001. URL: http://dx.doi.org/10.1016/j.osfp.2011.07.001.

[20] Tamaya Van Criekinge et al. "The effectiveness of trunk training on trunk control, sitting and standing balance and mobility post-stroke: a systematic review and meta-analysis". In: *Clinical Rehabilitation* 33.6 (2019), pp. 992–1002. ISSN: 14770873. DOI: 10.1177/0269215519830159. URL: https://doi.org/10.1177/0269215519830159.

[21] F. P. Franchignoni et al. "Trunk Control Test as an Early Predictor of Stroke Rehabilitation Outcome". In: *Stroke* 28.7 (1997), pp. 1382–1385. ISSN: 00392499. DOI: 10.1161/01.STR.28.7.1382. URL: https://www-ahajournals-org.ezproxy2.utwente.nl/doi/abs/10.1161/01.str.28.7.1382.

[22] The Vestibular et al. "The Vestibular System". In: ().

[23] Sivateja Panibatla, Vijaya Kumar, and Amitesh Narayan. "Relationship between trunk control and balance in children with spastic cerebral palsy: A cross-sectional study". In: *Journal of Clinical and Diagnostic Research* 11.9 (2017), YC05–YC08. ISSN: 0973709X. DOI: 10.7860/JCDR/2017/28388.10649.

[24] Sohrab Almasi et al. "Kinect-Based Rehabilitation Systems for Stroke Patients: A Scoping Review". In: *BioMed Research International* 2022 (2022). ISSN: 23146141. DOI: 10.1155/2022/4339054.

[25] Seng Kwee Wee et al. "Effect of trunk support on upper extremity function in people with chronic stroke and people who are healthy". In: *Physical Therapy* 95.8 (2015), pp. 1163–1171. ISSN: 15386724. DOI: 10.2522/ptj.20140487.

[26] National Institute of Neurological Disorders and of Health. *Post-Stroke Rehabilitation Fact Sheet: National Institute of Neurological Disorders and Stroke (NINDS)*. 2011. URL: https://www.ninds.nih.gov/post-stroke-rehabilitation-fact-sheet%20http://www.ninds.nih.gov/disorders/stroke/poststrokerehab.htm.

[27] Fan Su and Wendong Xu. "Enhancing Brain Plasticity to Promote Stroke Recovery". In: *Frontiers in Neurology* 11.October (2020), pp. 1–15. ISSN: 16642295. DOI: 10.3389/fneur.2020.554089.

[28] Stroke Association. *Neuroplasticity: re-wiring the brain — Stroke Association*. 2021. URL: https://www.stroke.org.uk/effects-of-stroke/neuroplasticity-rewiring-the-brain%20https://www.stroke.org.uk/effects-stroke/neuroplasticity-re-wiring-brain (visited on 09/12/2022).

[29] KNGF. "KNGF-richtlijn Beroerte Praktijkrichtlijn". In: (2014). URL: www.kngfrichtlijnen.nl..

[30] Anne Shumway-Cook and Marjorie H. Woollacott. *Motor control : translating research into clinical practice*. Wolters Kluwer Health/Lippincott Williams Wilkins, 2012, p. 641. ISBN: 9781608310180.

[31] April Pruski. *Stroke Recovery Timeline — Johns Hopkins Medicine*. 2021. URL: https://www.hopkinsmedicine.org/health/conditions-and-diseases/stroke/stroke-recovery-timeline (visited on 09/12/2022).

[32] FlintRehab. *Spontaneous Recovery After Stroke: How It Works — Flint Rehab*. 2020. URL: https://www.flintrehab.com/spontaneous-recovery-after-stroke/ (visited on 09/12/2022).

[33] Julie Bernhardt et al. "Agreed Definitions and a Shared Vision for New Standards in Stroke Recovery Research: The Stroke Recovery and Rehabilitation Roundtable Taskforce". In: *Neurorehabilitation and Neural Repair* 31.9 (2017), pp. 793–799. ISSN: 15526844. DOI: 10.1177/1545968317732668.

[34] Janice J. Eng. "Strength Training in Individuals with Stroke". In: *Physiotherapy Canada* 56.04 (2004), p. 189. ISSN: 0300-0508. DOI: 10.2310/6640.2004.00025.

[35] Patrick Kortebein et al. "Functional Impact of 10 Days of Bed Rest in Healthy Older Adults". In: *The Journals of Gerontology: Series A* 63.10 (Oct. 2008), pp. 1076–1081. ISSN: 1079-5006. DOI: 10.1093/GERONA/63.10.1076. URL: https://academic-oup-com.ezproxy2.utwente.nl/biomedgerontology/article/63/10/1076/559225.

[36] Selina M. Parry and Zudin A. Puthucheary. "The impact of extended bed rest on the musculoskeletal system in the critical care environment". In: *Extreme Physiology and Medicine* 4.1 (2015), pp. 1–8. ISSN: 20467648. DOI: 10.1186/s13728-015-0036-7.

[37] Robert Topp et al. “The effect of bed rest and potential of prehabilitation on patients in the intensive care unit”. In: *AACN clinical issues* 13 (2 2002), pp. 263–276. ISSN: 1079-0713. DOI: 10.1097/00044067-200205000-00011. URL: https://pubmed.ncbi.nlm.nih.gov/12011598/.

[38] B. Saltin et al. “Response to exercise after bed rest and after training.” In: *undefined* 71 (2 Aug. 1968), p. 444. ISSN: 0003-4819. DOI: 10.7326/0003-4819-71-2-444_1. URL: http://annals.org/article.aspx?doi=10.7326/0003-4819-71-2-444_1.

[39] Victor A. Convertino, Susan A. Bloomfield, and John E. Greenleaf. “An overview of the issues: physiological effects of bed rest and restricted physical activity”. In: *Medicine and science in sports and exercise* 29 (2 Feb. 1997), pp. 187–190. ISSN: 0195-9131. DOI: 10.1097/00005768-199702000-00004. URL: https://pubmed.ncbi.nlm.nih.gov/9044221/.

[40] Sandra A. Billinger et al. “Physical Activity and Exercise Recommendations for Stroke Survivors”. In: *Stroke* 45 (8 2014), pp. 2532–2553. ISSN: 15244628. DOI: 10.1161/STR.0000000000000022. URL: https://www-ahajournals-org.ezproxy2.utwente.nl/doi/abs/10.1161/str.0000000000000022.

[41] Kate Gamble, April Chiu, and Casey Peiris. “Core Stability Exercises in Addition to Usual Care Physiotherapy Improve Stability and Balance After Stroke: A Systematic Review and Meta-analysis”. In: *Archives of Physical Medicine and Rehabilitation* 102.4 (2021), pp. 762–775. ISSN: 1532821X. DOI: 10.1016/j.apmr.2020.09.388. URL: https://doi.org/10.1016/j.apmr.2020.09.388.

[42] David H. Saunders et al. “Physical fitness training for stroke patients”. In: *Cochrane Database of Systematic Reviews* 2020.3 (2020), pp. 1–3. ISSN: 1469493X. DOI: 10.1002/14651858.CD003316.pub7.

[43] Bernadette C Ammann et al. “Application of principles of exercise trainingin sub-acute and chronic stroke survivors:a systematic review”. In: *BMC neurology* (2014).

[44] Danielle E. Levac et al. “Promoting therapists’ use of motor learning strategies within virtual reality-based stroke rehabilitation”. In: *PLoS ONE* 11.12 (2016), pp. 1–16. ISSN: 19326203. DOI: 10.1371/journal.pone.0168311.

[45] Simone Dorsch, Louise Ada, and Daniella Alloggia. "Progressive resistance training increases strength after stroke but this may not carry over to activity: a systematic review". In: *Journal of Physiotherapy* 64.2 (2018), pp. 84–90. ISSN: 18369561. DOI: 10.1016/j.jphys.2018.02.012. URL: http://dx.doi.org/10.1016/j.jphys.2018.02.012.

[46] I. O. Sorinola, I. Powis, and C. M. White. "Does additional exercise improve trunk function recovery in stroke patients? A meta-analysis". In: *NeuroRehabilitation* 35.2 (Jan. 2014), pp. 205–213. ISSN: 1053-8135. DOI: 10.3233/NRE-141123.

[47] Sarah Gregor et al. "Study Paradigms and Principles Investigated in Motor Learning Research After Stroke: A Scoping Review". In: *Archives of Rehabilitation Research and Clinical Translation* 3.2 (2021), p. 100111. ISSN: 25901095. DOI: 10.1016/j.arrct.2021.100111.

[48] Edwards Williams. *Motor Learning And Control: From Theory To Practice (available Titles Coursemate)*. 2011, p. 544. ISBN: 0495010804. URL: https://www.cengage.com/c/motor-learning-and-control-from-theory-to-practice-1e-edwards/9780495010807/.

[49] Martina Maier, Belén Rubio Ballester, and Paul F.M.J. Verschure. "Principles of Neurorehabilitation After Stroke Based on Motor Learning and Brain Plasticity Mechanisms". In: *Frontiers in Systems Neuroscience* 13.December (2019), pp. 1–18. ISSN: 16625137. DOI: 10.3389/fnsys.2019.00074.

[50] "Principles of Neurorehabilitation After Stroke Based on Motor Learning and Brain Plasticity Mechanisms". In: *Frontiers in Systems Neuroscience* 13.December (2019), pp. 1–18. ISSN: 16625137. DOI: 10.3389/fnsys.2019.00074.

[51] John W. Krakauer. "Motor learning: Its relevance to stroke recovery and neurorehabilitation". In: *Current Opinion in Neurology* 19.1 (2006), pp. 84–90. ISSN: 13507540. DOI: 10.1097/01.wco.0000200544.29915.cc.

[52] Jill Whitall. "Stroke Rehabilitation Research: Time to Answer More Specific Questions?" In: *Neurorehabilitation and Neural Repair* 18.1 (2004), pp. 3–11. ISSN: 15459683. DOI: 10.1177/0888439003262876.

[53] Isobel J. Hubbard et al. "Task-specific training: Evidence for and translation to clinical practice". In: *Occupational Therapy International* 16.3-4 (2009), pp. 175–189. ISSN: 09667903. DOI: 10.1002/oti.275.

[54] Seline Wüest et al. *Usability and Effects of an Exergame-Based Balance Training Program*. 2014. DOI: 10.1089/g4h.2013.0093.

[55] Simone K. Huber et al. “Personalized Motor-Cognitive Exergame Training in Chronic Stroke Patients—A Feasibility Study”. In: *Frontiers in Aging Neuroscience* 13.October (2021), pp. 1–19. ISSN: 16634365. DOI: 10.3389/fnagi.2021.730801.

[56] Meiqi Yao et al. “Defining the rehabilitation adherence curve and adherence phases of stroke patients: An observational study”. In: *Patient Preference and Adherence* 11 (2017), pp. 1435–1441. ISSN: 1177889X. DOI: 10.2147/PPA.S139854.

[57] Taiki Yoshida et al. “Motivation for Rehabilitation in Patients With Subacute Stroke: A Qualitative Study”. In: *Frontiers in Rehabilitation Sciences* 2.June (2021), pp. 1–10. DOI: 10.3389/fresc.2021.664758.

[58] Heather Patrick and Geoffrey C Williams. “Self-determination theory: its application to health behavior and complementarity with motivational interviewing”. In: *International Journal of Behavioral Nutrition and Physical Activity* 9 (2012), p. 18. DOI: 10.1186/1479-5868-9-18. URL: http://www.ijbnpa.org/content/9/1/18.

[59] Pierre Yves Oudeyer and Frederic Kaplan. “What is intrinsic motivation? A typology of computational approaches”. In: *Frontiers in Neurorobotics* 3.NOV (2009), p. 6. ISSN: 16625218. DOI: 10.3389/NEURO.12.006.2007/BIBTEX.

[60] Katinka van der Kooij et al. “Gamification as a sustainable source of enjoyment during balance and gait exercises”. In: *Frontiers in Psychology* 10.MAR (2019), pp. 1–12. ISSN: 16641078. DOI: 10.3389/fpsyg.2019.00294.

[61] Michael L. Wehmeyer and Karrie A. Shogren. “Self-Determination and Choice”. In: Springer, Cham, 2016, pp. 561–584. DOI: 10.1007/978-3-319-26583-4_21. URL: https://link.springer.com/chapter/10.1007/978-3-319-26583-4%7B%5C_%7D21.

[62] C. Scott Rigby and Richard M. Ryan. “Self-Determination Theory in Human Resource Development: New Directions and Practical Considerations”. In: *Advances in Developing Human Resources* 20.2 (May 2018), pp. 133–147. ISSN: 15523055. DOI: 10.1177/1523422318756954/ASSET/IMAGES/LARGE/10.1177_1523422318756954-FIG1.JPEG. URL: https://journals-sagepub-com.ezproxy2.utwente.nl/doi/10.1177/1523422318756954.

[63] Kazuaki Oyake et al. “Motivational Strategies for Stroke Rehabilitation: A Delphi Study”. In: *Archives of Physical Medicine and Rehabilitation* 101.11 (2020), pp. 1929–1936. ISSN: 1532821X. DOI: 10.1016/j.apmr.2020.06.007. URL: https://doi.org/10.1016/j.apmr.2020.06.007.

[64] Stephanie M. Jansen-Kosterink et al. “A Serious Exergame for Patients Suffering from Chronic Musculoskeletal Back and Neck Pain: A Pilot Study”. In: *Games for Health Journal* 2.5 (2013), pp. 299–307. ISSN: 21617856. DOI: 10.1089/g4h.2013.0043.

[65] Silvia Pintado-Izquierdo, Roberto Cano-de-la-Cuerda, and Rosa María Ortiz-Gutiérrez. “Video game-based therapy on balance and gait of patients with stroke: A systematic review”. In: *Applied Sciences (Switzerland)* 10.18 (2020), pp. 1–33. ISSN: 20763417. DOI: 10.3390/APP10186426.

[66] Myung Mo Lee, Doo Chul Shin, and Chang Ho Song. “Canoe game-based virtual reality training to improve trunk postural stability, balance, and upper limb motor function in subacute stroke patients: A randomized controlled pilot study”. In: *Journal of Physical Therapy Science* 28.7 (2016), pp. 2019–2024. ISSN: 09155287. DOI: 10.1589/jpts.28.2019.

[67] Daegyun Lee and Youngsook Bae. “The Effectiveness of Driving Game on Trunk Control and Gait Ability in Stroke”. In: *Journal of Motor Behavior* 52.1 (2020), pp. 33–40. ISSN: 19401027. DOI: 10.1080/00222895.2019.1574259.

[68] Aimee L. Betker et al. “Video Game-Based Exercises for Balance Rehabilitation: A Single-Subject Design”. In: *Archives of Physical Medicine and Rehabilitation* 87.8 (2006), pp. 1141–1149. ISSN: 00039993. DOI: 10.1016/j.apmr.2006.04.010.

[69] Richard Rouse. *Game Design: Theory and Practice, Second Edition: Theory and Practice, Second Edition*. 2004, p. 730. ISBN: 9781556229121.

[70] Ernest Adams. *Fundementals of Game Design*. 2010, p. 675. ISBN: 9780321643377.

[71] *Theory – Interaction Models — tomfabrygamesdesign*. URL: https://tomfabrygamesdesign.wordpress.com/2016/01/24/theory-interaction-models/ (visited on 09/30/2022).

[72] Saiqa Aleem, Luiz Fernando Capretz, and Faheem Ahmed. "Game development software engineering process life cycle: a systematic review". In: *Journal of Software Engineering Research and Development* 4.1 (2016). ISSN: 2195-1721. DOI: 10 . 1186 / s40411 - 016 - 0032 - 7. URL: http://dx.doi.org/10.1186/s40411-016-0032-7.

[73] Rido Ramadan and Yani Widyani. "Game development life cycle guidelines". In: *2013 International Conference on Advanced Computer Science and Information Systems, ICACSIS 2013* June (2013), pp. 95–100. DOI: 10.1109/ICACSIS.2013.6761558.

[74] Ellen Brox, Stathis Th Konstantinidis, and Gunn Evertsen. "User-centered design of serious games for older adults following 3 years of experience with exergames for seniors: A study design". In: *JMIR Serious Games* 5.1 (2017), pp. 1–14. ISSN: 22919279. DOI: 10.2196/games.6254.

[75] Timo Jokela et al. "The standard of user-centered design and the standard definition of usability: Analyzing ISO 13407 against ISO 9241-11". In: *ACM International Conference Proceeding Series* 46.January (2003), pp. 53–60.

[76] Federica Savazzi et al. "Engaged in learning neurorehabilitation: Development and validation of a serious game with user-centered design". In: *Computers and Education* 125.July 2017 (2018), pp. 53–61. ISSN: 03601315. DOI: 10 . 1016 / j . compedu . 2018 . 06 . 001. URL: https://doi.org/10.1016/j.compedu.2018.06.001.

[77] Matthew Schmidt et al. "Methods of User Centered Design and Evaluation for Learning Designers". In: *Learner and User Experience Research* 5.2 (May 2020), pp. 1–129. ISSN: 1946-7680. DOI: 10.2200/S00418ED1V01Y201205HCI014. URL: https://edtechbooks.org/ux/ucd%7B%5C_%7Dmethods%7B%5C_%7Dfor%7B%5C_%7Dlx.

[78] Rianne M.H.A. Huis in't Veld et al. "A scenario guideline for designing new teletreatments: A multidisciplinary approach". In: *Journal of Telemedicine and Telecare* 16.6 (2010), pp. 302–307. ISSN: 1357633X. DOI: 10.1258/jtt.2010.006003.

[79] *User-centred design: UCD methods*. URL: https://inviqa.com/blog/user-centred-design-6-popular-ucd-methods (visited on 10/01/2022).

[80] Jessamyn Burns Wendell. "Morgan Kaufmann - Rapid Contextual Design - A How-to Guide to Key Techniques for User Centered Design - 2005 - (By Laxxuss).pdf". In: ().

[81] Sophie D E Haan. “Application Design for the Quantified Pet Domain from a User Centered Design Perspective Application Design for the Quantified Pet Domain from a User Centered Design Perspective Applikationsdesign Inom Forskningsområdet Kvantifierade Husdjur ur ett Använd”. In: (2018).

[82] Cynthia LeRouge et al. “User profiles and personas in the design and development of consumer health technologies”. In: *International Journal of Medical Informatics* 82.11 (2013), e251–e268. ISSN: 13865056. DOI: 10.1016/j.ijmedinf.2011.03.006. URL: http://dx.doi.org/10.1016/j.ijmedinf.2011.03.006.

[83] Martin Maguire and Nigel Bevan. “Usability: Gaining a Competitive Edge IFIP World Computer Congress”. In: (2002). URL: www.mib.org.ukldigital.

[84] “Methods for concept ideation”. In: *The Mathematics Teacher* 110.6 (2017), p. 474. ISSN: 00255769. DOI: 10.5951/mathteacher.110.6.0474.

[85] Jacob Rodda, Charlie Ranscombe, and Blair Kuys. “A method to explore strategies to communicate user experience through storyboards: an automotive design case study”. In: *AI EDAM* 36 (Mar. 2022), e16. ISSN: 0890-0604. DOI: 10.1017/S0890060421000287. URL: https://www-cambridge-org.ezproxy2.utwente.nl/core/journals/ai-edam/article/method-to-explore-strategies-to-communicate-user-experience-through-storyboards-an-automotive-design-case-study/A582CD1AFAF3DA8823C0A2615D34F26A.

[86] Makayla Lewis and Miriam Sturdee. “Curricula Design & Pedagogy for Sketching Within HCI & UX Education”. In: *Frontiers in Computer Science* 4 (Apr. 2022), p. 35. ISSN: 26249898. DOI: 10.3389/FCOMP.2022.826445/BIBTEX.

[87] Yizhen Liu, Yingxin Tong, and Yuqi Yang. “The Application of Mind Mapping into College Computer Programming Teaching”. In: *Procedia Computer Science* 129 (2018), pp. 66–70. ISSN: 18770509. DOI: 10.1016/j.procs.2018.03.047. URL: https://doi.org/10.1016/j.procs.2018.03.047.

[88] Amjad Hudaib et al. “Requirements Prioritization Techniques Comparison”. In: *Modern Applied Science* 12.2 (2018), p. 62. ISSN: 1913-1844. DOI: 10.5539/mas.v12n2p62.

[89] Muhammad Rashid. “Common Requirements Management Elicitation Techniques”. In: *PMI Southern Germany* 5 (2017), pp. 16–26. URL: https://www.softwaretestinghelp.com/requirements-elicitation-techniques/.

[90] John P.T. Mo, Cees Bil, and Arvind Sinha. *Engineering systems acquisition and support*. 2014, pp. 1–222. ISBN: 9780857092120. DOI: 10.1016/C2013-0-16187-9.

[91] Joep Janssen et al. “Gamification in Physical Therapy: More Than Using Games”. In: (2017). DOI: 10.1097/PEP.0000000000000326.

[92] T. Takken et al. “Recommendations for physical activity, recreation sport, and exercise training in paediatric patients with congenital heart disease: A report from the Exercise, Basic & Translational Research Section of the European Association of Cardiovascular Preventio”. In: *European Journal of Preventive Cardiology* 19.5 (2012), pp. 1034–1065. ISSN: 20474873. DOI: 10.1177/1741826711420000.

[93] André Godoy and Ellen F Barbosa. “Game-Scrum: An Approach to Agile Game Development”. In: *SBCGames* (2010), pp. 292–295. URL: http://www.sbgames.org/sbgames2010/proceedings/computing/short/Computing%7B%5C_%7Dshort19.pdf.

[94] Danielle Herro. “Elements of Game Design”. In: *K-12 Education* (2013), pp. 269–280. DOI: 10.4018/978-1-4666-4502-8.ch015.

[95] Yu Rong Mao et al. “The crucial changes of sit-to-stand phases in subacute stroke survivors identified by movement decomposition analysis”. In: *Frontiers in Neurology* 9.MAR (2018), pp. 1–8. ISSN: 16642295. DOI: 10.3389/fneur.2018.00185.

[96] Byeong Mu Mun et al. “Study on the usefulness of sit to stand training in self-directed treatment of stroke patients”. In: *Journal of Physical Therapy Science* 26.4 (2014), pp. 483–485. ISSN: 09155287. DOI: 10.1589/jpts.26.483.

[97] Takuya Isho and Shigeru Usuda. “Association of trunk control with mobility performance and accelerometry-based gait characteristics in hemiparetic patients with subacute stroke”. In: (). DOI: 10.1016/j.gaitpost.2015.11.011. URL: http://dx.doi.org/10.1016/j.gaitpost.2015.11.011.

[98] Maurizio Paciaroni and Monica Acciarresi. “Poststroke Fatigue”. In: *Stroke* 50.7 (2019), pp. 1927–1933. ISSN: 15244628. DOI: 10.1161/STROKEAHA.119.023552.

[99] Krupp et al. “Fatigue Severity Scale (FSS)”. In: *A Compendium of Tests, Scales and Questionnaires* 88.2005 (2020), pp. 307–310. DOI: 10.4324/9781003076391-79.

[100] Suruliraj Karthikbabu and Geert Verheyden. “Relationship between trunk control, core muscle strength and balance confidence in community-dwelling patients with chronic stroke”. In: *Topics in Stroke Rehabilitation* 28.2 (2021), pp. 88–95. ISSN: 19455119. DOI: 10 . 1080 / 10749357 . 2020 . 1783896. URL: https://doi.org/10.1080/10749357.2020.1783896.

[101] Dominik Siemon, Felix Becker, and Susanne Robra-Bissantz. “How Might We? From Design Challenges to Business Innovation BeDien-Begleitforschung Personennahe Dienstleistungen View project”. In: December (2018). URL: www.journalcbi.com.

[102] EMD Assets. *Character-pack-lowpoly-free*. URL: https://assetstore.unity.com/packages/3d/characters/humanoids/c.

[103] Lana Polansky. *The Leaderboard: The Loneliness of the Endless Runner - Paste*. 2013. URL: https : / / www . pastemagazine . com / games / the - leaderboard-the-loneliness-of-the-endless-runn/.

[104] Consumer-centered Computer-supported Care For. *Studies in Health Technology and Informatics*. Vol. 270. 2020. ISBN: 9781643680828.

[105] Andisheh Feizi and Chui Yin Wong. “Usability of user interface styles for learning a graphical software application”. In: *2012 International Conference on Computer and Information Science, ICCIS 2012 - A Conference of World Engineering, Science and Technology Congress, ESTCON 2012 - Conference Proceedings* 2.October (2012), pp. 1089–1094. DOI: 10.1109/ICCISci.2012.6297188.

[106] K. Poels, Y.A.W. de Kort, and W.A. IJsselsteijn. “Game Experience Questionnaire The fun of gaming: Measuring the human experience of media enjoyment”. In: 2007 (2007).

[107] LIM YONG QUAN, CHEONG HUI QI, and SAW SHI QI. *THE CORRELATION OF VIDEO GAMES WITH POSITIVE AFFECT AND NEGATIVE AFFECT AMONG UTAR (PERAK CAMPUS) UNDERGRADUATE STUDENTS*. Tech. rep. October. UNIVERSITY TUNKU ABDUL RAHMAN, 2015, p. 32.

[108] Stephen J May. “Patient Satisfaction with Management of Back Pain Main”. In: *Physiotherapy* 87.1 (2001), pp. 4–20. ISSN: 00319406. DOI: 10.1016/s0031-9406(05)61186-8.

[109] Frederiek De Vette et al. “Engaging elderly people in telemedicine through gamification”. In: *JMIR Serious Games* 3.2 (2015), pp. 1–13. ISSN: 22919279. DOI: 10.2196/games.4561.

[110] A. Dickinson, J. Arnott, and S. Prior. “Methods for human-computer interaction research with older people”. In: *Behaviour and Information Technology* 26.4 (2007), pp. 343–352. ISSN: 0144929X. DOI: 10.1080/01449290601176948.

[111] Brandon Taylor et al. “Using Physiological Sensors to Detect Levels of User Frustration Induced by System Delays”. In: (2015). DOI: 10.1145/2750858.2805847. URL: http://dx.doi.org/10.1145/2750858.2805847.

[112] Wessel W Nieuwenhuys. “The Comparison of the Accuracy of Camera-based Skeleton Trackers During the Stepping Response for Recovering Balance in a Home Based”. In: (2022).

[113] Christina N. Harrington, Lyndsie Marie Koon, and Wendy A. Rogers. *Design of health information and communication technologies for older adults*. INC, 2020, pp. 341–363. ISBN: 9780128164273. DOI: 10 . 1016 / b978 - 0 - 12 - 816427 - 3 . 00017 - 8. URL: http://dx.doi.org/10.1016/B978-0-12-816427-3.00017-8.

[114] Michael Sailer et al. “How gamification motivates: An experimental study of the effects of specific game design elements on psychological need satisfaction”. In: *Computers in Human Behavior* 69 (Apr. 2017), pp. 371–380. ISSN: 0747-5632. DOI: 10.1016/J.CHB.2016.12.033.

[115] PhysioMed. “Correct Sitting Posture: Office”. In: *Maintaining a fit and healthy workforce* (2020). URL: www.physiomed.co.uk.

[116] *Neck pain from gaming, simplified – Esports Healthcare*. URL: https://esportshealthcare.com/neck-pain-from-gaming/ (visited on 09/20/2022).

[117] Chuck Tholl et al. “Musculoskeletal disorders in video gamers – a systematic review”. In: *BMC Musculoskeletal Disorders* 23.1 (Dec. 2022), pp. 1–16. ISSN: 14712474. DOI: 10.1186/S12891-022-05614-0/TABLES/3. URL: https://bmcmusculoskeletdisord.biomedcentral.com/articles/10.1186/s12891-022-05614-0.

Appendix A

Stage I. Understanding the context

A.1 Gamer protocol

INTRODUCTION

Good morningmy name is Samantha Orozco.. My research is about the design and development of an exergame for trunk stability for Chronic stroke patients. The following interview was proposed in order to get more insights about key elements for the design of the game from the point of view of a gamer that had suffered a stroke.

The idea of the system is that it will be designed following neurorehabilitation concepts and patients will be able to play using their body as a controller.

For keeping your privacy, the data that we will collect today will be anonymized. If at any point you do not want to continue, please feel free to interrupt me or let me know so we can stop.

For the sake of the interview could you state your name and age.

This interview consists of 3 topics. We will start with the 1st one that is.... Follow up Rehabilitation

Follow up Rehabilitation	
P	1. During your rehabilitation did you train balance stability? • Once you were discharged from hospital and you were on your own. Did you continue rehabilitation? • If yes: What type? and did you focus on that training in the trunk, at home? o How frequently? • If no: was there any factor that kept, you from continuing therapy?
A	**If the previous question was answered YES, then:** 1. What type of trunk control/balance exercises do you perform during home therapy? 2. If answer involves only muscle strength exercises: • Does the program include another type of intervention e.g., Coordination? **If the previous question was answered NO, then:** 3. Did you do other activities that you think stimulated your recovery? • If yes: Which ones? Did you do them for pleasure or with the purpose of recovery? • If no: in your perspective, what do you believe is A MUST DO?
C	1. What do you think about social aspects during a game? How would you find sharing experiences with peers, playing against other people, etc.? 2. What motivational aspects do you find enriching, and which one do you think can make you feel frustrated? E.g., Scoring system, reminders Duolingo like
T	4. From previous interviews you mentioned that you have used some rehabilitation devices is that correct?

<table>
<tr><td></td><td>

If no: Would you like to use one? Why no or yes?
If yes: Which ones? Does any of those focused on trunk stability and did you noticed progress while using them?

</td></tr>
</table>

<table>
<tr><td colspan="2">User requirements</td></tr>
<tr><td>P</td><td>
1. How would you describe your balance and core strength?

2. Which are other side effects from the stroke, besides balance impairment, that could affect the enjoyment of the game?
(<u>Aphasia</u>, the controllers, etc)
3. According to literature during the first year after the stroke cognitive functions can represent a challenge. Did you experience something like this?

4. As a gamer did something change? Could you describe for me how it is? And when did you start to play again?
</td></tr>
<tr><td>A</td><td>
5. What do you think was the hardest part of playing again?
6. When you were playing did you ever feel that the graphics could increase the balance impairment (sitting)?
* If help needed mention types of motion: sudden tilde of the head, closing eyes, quick movements
7. Do you think games have helped you to improve?

If yes: In what aspects?
If no: Why do you think that?

</td></tr>
<tr><td>C</td><td>
8. What do you think about multitasking (dual-task) in terms of playing, is that comfortable or does it require a lot of effort? E.g., playing the game and at the same time receiving feedback to correct the movement or posture?

9. What do you think about games that are related to daily living activities? Would you find that interesting?

If no: What would you think is interesting?
If yes: do you think that in the long term will still be interesting?

10. Let's say you already have the system; I just give it to you, and you are going to play. In which room do you think you would play?

11. Now you are in the room. Could you tell me what factors from this space could affect you playing the game?
</td></tr>
<tr><td>T</td><td>
12. Do you usually play commercial games?

If yes: Comparing therapeutical games to commercial games, Have you found differences?

</td></tr>
</table>

	o If yes: Which ones? Do you think that those are important to improve? o If not: Any improvements that you think are important? • If no: is there a reason for that? 13. What is your experience as a user using controllers and sensors like Kinect? a. If you have used Kinect or a motion sensor What would you say are its advantages and disadvantages to use? 14. If you look at a screen and there is a lot happening (objects moving, bright colors, unexpected sounds) how does that make you feel? *. If Help needed mention challenging, frustration, confusion. **If answer related to hassle:** • Is the something else on a game that can cause the same effect • How do you manage it?

Data	
P	1. How do you feel when you notice progress? Does it make a difference mentally talking? Feeling more confident, wanting to try new things, etc
A	2. If you notice progress on certain activity related balance or trunk control, do you challenge yourself to keep improving? 3. If you were using a system/game like this for a long term. What characteristics do you think are important to keep your interest?
C	4. What information about progress from the game would you find useful? (e.g., progress or motion quality)
T	5. Have you tried any app or method to keep track of your progress? • If yes: How does the information is displayed and what do you like/dislike? • If no: Would you find this information useful? Why?

A.2 Patient protocol

INTRODUCTION

Good morning my name is Samantha Orozco. I am a Biomedical engineer working under the supervision of Aurora. My research is about the design and development of an exergame for trunk stability for Chronic stroke patients.

The following interview was proposed in order to get more insights about key elements for the design of the game and understanding the needs of patients.

The idea of the system is that it will be designed following neurorehabilitation concepts and patients will be able to play using their body as a controller.

For keeping your privacy, the data that we will collect today will be anonymized. If at any point you do not want to continue, please feel free to interrupt me or let me know so we can stop.

For the sake of the interview could you state your name and age.

This interview consists of 4 topics. We will start with the 1st one that is.... Follow up Rehabilitation

Follow up Rehabilitation	
P	1. During your rehabilitation did you train balance stability? 2. Once you were discharged from hospital and you were on your own. Did you continue rehabilitation? • If yes: What type? and did you focus on that training in the trunk, at home? o How frequently? • If no: was there any factor that kept, you from continuing therapy?
A	**If the previous question was answered YES, then:** 3. If answer involves only muscle strength exercises: • Does the program include another type of intervention e.g., Coordination? **If the previous question was answered NO, then:** 4. Did you do other activities that you think stimulated your recovery? • If yes: Which ones? Did you do them for pleasure or with the purpose of recovery? • If no: in your perspective, what do you believe is A MUST DO?
C	5. **If the previous section/question was answered YES, then** 6. *Comparing the rehabilitation setting to* in-home therapy, what do you think are some key points missing from in-home therapy? 7. 8. From your experience, how would you describe confidence in your body with respect balance? a. Follow up: And regarding your home, is there anything that may affect your balance?

	9. What have you noticed has more impact in gaining that confidence?
T	10. From where you get information about recommendations of exercises 11. Have you heard about devices that help you to rehabilitate the trunk? • If no: Would you like to use one? Why no or yes? • If yes: Which ones? Have you used one before?

User requirements	
P	1. How would you describe your balance and core strength? 2. Which are other side effects from the stroke, besides balance impairment, that could affect the enjoyment of the game? • **If mention cognitive:** • Could you describe for me how it is?
A	3. When performing a (daily life)activity or your exercises, is there something that can increase the balance impairment? * If help needed mention types of motion: sudden tilde of the head, closing eyes, quick movements
C	4. What do you think about multitasking (dual-task), is that comfortable or does it require a lot of effort? E.g., playing the game and at the same time receiving feedback to correct the movement or posture? 5. Let's say you already have the system; I just give it to you, and you are going to play. In which room do you think you would play? 6. Now you are in the room. Could you tell me what factors from this space could affect you playing the game?
T	7. If you look at a screen and there is a lot happening (objects moving, bright colors, unexpected sounds) how does that make you feel? *. If Help needed mention challenging, frustration, confusion. **If answer related to is a hassle:** • How do you manage it?

Motivation	
P	1. We will develop a game specifically for chronic stroke patients. What do you think can be some challenges for you to adopt this as a tool?
A	2. What do you think about playing with others during a game? How would you find sharing experiences with peers (friends and family), playing against other people, etc.? Regarding the game for trunk stability... 3. What motivational aspects would you find enriching? E.g., Scoring system 4. Which aspects do you think can make you feel frustrated? E.g. reminders like Duolingo 5. What do you think about setting goals? Was it useful for you? • If no: What do you think is better to motivate you playing the game?
C	6. If you notice progress on certain activity related balance or trunk control, do you challenge yourself to keep improving?
T	7. What would you thing if you had a system on which you were able to see your progress to accomplish the goals you set up? 8. What would you thing if you had a system that recommend you to do exercise to keep improving?

Data	
P	1. How do you feel when you notice progress in your rehabilitation? a. Does it make a difference? Feeling more confident, wanting to try new things, etc
A	2. Do you have a favorite activity/game that you have performed/played for a long time? 3. If yes: Which one? What characteristics do you think keep your interest? 4. If no: what would be the elements that keep you interested?
C	5. What information about progress from the game would you find useful? (e.g., progress or motion quality)
T	6. Have you tried any app or method to keep track of your progress? • If yes: How does the information is displayed and what do you like/dislike? • If no: Would you find this information useful? Why?

A.3 Physiotherapists protocol

INTRODUCTION

Mi nombre es Samantha Orozco. Soy ingeniero Biomédico trabajando bajo la supervisión de Aurora. Mi investigación trata sobre el diseño y desarrollo de un exergame para la estabilidad del tronco en pacientes con ictus crónico. La siguiente entrevista se propuso con el fin de obtener más información sobre elementos clave para el diseño del juego en términos de protocolos de rehabilitación, conceptos de neurorrehabilitación y datos que se pueden extraer del juego, entre otros.

La idea del sistema es que estará diseñado siguiendo conceptos de neurorrehabilitación y los pacientes podrán jugar usando su cuerpo como controlador.

Para mantener su privacidad, los datos que recopilaremos hoy serán anonimizados. Ahora comenzaremos con la entrevista ¿podría indicar su nombre y profesión?

Si en algún momento no desea continuar, no dude en interrumpirme o hágamelo saber para que podamos detenernos.

Esta entrevista consta de 3 temas. Comenzaremos con el 1ro que es…. Actividades

Actividades	
P	
A	1. Durante entrevistas anteriores, algunas actividades parecen ser una problemática general relacionada con la estabilidad del tronco entre los pacientes crónicos: ir al baño, sentarse de pie, equilibrio estático mientras está sentado, recoger cosas del suelo o de las alturas, ¿Podría mencionar otra queja de los pacientes crónicos? que crees que es muy importante para las actividades de la vida diaria con respecto a la estabilidad (tronco)?
C	
T	

Rehabilitation Protocols	

P	Usted da terápia en casa?
	• Si: Con respecto a las actividades de vida diaria mencionadas , existen algunas guias de rehabilitación para el control del tronco?
	  ▪ Si: Cuales?
	  ▪ No: De donde basa el programa de rehabilitación?
	o No:Les deja terápia de tarea a sus pacientes? Cómo es? Qué tanto cree que si la hagan?.

A	2. Durante entrevistas anteriores, algunas actividades parecen ser una problemática general relacionada con la estabilidad del tronco entre los pacientes crónicos: como son los traslados o control postural ¿Podría mencionar cual actividad de la vida diaria relacionada a la estabilidad del tronco es indispensable? 3. Cuando identifica que la persona tienen problemas con eso, ¿Qué tipos de ejercicios realiza? 4. Que otros aspectos son necesario para la rehabilitación del tronco? Además de la fuerza muscular. 5. Para evitar fatiga. Cree que intervenciones pequeñas con suficiente tiempo de descanso entre repeticiones podría ser más efectivo que una intervención larga? Por qué? 6. Sigue algún estandar para definir cuantas repeticiones, intensidad, diversidad de ejercicios el paciente tiene que realizar? 7. Algunos pacientes hacen ciertas actividades como tomar el vaso e inclinarse. Es posible evitar estrategias compensatorias o al final es mejor darle libertad al paciente de usar la estrategia que le permita realizar actividades aun cuando esto signifique que no es recuperación?
C	8. Qué parámetros son los que cambian en un programa de rehabilitación del tronco? 9. Cómo decide eso? Y cuando se hace el cambio? 10. En su experiencia, qué ha notado tiene mayor impacto en la rehabilitación del tronco? Algo que se debe hacer.
T	11. Ha escuchado o usado algún dispositivo para la rehabilitación del tronco? • si: cuales y que ventajas y desventajas ha visto en ellos? • If no: cree que es posible usarlos como una herramienta? 12. SI DA TERAPIA EN CASA: Qué factores considera hacen falta en la terápia en casa?

Neurorehabilitation Concepts. DURING CHRONIC PHASE	
P	1. Ha escuchado de unas estrategias llamadas Prácticas de aprendizaje motor? a. SI: Ha puesto alguna en práctica? b. NO: Sigue alguna corriente en especifico de la fisioterápia o que es algo que por experiencia es muy util para la rehabilitación de pacientes en cuanto a balance, control postural?

A	13. **ONLY IF THAT PERSON KNOWS ABOUT ML**. a. Qué tal ha funcionado? b. Hay alguna que cree que sea mejor para las actividades que hemos mencionado anteriormente? 14. Hay una estrategia donde se deja al paciente “Solo” hacer el ejercicio. Si se le da una guia de lo que debe hacer. La teoría dice que de esta manera se favorece más la neuroplasticidad, memoria y aprendizaje motor a largo plazo. Ha puesto en práctica algo como esto? O Hay alguna técnica que usted diga esto les ha ayudado mucho en esos aspectos?
C	15. La capacidad que tiene un paciente para memorizar o aprender el movimiento también depende de la severidad del CVA. Durante sus terápias de qué forma estimula este aprendizaje? *16. Piensa que el ambiente donde esta el paciente influye en este aprendizaje?* *a. Si: Qué características lo hacen positivo?* *b. No:*
T	

Data	
P	1. Mide de alguna forma el progreso del paciente? a. SI: Qué utiliza? b. NO: Qué información es la que mide en cuanto a rehabilitación?
A	2. Qué tipo de información le da al paciente en cuanto a su diagnóstico? 3. Cree que esta información es importante de dar?
C	4. En su experiencia, ‘Cómo presenta la información a los pacientes para que sea clara? 5. Esta herramienta nos va a dar un análisis del movimiento del paciente. Qué información le sería muy útil a usted en cuanto a la calidad del movimiento o quizá puede ser del progreso? 6. Qué otro tipo de información o datos considera que son importantes?
T	

A.4 Specific type of exercise protocol

INTRODUCTION

Good morning my name is Samantha Orozco. I am a Biomedical engineer studying at the University of Twente. My research is about the design and development of an exergame for trunk stability for Chronic stroke patients. The following interview was proposed in order to get information about exercises and activities for the rehabilitation of trunk stability in chronic stroke patients.

The idea of the system is that it will be designed following neurorehabilitation concepts and patients will be able to play using their body as a controller.

For keeping your privacy, the data that we will collect today will be anonymized. For the sake of the interview could you state your name and profession (or any other demographic that you need for your analysis).

If at any point you do not want to continue, please feel free to interrupt me or let me know so we can stop.

Rehabilitation Protocols	
P	1. On average, how would you describe the current home situation of chronic stroke patients? 2. On percentages, how many patients do not have any follow up, and how many continue receiving physiotherapy?
A	3. I understand that patients that receive a follow-up at least once per week can be more stimulated and guided than those who do not receive a follow-up. Thus, is it difficult for patients in general to maintain the functionality reached during the clinical setting once they are in-home? Why? 4. Besides muscle strength training, what other elements for a complete follow up rehabilitation program are recommended for chronic patients in a home environment? 5. Is it important to include a warming up and a cool down during the rehabilitation session? 6. Based on previous interviews and literature reviews, data indicated that these three activities are indispensable for daily living activities and quality of life that are related to trunk stability: a. Walking = Dynamic balance b. Sit to Stand up c. Keeping balance while sitting and standing = Static balance Which one do you think is more beneficial for chronic patients in the long term? Do you have any other suggestions about essential activities?
C	7. **Based on this activity**, what type of exercises are performed or recommended for a home environment? 7.1. Walking = Dynamic balance 7.2. Sit to Stand up 7.3. Keeping balance while sitting and standing = Static balance 7.4. The other activity 8. How do you decide the intensity, and dosage of an exercise for these patients? 9. What way of giving feedback has turned out to be very effective? 10. For the chronic stroke patients and the system that I want to develop, considering all the elements that we have discussed, which of these activities could be trained in a virtual environment? 10.1. Why yes? 10.2. Why not?

	11. Have you heard about Gentile's motor skill taxonomy? 11.1. Yes: For what have you implemented it? And what benefits did you observe? 11.2. No: The game will be divided into adaptative levels: Let's say easy, intermedium, and hard. What parameters from those exercises would change once the patient has improved or adapted? 12. I have read the guideline of KNGF-richtlijn Beroerte there are some recommendations there for motor learning principles. For the activity we have discussed, which principle do you think will boost learning in the long term? 13. During the chronic phase, once patients are in their house without supervision how can they still stimulate: 13.1. Coordination 13.2. Proprioception 13.3. Conscious of the movement?
T	2. Have you recommended or used any device for the rehabilitation of trunk stability? • Yes: Which ones? What is your opinion on them: advantages and disadvantages? • If not: Do you think it is a tool that can be used?

Metrics	
P	1. With this system we could make a motion analysis. What measurements regarding the discussed activity would be important to consider that can give important data as a physiotherapist? **BASED ON THE ANSWERE:** 2. Where to find a correct movement metric? Or compared with what to be considered a "good movement"? 3. What type of information regarding progress, and the rehabilitation program do the patients need and is beneficial for them? 4. What type of information do the patients ask you?
A	5. How do you measure progress in the chronic phase?
C	6. Is there any test or golden standard that you can recommend that can be used to evaluate the game in terms of patient improvement?
T	7. Is there any system that you use to measure progress or motion analysis measurements of chronic stroke patients?

A.5 Consent form

A.5.1 Contextual study

Consent Form "Master Assignment: Exergame for trunk stability"

YOU WILL BE GIVEN A COPY OF THIS INFORMED CONSENT FORM

Please tick the appropriate boxes	**Yes**	**No**
Taking part in the study		
I have read and understood the study information dated **[ ],** or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	○	○
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	○	○
I understand that information I provide will be used to understand the current situation of the rehabilitation of trunk stability among chronic stroke patients, seeing where possible improvements can be made.	○	○
I understand that personal information collected about me that can identify me, such as my name or where I live, will not be shared beyond the study team.	○	○
I agree that my information can be quoted in research outputs	○	○
I agree to be audio/video recorded.	○	○
Future use and reuse of the information by others		
I give permission for the information that I will give during the interview be archived in as a transcript so it can be used for future research and learning. Personal information such as name will be anonymized from the archived transcript.	○	○
I agree that my information may be shared with other researchers for future research studies that may be similar to this study. The information shared with other researchers will not include any information that can directly identify me. Researchers will not contact me for additional permission to use this information.	○	○
I give the researchers permission to keep my contact information and to contact me for future research projects.	○	○

Signatures

______________________ ______________________ ________

Name of participant Signature Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Samantha Orozco Carvallo ___________________ ________

Researcher name Signature Date

Study contact details for further information:

Phone: +31 687901697

Email: s.orozcocarvallo@student.utwente.nl

UNIVERSITY OF TWENTE.

Information Brochure

INTRODUCTION

The proposed research aims to develop and evaluate an exergaming system for home rehabilitation whose rehabilitation protocol will be based on recent findings in Motor learning strategies and Neuroplasticity processes for the rehabilitation of trunk control in chronic stroke patients.

The following interview was designed to get more insights about the current situation of the rehabilitation of chronic stroke patients regarding follow up treatment, motivation, challenges to perform Daily Living Activities, game interests, and neurorehabilitation strategies. The total duration of the interview is 1 hour.

This research is part of a master assignment from the University of Twente in Enschede, The Netherlands.

For keeping your privacy, the data that we will collect today will be anonymized. If at any point you do not want to continue, please feel free to interrupt me or let me know so we can stop.

In case of complaints, questions or the wish to withdraw from the study, you can reach the researchers, Samantha Orozco Carvallo, Aurora Ruiz Rodriguez or Edwin van Asseldonk on the following email addresses: s.orozcocarvallo@student.utwente.nl, a.ruizrodriguez@utwente.nl or e.h.f.vanasseldonk@utwente.nl.

Study contact details for further information:

Phone: +31 687901697

Email: s.orozcocarvallo@student.utwente.nl

UNIVERSITY OF TWENTE.

A.5.2 Exergame evaluation

If you agree to participate in the study please tick YES to the following boxes	**Yes**	**No**
Taking part in the study		
I have read and understood the study information dated **[ ],** or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	○	○
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	○	○
I hereby declare that (currently) I do not have suffered a stroke in the past, suffer from balance impairment, or have any injury that does not allow me to perform trunk flexion movements.	○	○
I understand that personal information collected about me that can identify me, such as my name or age, will not be shared beyond the study team.	○	○
Risks associated with participating in the study		
I understand that taking part in the study involves the following negligible risks: Falling over while performing the experiment, dizziness, and risk of hitting an object while playing.	○	○
Use of the information in the study		
I understand that information I provide will be used for a research paper assessing the employed user-centered methodology to better help the HEROES Project (and further movement analysis projects) determine the level of detail necessary for a scalable methodology.	○	○
Future use and reuse of the information by others		
I give permission for the information that I will give during the intervention to be archived so it can be used for future research and learning.	○	○
I agree that my information may be shared with other researchers for future research studies that may be similar to this study. The information shared with other researchers will not include any information that can directly identify me. Researchers will not contact me for additional permission to use this information.	○	○

Signatures

______________________ ______________________ _________

Name of participant Signature Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Samantha Orozco Carvallo ___________________ _________

Researcher name Signature Date

Consent Form "Design and development of a Trunk Stability Exergame for chronic stroke patients"

YOU WILL BE GIVEN A COPY OF THIS INFORMED CONSENT FORM

Background and purpose of this study

The HEROES project goal is to prevent falls and related injuries, reduce fall-related health-care utilization and associated costs, and help People with stroke maintain independence in daily life. The Project aims to achieve this by developing and evaluating an exergaming system for home rehabilitation following a user-centered methodology.
The proposed methodology is meant for the design and development of exergames for motor rehabilitation therapy with the required steps to get to a commercially available exergame. This provides a balance between the need of the patient as a user and the health specialist to create the video game. In order to achieve this, the methodology moves between different stages of the design thinking process, providing sufficient detail for each phase. With these outputs, the user and system requirements are determined as well as the main goals of the exergame.

The current research aims to design and develop an exergame for balance control of the trunk while sitting following the mentioned methodology. With the objective of quantifying and evaluating the feasibility of the integration of these concepts and generating knowledge that will contribute to the development of motor rehabilitation therapy exergames.

Potential risks of participating

In the developed exergame the participant has to perform certain movements while sitting in a home environment. These are some of the potential risks that may phase: Dizziness, a Small risk of falling, and a Negligible risk of hitting an object while playing.

Procedures for withdrawal from the study

Participation is entirely voluntary. You have the right to choose to stop the study whenever they feel necessary without a reason. However, you should immediately inform the researcher. You can send an email to the researcher listed on this sheet. All collected data of you will immediately be deleted.

Collection of personal data

This study includes filling up a survey and being observed during playing. This data will be stored and later used for the assessment of the developed game. All information will be anonymized and saved under participant[number] to ensure names are not needed. Personal information, like your age, and gender will also be collected. This information will be saved in the same manner.

Retention period of data

The collected data will be used during the HEROES Project. This project will run for at least 3 more years. The data will be retained for 5 years.

Contact information and questions

In case of complaints, questions, or the wish to withdraw from the study, you can reach the researchers, Samantha Orozco Carvallo, Aurora Ruiz Rodriguez, or Edwin van Asseldonk at the following email addresses: s.orozcocarvallo@student.utwente.nl, a.ruizrodriguez@utwente.nl, or e.h.f.vanasseldonk@utwente.nl

A.6 Affinity diagrams and Written summary

Table A.1: Chronic stroke rehabilitation topic summary

Chronic Stroke Rehabilitation
1. **Rehabilitation Protocol:** Unique for every patient, No guidelines for the chronic stroke phase, Training: strength, coordination, balance, resistance, reflexes, and proprioception. Rest is important. a. *Frequency:* Distribution of the workout through the week, Baseline routine of sets of 10 repetitions with variability on amount depending on the capabilities and needs of the patient. b. *Parameters that change:* Environment, intensity, and mobilization. 2. **Exercises:** No isolation of trunk exercises, work as a compound, train balance within the activity that the patient wants to improve. 3. **Most impact in rehabilitation:** Constant stimulation, Motivation, self-awareness of the activity or movement the patient is performing, Quality is more important than quantity. 4. **Motor Learning:** Task-oriented, Mirror, depends on the patients and how they learn. 5. **Feedback:** Visual, video recording. 6. **Devices:** No use of tools or devices due to cost. Some physiotherapists use web portals to give patients some suggestions about exercises. 7. **Activities that are affected:** a. *Mobilization:* Walking, static sitting. b. *Transfers:* Moving from supine position to sitting to out of the bed and back. c. *ADL:* Personal hygiene, dressing, showering, moving onto and off a toilet. 8. **Segmentation of tasks:** An action can be segmented in small tasks. 9. **Golden Standards:** Berg Balance Scale. 10. **Home vs Clinic rehabilitation:** Identification of particular problems, teach the patient to deal with their current environment.

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Table A.2: Chronic stroke patient requirements topic summary

Chronic Stroke Patient Requirements
1. **Stroke dealings:** Cognitive functions, task-specific activities (e.g. how to dress), understanding during communication, hemiplegia, hemianopia. 2. **Activities that increase imbalance:** Biking, walking, picking up things from the ground, visual input. 3. **Concerns:** Being surprised by losing control of the balance, not being strong enough as normal people, independence, safety, fear of falling. 4. **Patient characteristics:**Lazy want to avoid exercises, mental barriers about capabilities, prefer to use aids instead to recover a function (depending on the importance of the activity for them), struggles with participating in the normal world 5. **Mental health:** Depression, sadness, from very motivated patients to very demotivated.

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Table A.3: Game and engagement topic summary

Game and Engagement
1. **Gamification:** Sharing experiences, playing with others that have same capabilities, not noticing that you are learning. 2. **Data:** For patients data does not matter, patients prefer to see it during their daily living activities, progress is measured by objectives. 3. **Game interests:** Something that has a story or is more than scoring points, prefer avatars than seeing myself. 4. **Motivation:**Introspection is a persuasive way to engage the patient, positive scoring, and setting goals from the beginning. 5. **Commercial vs rehabilitation games:** Commercial games have a longer story and they do level up compared with rehabilitation games. 6. **Depth camera games** Not fun enough and costly. 7. **Challenges:** Hard for some patients to see their own progress, and it is difficult to receive a lot of input. 8. **Measurements:** Capability to start and finish a movement, is most important to perform the activity than symmetry; therefore, the measurement of a correct movement is not assessed. Once the patient is able to perform the activity is guided to improve the quality of the motion. 9. **Tailoring:** Levels that adapt to patients might be ideal.

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Appendix B

Stage IV. Exergame Evaluation

B.1 QUIS questionnaire

The QUIS is a ten-point Likert-type scale with opposing adjectives on each end of the scale and has a reported reliability of 0.939 (Cronbach's alpha). There are a total of 5 categories in which the system is evaluated:

- The overall reaction to the videogame
- Screen
- Terminology and System information
- Learning
- Usability and UI

The QUIS had users rate factors on a scale from zero to nine. A higher score indicates higher user satisfaction. The acceptance levels are divided into the following: Poor acceptance: $<$5, Moderate satisfaction 5$<$ x $<$7, High satisfaction

$$\geq 7$$

[105][104].

B.2 GEQ questionnaire

The GEQ is a reliable, valid, and sensitive tool for measuring game experience[106]. It uses a five-point Likert scale going from 0 to 4.
The GEQ is composed of a modular structure consisting of a Core questionnaire, a post-game questionnaire and a social presence module[106]. For this research, the

English paper version was used. The social presence module was not carried out because the developed game does not contain any sort of cooperative playing. The core questionnaire assessed the game experience as scores of seven components: Sensory and imaginative immersion, Flow. Challenge. Competence. Positive Affect. Negative Affect. Tension. For robust measurement, 5 items are needed per component [106]. The post-game questionnaire evaluates how players felt after they had stopped playing. Is composed of 4 components: Positive experience, Negative experience, Tiredness Returning to reality.

B.3 Quality Form

Date:

Subject:

EXP	TL		FL	TOTAL P:
P	NO		YES	DESCRIPTION
1				
2				
3				
4				
EXP	TL		FL	TOTAL P:
P	NO		YES	DESCRIPTION
1				
2				
3				
4				
Cross-Road	RIGHT	CENTER	LEFT	DESCRIPTION
EXP	TL		FL	TOTAL P:
P	NO		YES	DESCRIPTION
1				
2				
3				
4				

HELP SCREEN

B.4 Exergame questionnaire evaluation

USER-EVALUATION: TRUNK STABILITY EXERGAME

The survey is divided in 3 topics that evaluates the system, User experience and Therapeutical concepts included in the game.

Try to respond to all the items.

For each of the following questions, rate from 0 to 9 your opinion of the system.

For items that are not applicable, mark the Not applicable cell.

System Evaluation

OVERALL REACTIONS TO THE VIDEOGAME

Terrible	0 1 2 3 4 5 6 7 8 9	Wonderful
Difficult	0 1 2 3 4 5 6 7 8 9	Easy
Frustrating	0 1 2 3 4 5 6 7 8 9	Satisfying
Boring	0 1 2 3 4 5 6 7 8 9	Engaging

SCREEN

Characters on the computer screen		
Hard to read	0 1 2 3 4 5 6 7 8 9	easy to read
Information displayed on screen		
Confusing	0 1 2 3 4 5 6 7 8 9	Very clear

TERMINOLOGY AND SYSTEM INFORMATION

Use of terms throughout system		
Inconsistent	0 1 2 3 4 5 6 7 8 9	Consistent
Position of messages on screen		
Inconsistent	0 1 2 3 4 5 6 7 8 9	Consistent
Messages and/ or images on screen		
Inconsistent	0 1 2 3 4 5 6 7 8 9	Consistent
The videogame keeps you informed about your progress		
Never	0 1 2 3 4 5 6 7 8 9	Always
Audio feedback information		
Confusing	0 1 2 3 4 5 6 7 8 9	Clear
Slider visual feedback information		
Confusing	0 1 2 3 4 5 6 7 8 9	Clear
The end score menu information		
Confusing	0 1 2 3 4 5 6 7 8 9	Clear

LEARNING

Learning to operate the system			
Difficult	0 1 2 3 4 5 6 7 8 9	Easy	
Remembering movements and use of commands			
Difficult	0 1 2 3 4 5 6 7 8 9	Easy	
Tasks can be performed in a straight-forward manner			
Never	0 1 2 3 4 5 6 7 8 9	Always	
Help messages on the screen			
Unhelpful	0 1 2 3 4 5 6 7 8 9	Helpful	No APPLY
Supplemental animations			
Confusing	0 1 2 3 4 5 6 7 8 9	Clear	

USABILITY AND UI

Use of colors and sounds		
Poor	0 1 2 3 4 5 6 7 8 9	Good
System feedback		
Poor	0 1 2 3 4 5 6 7 8 9	Good
Audio feedback messages		
Pushy	0 1 2 3 4 5 6 7 8 9	Modest
System messages and reports		
Poor	0 1 2 3 4 5 6 7 8 9	Good

USER EXPERIENCE WHILE PLAYING

Please indicate how you felt **WHILE PLAYING** the game for each of the items,

Was deeply concentrated in the game		
Strongly disagree	0 1 2 3 4 5 6 7 8 9	Strongly agree
Felt that I fail		
Strongly disagree	0 1 2 3 4 5 6 7 8 9	Strongly agree
Felt frustrated		
Strongly disagree	0 1 2 3 4 5 6 7 8 9	Strongly disagree
Felt curious		
Strongly disagree	0 1 2 3 4 5 6 7 8 9	Strongly agree
Felt annoyed		
Strongly disagree	0 1 2 3 4 5 6 7 8 9	Strongly agree
Felt could explore		
Strongly disagree	0 1 2 3 4 5 6 7 8 9	Strongly agree
Felt successful		
Strongly disagree	0 1 2 3 4 5 6 7 8 9	Strongly agree
Felt irritated		
Strongly disagree	0 1 2 3 4 5 6 7 8 9	Strongly agree
Felt capable		
Strongly disagree	0 1 2 3 4 5 6 7 8 9	Strongly agree
Felt skillful		
Strongly disagree	0 1 2 3 4 5 6 7 8 9	Strongly agree
Felt happy		
Strongly disagree	0 1 2 3 4 5 6 7 8 9	Strongly agree

STORY

I was interested in the game story		
Strongly disagree	0 1 2 3 4 5 6 7 8 9	Strongly agree
Felt bored		
Strongly disagree	0 1 2 3 4 5 6 7 8 9	Strongly agree
Rich experience		
Strongly disagree	0 1 2 3 4 5 6 7 8 9	Strongly agree

Safety

Felt comfortable while performing the movements		
Strongly disagree	0 1 2 3 4 5 6 7 8 9	Strongly agree
Felt the movements were physically demanding		
Strongly disagree	0 1 2 3 4 5 6 7 8 9	Strongly agree
Felt unsecure while playing		
Strongly disagree	0 1 2 3 4 5 6 7 8 9	Strongly agree
Felt I was going to fall while playing		
Strongly disagree	0 1 2 3 4 5 6 7 8 9	Strongly agree

Any further comment regarding any complains caused while playing

USER EXPERIENCE ENDING THE GAME

Please indicate how you felt **WHEN YOU FINISHED** playing the game for each of the items,

Felt bad		
Strongly disagree	0 1 2 3 4 5 6 7 8 9	Strongly agree
Felt was hard to come back to reality		
Strongly disagree	0 1 2 3 4 5 6 7 8 9	Strongly agree
Felt exhausted		
Strongly disagree	0 1 2 3 4 5 6 7 8 9	Strongly agree
Felt I could have done it better		
Strongly disagree	0 1 2 3 4 5 6 7 8 9	Strongly agree
Felt proud of my accomplishments		
Strongly disagree	0 1 2 3 4 5 6 7 8 9	Strongly agree
Had a sense I That I came from a journey		
Strongly disagree	0 1 2 3 4 5 6 7 8 9	Strongly agree

THERAPEUTICAL ASPECTS

I am completely satisfied with the intervention I received		
Strongly disagree	0 1 2 3 4 5 6 7 8 9	Strongly agree
I felt encouraged to perform the exercises		
Strongly disagree	0 1 2 3 4 5 6 7 8 9	Strongly agree
I felt I was exercising and not playing		
Strongly disagree	0 1 2 3 4 5 6 7 8 9	Strongly agree
The game advised me on ways to avoid future errors		
Strongly disagree	0 1 2 3 4 5 6 7 8 9	Strongly agree
The game gives me detailed instructions regarding what I need to do		
Strongly disagree	0 1 2 3 4 5 6 7 8 9	Strongly agree
If I had the opportunity, I would play again		
Strongly disagree	0 1 2 3 4 5 6 7 8 9	Strongly agree

Appendix C

Design session

C.1 Information Brochure

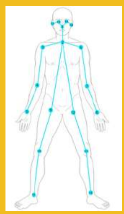
INFORMATION BROCHURE

Design session for a trunk stability exergame.

Together we will generate ideas on what the game would look like taking into account the needs and requirements of chronic stroke patients.

SYSTEM

Sensor
Depth Camera



User Recognition

Videogame
Controlled by the motion of the user

END USER CHARACTERISTICS

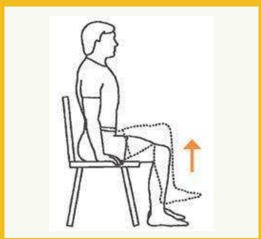
Mrs. Jean J is an 82-year-old woman who had a stroke approximately 6 years ago. The stroke has produced motor dyscontrol in her right side. She has a resultant right hemiparesis, decreased sensation in the right upper and lower extremities, and can barely see objects on the lateral sides of his view field. She has good language skills, but she finds it difficult to follow instructions when words are complicated.

Martin is a 59 years old man who suffered a cerebral vascular accident 2 years ago. He lives in his own home with his wife, who is in relatively good health. His balance and walking have become increasingly worse, as has his ability to assist transfers. He is beginning to fall when trying to stand from a chair. Besides that he has difficulty with his activities of daily living (ADLs) including toileting, pick up things and grooming, because of dysmetria and dyscoordination

EXERCISES

Trunk Flexion

Lateral trunk Flexion



Hip Flexion

Information source Encyclopaedia Britannica
https://www.britannica.com/science/Newtons-laws-of-motion

AGENDA OVERVIEW

Time	Activity	Duration
9:00 Am	Introduction	5 min
	Description of the assignment	
9:05 Am	I. Type of game	17 min
9:22 Am	II. Level-UP	17 min
9:39 Am	III. Data measurements	16 min
9:55 Am	Re-Cap	5 min
10:00 Am	End of the meeting	

MURAL TUTORIAL

Navigate the mural

- Use your mouse to zoom
- Click and drag to move

Edit elements

- Double click Sticky Notes, Text Boxes and Titles to edit their text
- Right click any element for more options

Add elements

- **Add sticky notes** by double clicking on the canvas
- **Add text and other objects** by dragging them from the sidebar
- **Add images** by dragging them in from your computer
- **Add links and other files** by pasting them into the mural (Ctrl + V)

C.2 Concept validation protocols

Playability (Speelbaarheid)

The adventure begins with the player seated, as it progresses the actions change to more dynamic positions until reaching the sit to stand movement.

For this part we will focus only on level one. Sitting exercises

Questions

- With what elements is possible to interact with?
- Does the adventurer is going by Bike? Horse? Magical creature?
- One boss that evaluate your abilities to pass to the next section? Or an obstacle?
- Beside the environment rewards, what other rewards do you think would be nice to have?

Therapeutic concepts

- Every level starts with a baseline measurement to get personalized information of the capabilities of the user on the tasks that the level involve
- Series of 3*10 – Probably the patient has to stay at least 1 month on each level. Depends on own progress.
- If a certain task is detected to be more weak than the others then the repetitions increase for that task.
- Mirror feedback to correct the patient while performing the exercise

Personalization & training

- What activities can be rewarded? (Number of repetitions, Quality of movement)
- Does parameters as quality of movement and speed matter?
- What parameters from the exercises can be modified? Beside the threshold.
- On month of training and then the testing?
- Is it important to test basic skills on advanced levels? E.g. If user is on level 4 also test skills of level 1

C.3 Game References

Art References & Narrative

Games

Old's man journey

An adventure game on which the player has to unfold the story of an old man by solving pressure free puzzles. The game uses visual narrative as a tool to guide the players journey fomenting a calm and joyful environment. The users can explore the environment by pointing and clicking on different objects of the game world. The art concept follows a minimalistic art, with soft colors and calm music.

Flower

An adventure game on which the player controls the wind to collect flowers and help to bring to life the surrounding nature. The controllers are simple with only one action button to control the direction of the wind. The game mechanics uses a third person perspective and a 3D world to construct a calm environmental. Elements like music and the aesthetics are used as interactive tools that change as a consequence of the action of the player. There are no enemies to defeat or lives to lose.

Monument valley

A visual appealing game that uses an isometric view to visualize each level. The art concept uses a minimalistic and geometric style with a soft color palette. Here the player needs to interact with the environment and guide an avatar through different platforms avoiding some enemies that Block the path. The game world is shape as a pent rose stair, an optical illusion that simulate an endless stair

Journey

An adventure game on which the aim is to guide an avatar to the top of a mountain. This game is played on an online multiplayer mode. The vast world of Journey allows to find other players but the only way of communication is through music. This way the developers try to create a game world on which anonymous players can form an emotional connection by evoking the sense of smallness and wonder Journey uses a first-person perspective with a minimalistic style and a red soft color palette.

Gris

An action-adventure game on which the player has to solve puzzles and other challenges while passing through the levels. The game uses visual narrative to tell the story of gris, a girl that suffered a terrible lost. The player will help gris to overcome the pain and will watch gris grow emotionally. The art concept uses minimalistic drawings and the game is showed on a side view perspective. The color palette uses cold colors to evoke sadness but that fade into warmer colors every time a challenge is completed.

Aesthetics

Old’s man journey

http://www.oldmansjourney.com/

Flower

https://store.steampowered.com/app/966330/Flower/

Monument Valley


https://www.ustwogames.co.uk/games/monument-valley/

Journey

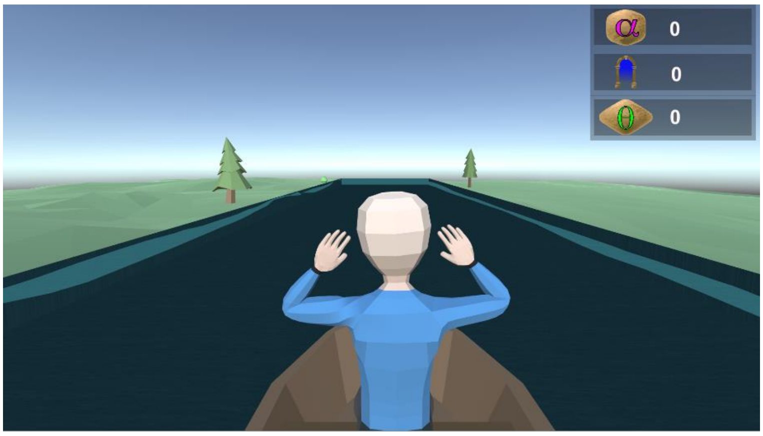
https://www.independent.ie/entertainment/games/reviews/journey-ps4-review-what-a-trip-31407770.html

Gris

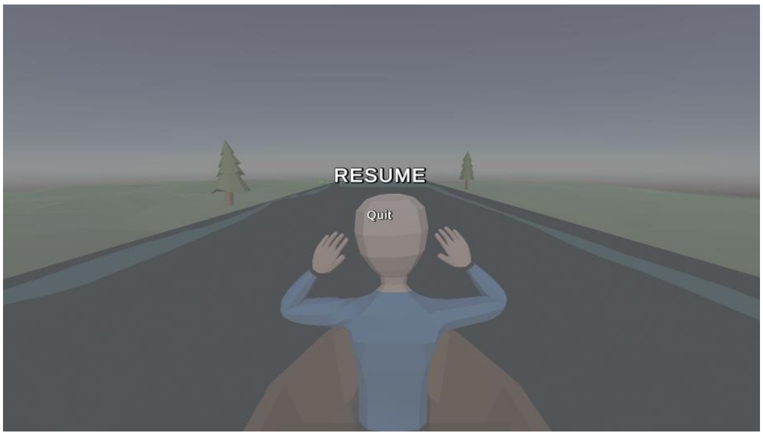
Mental Health in Games: Gris – Emmen Gaming

GAME SCREENS

Game screen

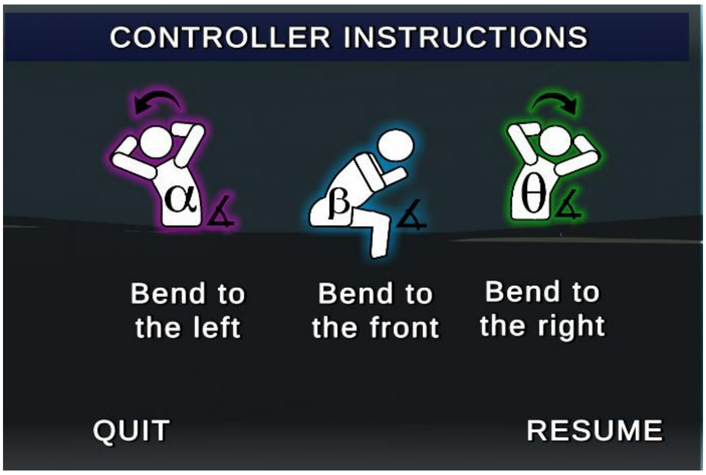


Pause screen



Decision screen

Controller instruction screen



Tutorial screens