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Analysis, Design, Development and Evaluation of an Exergame for Breast Cancer Patients Supporting Rehabilitation Exercising and Management in a Pre- and Postoperative Setting

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Julia Kren, BSc.
Matrikelnummer 01634052

an der Fakultät für Informatik

der Technischen Universität Wien

Betreuung: Dipl.-Ing. Dr.techn. Bakk.techn. René Baranyi
Mitwirkung: Ao.Univ.Prof. Dipl.-Ing. Dr.techn. Thomas Grechenig

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Diplom-Ingenieurin

in

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by

Julia Kren, BSc.
Registration Number 01634052

to the Faculty of Informatics

at the TU Wien

Advisor: Dipl.-Ing. Dr.techn. Bakk.techn. René Baranyi
Assistance: Ao.Univ.Prof. Dipl.-Ing. Dr.techn. Thomas Grechenig

Vienna, 6th July, 2023

Signature Author

Signature Advisor

Erklärung zur Verfassung der Arbeit

Julia Kren, BSc.

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Wien, 6. Juli 2023

Julia Kren

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Kurzfassung

Der weibliche Brustkrebs gehört zu den am häufigsten diagnostizierten Karzinomen. Risikofaktoren sind, unter anderem, Alter, weibliches Geschlecht, familiäre Prädisposition und andere Faktoren wie Essens- und Bewegungsgewohnheiten. Bewegung ist ein zentrales Thema in der Onkologie, da sie das Rezidivrisiko senkt. Die Überlebenswahrscheinlichkeit für Brustkrebserkrankte steigt, jedoch werden viele PatientInnen mit Nebenwirkungen und Langzeiteinschränkungen konfrontiert. Die Rehabilitation ist ein wichtiges Instrument den Symptomen entgegenzuwirken, jedoch ist weithin erforscht worden, dass nicht alle PatientInnen mit Einschränkungen auch eine angemessene Rehabilitation erfahren. Gründe dafür liegen im Mangel an Fachpersonal aber auch in der fehlenden Aufmerksamkeit für das Thema, sowohl patientenseitig als auch bei MedizinerInnen.

Diese Masterarbeit stellt ein Exergame für sowohl preoperative als auch postoperative BrustkrebspatientInnen vor. Die mobile App basiert auf der Idee der prospektiven Beobachtung (im deutschen Sprachraum auch als Prähabilitation bekannt), welche einen preoperativen Start der Rehabilitation vorschlägt. Dadurch werden Einschränkungen früher erkannt und PatientInnen dem Thema gegenüber früh sensibilisiert. Durch den Einfluss dieses Modells verfolgt die vorliegende digitale Lösung einen Ansatz, bei dem die Aufmerksamkeit auf regelmäßige Bewegung gerichtet werden soll. Darüberhinaus gibt sie PatientInnen die Möglichkeit, einen Teil ihrer Gesundheit selbst in die Hand zu nehmen.

Das Ergebnis wurde mithilfe von folgenden Techniken erzielt. Zuerst wurden ExpertInnen-Interviews durchgeführt um einerseits die Anforderungen zu erheben und anderseits um den Systemkontext zu erforschen. Danach haben weitere ExpertInnen dazu beigetragen, sinnvolle, einfache und wirksame Übungen auszuarbeiten, die die PatientInnen in der App machen können. Insgesamt wurden 14 Interviews mit 7 Personen durchgeführt. Zusätzlich wurde eine Online-Umfrage für BrustkrebspatientInnen eingerichtet, die die Benutzerperspektive von 16 Teilnehmerinnen berücksichtigt. Um das Resultat zu validieren, wurden zwei Evaluierungen durchgeführt. Einerseits hat eine Benutzbarkeitsstudie mit vier Personen Schwächen in der Usability aufgedeckt. Andererseits wurden zum Schluss drei ExpertInnen eingeladen, den erstellten Prototypen zu sichten, um Fehler in der Anforderungserhebung auszuschließen sowie den klinischen Zweck zu bestätigen.

Keywords: *Brustkrebs, Rehabilitation, Prähabilitation, Exergame, Mobile App, Bewegung, Gamification*

Abstract

Female breast cancer is the most commonly diagnosed cancer. Risk factors include age, female gender, familial susceptibility, and other factors like habits. Physical activity is known to reduce the risk of breast cancer and its recurrence. The survival rate of breast cancer patients increases. As the majority of survivors experience (late) side effects, rehabilitation plays a central role. Evidence suggests that not all individuals with functional dysfunctions get the rehabilitation they need. Barriers include a lack of specialized healthcare professionals and a lack of awareness on both the patient and the expert side.

This thesis contributes in providing an exergame for breast cancer patients in all phases of the patient journey. The application is based on the idea of prospective surveillance, which suggests an early start of rehabilitation before the surgery to detect impairments as early as possible and also to educate patients on healthy behaviors like physical exercise. In considering this model, both the pre- and postoperative phases are emphasized, and awareness is directed to regular exercise. Moreover, with the application, patients are provided with the opportunity to actively influence their health.

To that end, 7 experts from the field were interviewed to elicit requirements and analyze the system context this thesis is embedded in. Additionally, experts contributed in developing exercises for early- and late-postoperative patients that are simple, efficient and safe to carry out. In sum, 14 interviews were conducted. To include the user perspective, a questionnaire addressing breast cancer patients was provided, which led to 16 responses. To validate the results, two evaluations were carried out. A usability study with four participants showed improvements in usability. An expert review ensured the correctness of the requirements and the usefulness of the exercises.

Keywords: *breast cancer, rehabilitation, prospective surveillance, exergame, mobile app, physical activity, gamification*

Contents

CHAPTER 1

Introduction

As female breast cancer is the most commonly diagnosed cancer, and physical activity is vital for reducing the risk of recurrence, this thesis contributes in providing an exergame for breast cancer patients. This chapter deals with the context, aims, methodologies and lastly the structure of this master thesis.

1.1 Problem Statement

According to the Global Cancer Statistics 2020, female breast cancer is the most commonly diagnosed cancer (11.7%) and its incidence is ranked first in 86% of 185 countries [138]. In fact, breast cancer incidence has risen about 0.3% per year since 2004 [29]. Risk factors include patient's age, female gender, familial susceptibility, hormonal factors, bad diet habits and obesity. Moreover it has been shown that regular physical activity (3-5 times/week) reduced the risk of breast cancer by 20%-40% [72]. The choice of treatment depends on the characteristic and extent of the tumor, however, surgical intervention remains the primary treatment of breast cancer. Other common therapies include chemotherapy, endocrine therapy, neoadjuvant therapy and radiation therapy [85].

Breast cancer survival depends on stage and grade of the tumor and receptor status. Due to improvements in treatment and mammography screenings, the survival rate of breast cancer patients increases. In fact, the majority of breast cancer survivors is older than 64 years [88]. A majority of survivors experience side effects, for example, fatigue, pain, neuropathy or cogitive deficits. [134]. Long-term effects include numbness, pain, limited range of motion (ROM), fatigue, lymphedema, cognitive impairment and hair loss, and may come from surgery or non-surgical treatments [121].

Rehabilitation is to help patients to restore their maximum physical, psychosocial, recreational, sexual, social, economic and vocational functioning, with regard to limits set by disease and treatments [86]. In a breast cancer survivorship care guideline [121], it is recommended to counsel survivors to engage in regular physical activity. In particular, inactivity should be avoided and patients shall return as soon as possible to normal activities after diagnosis. The recommended amount of exercising is 150 minutes if moderate or 75 minutes of vigorous intensity per week. The importance of physical activity is highlighted in various guidelines, for example [118, 134].

Prospective surveillance is to actively assess patients for physical impairments associated with cancer treatment, even in the absence of such impairments to foster early detection and intervention. As such, the prospective surveillance model for women with breast cancer presented by Stout et. al in 2012 [133] allows for preoperative rehabilitation, early postoperative reassessment and ongoing surveillance. It consists of two primary components, impairment identification and management; and health-promoting skills and behaviors. The model enables an earlier start of the rehabilitation than in traditional impairment-based models. Unfortunately, there is a lack of professionals in oncology to meet patients' needs [133].

Patients do not always get prepared for issues during survivorship [73] and are often surprised about long-term effects [6, 55]. Recent evidence shows that only 9% of cancer patients are referred to rehabilitation, while around 60% suffer from high functional morbidity. Reasons for missing rehabilitation service delivery may lie in a lack of awareness among both oncology providers and patients, inadequate integration of rehabilitation services into oncology care [134] or in failed patient-clinican communication [22]. Baseline assessments would further help notice treatment-related problems but are not often carried out [6]. There are also rehabilitation barriers from the patient side, for example, lack of motivation [78].

Games increase motivation and thereby tackle the problem of rehabilitation exercises being repetitive (and therefore often boring) by nature. Moreover, they can address characteristics of rehabilitation like goal setting, carrying out specific tasks or increasing difficulty according to the progress [116]. In *Exergames*, patients can exercise while playing a game. Besides the movements that are translated into game actions, the question of *how* an exercise has to be carried out is a key factor. As such, exergames offer the possibility to do autonomous rehabilitation at home [110].

1.2 Expected Results

The goal of the thesis is to elicit requirements of a technical solution supporting the rehabilitation of breast cancer patients/survivors in terms of exercising and its management in a pre- and postoperative setting and assess positive effects for patients. Research questions are as follows:
Firstly, **RQ1:** What are the requirements of health care professionals and breast cancer patients for a software solution that supports the management, tracking and execution of breast cancer rehabilitation?

Secondly, **RQ2:** Which exercises are suitable to be implemented in an exergame?

As stated in the problem description, the late start of rehabilitation appears to be a challenge. The application developed within the master thesis addresses this problem by enabling patients to assess their fitness preoperatively, to allow for a comparison to later stages of the patient journey (postoperative). In addition to that, the application allows for smyptom tracking. All in all, having an application for rehabilitation at hand may increase awareness so that patients may speak up sooner to their healthcare professionals about going on a funded rehabilitation program.

To tackle the lack of motivation in patients and the monotony of exercises, the developed application is implemented as an exergame. Furthermore, the app is configurable and therefore adapts to the situation of the patients.

The application was developed iteratively, which means that low- and high-fidelity prototypes will precede the fully functional application. A vital part was to determine suitable exercises for the exergame, supported by the domain expert.

Based on the requirements and constraints, it was analyzed what technology will be used for the implementation of the exergame. Different game editors were investigated. Especially Unity[1] is known for relatively easy game development and a broad community and was finally chosen.

1.3 Methodological Approach

The methodological approach can be described in four iterations, as can be seen in Figure 1.1.

The goal of the first iteration was to develop the initial prototype. For this, the following steps were required. Firstly, for acquiring stakeholders, healthcare professionals and patients were contacted whether they would join the project. Secondly, exploratory interviews [111] were carried out to elicit basic requirements, investigate the system context and to answer **RQ1**. Thirdly, the findings have been analyzed and were modeled and specified through requirements and use cases. Additionally, initial requirements were influenced by the literature. Finally, a mock-up was created which acts, together with requirements documents, as the first prototype and acted as a basis for feedback sessions.

For the second iteration, it was vital to define more details. An important part was to learn about rehabilitation exercises from domain experts in a qualitative manner. To answer **RQ2**, exercises were gathered and analyzed with regard to the planned game design and the assessed requirements and constraints. Using a framework for the definition of exercises within therapeutic exergames [110], each suitable exercise was thoroughly defined. Moreover, this iteration entailed UI considerations: a heuristic evaluation [99] was carried out, additionally, device-specific design guidelines were investigated.

[1] `https://unity.com/`

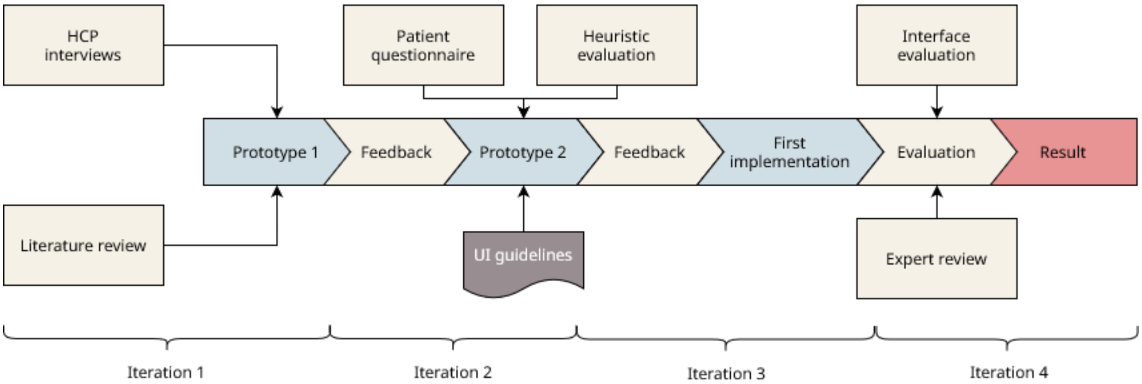


Figure 1.1: Overview of the methodological approach that was followed.

Furthermore, a questionnaire for patients was created and served as another input for answering **RQ1**. All these methods enabled the improvement of the previous prototype: A more detailed mock-up was created, which again was subject to further reviews. Also, requirements and use cases were updated according to the work done within the second iteration.

In the third iteration, the prototype was finally implemented. The implementation was influenced by the prioritization of requirements.

In the last fourth iteration, an evaluation was carried out. On the one hand, an interface evaluation [100] provided user feedback and was carried out in the form of a moderated usability study. On the other hand, feedback from experts was collected. The findings were prioritized and in most cases corrected. Both evaluation methods contributed to answering research questions **RQ1** and **RQ2** through validation. The results in the final implementation, accompanied by requirements, use cases and preceding mock-ups and drafts.

In all iterations, work depended on other persons' availability and motivation. Therefore, when the project time scope depended on the response of a stakeholder, the time was used to write the thesis, document items that have been worked on and to plan the next steps.

1.4 Structure

The thesis is composed of four main parts.

Chapters 2 and 3 deal with the theoretical background of the thesis and the environment it is embedded in. Basic knowledge about breast cancer but also technical topics like requirements- and usability engineering are addressed. Additionally, the terms *serious game* and *exergame* are explained.

Chapter 4, is concerned with the state of the art within the scope of this thesis. Selected examples within the fields of breast cancer, exergaming and digital interventions in healthcare are presented.

Chapter 5 describes the results of the thesis by explaining each of the four iterations thoroughly which led to the creation of the final result. The final result will be presented, underpinned by screenshots and use case descriptions. Additionally, the planning, execution and results of the evaluation are described.

Lastly, chapter 6 discusses the results, limitations and future work. Additionally, chapter 7 summarizes the findings of this master thesis.

CHAPTER 2

Medical Basics

This chapter deals with the theoretical basis of medical-related topics connected to this master thesis.

The first section 2.1 gives an overview of cancer in general and its biology, diagnosis and treatment. Next, breast cancer is explained, orienting on the typical breast cancer patient journey as displayed in Figure 2.1. Firstly, section 2.2 deals with topics in the field of preoperative breast cancer, prevention and risk factors, classification and staging of breast cancer and surgical therapy. Secondly, section 2.3 describes topics relevant after the surgery, therapy options (chemotherapy, radiation therapy etc.), side effects of survivors and rehabilitation barriers and recommendations. The last section 2.4 describes activities within the field of rehabilitation taking place throughout the patient journey, especially before any treatments are administered.

2.1 Cancer

Cancer (carcinoma) is a general term referring to a group of about 200 diseases. The common characteristic they share lies in their unregulated growth to other parts of the body [41]. Therapy options vary depending on patient and tumor factors like the age of the patient and size of the tumor [67].

This section provides an overview of the basics of cancer, in particular its epidemiology, causes and development, diagnosis and staging as well as treatment options.

2.1.1 Epidemiology

Epidemiology comes from Greek and can be directly translated as 'upon people'. It studies the factors influencing disease and health occurrence and distribution in the population [140].

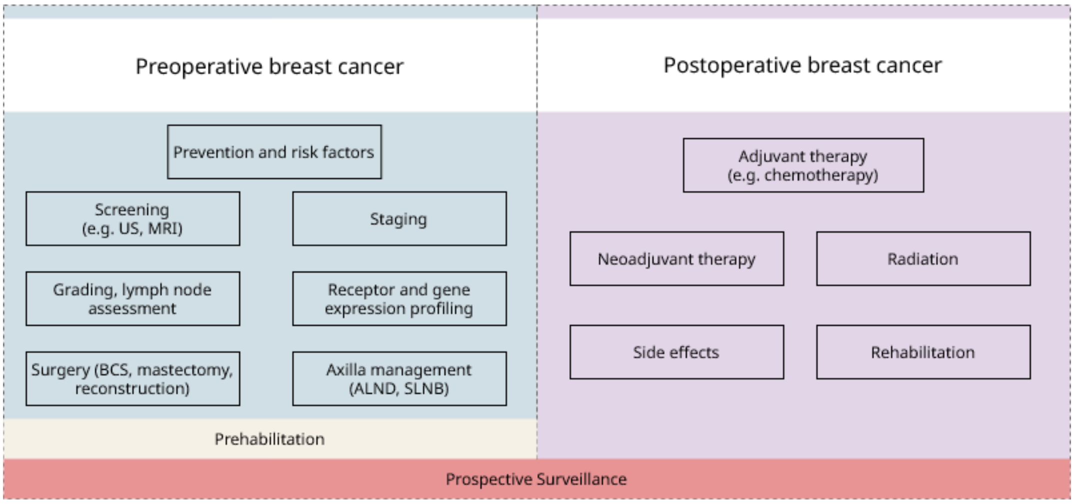


Figure 2.1: Overview of breast cancer journey steps within breast cancer management, based on [85].

The incidence rate describes the number of new cases of a particular disease (e.g. cancer) in a population during a certain period divided by the total number of persons per year (e.g. 100,000). Mortality rate is defined as the number of deaths from a particular disease in a population during a certain period divided by the total number of persons per year (e.g. 100,000) [140].
In 2020, the incidence rate for all cancers in men was 222 per 100,000 and for women 186 per 100,000. In men, prostate cancer had the highest cancer incidence in 112 countries and accounts for 7.3% of total cases. In women, breast cancer had the highest incidence in 159 countries and accounts for 11.7% of total cases. In 2020, the mortality was higher for men (120.8/100,000) than for women (84.2/100,000). Lung cancer is the leading cause of cancer deaths, accounting for 18% (total) [138].

In the US, the number of cancer survivors increases. On January, 1st of 2019, there were living about 17 million Americans with a history of cancer. The majority of survivors was diagnosed more than 4 years ago. Almost two-thirds of cancer survivors are 65 years old or older, whereas there is to say that this varies by cancer type [88].

2.1.2 Biology

Humans are comprised of millions of cells. Each cell may undergo malignant changes, which leads to the development of a carcinoma. When malignant cells replicate, they grow irregularly and infiltrate the tissue surrounding them (metastases). This can occur when normal cell mechanisms fail or become disrupted [41]. The following subsection provides information on the functioning of a normal in comparison to a cancer cell.

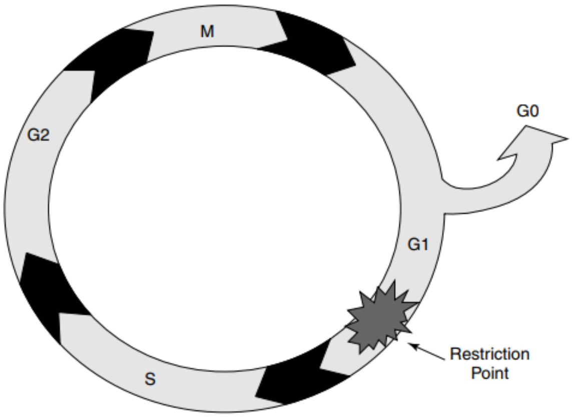


Figure 2.2: A visual expression of the cell cycle, which consists of 4 phases G1, S, G2 and M. G0 is the exiting of the progress, also known as quiescence [104].

The normal cell Cellular reproduction is to pass genetic information to daughter cells. However, the regulation of cell division is vital for normal growth and development. The cell cycle can be described in two parts.
Firstly, in the interphase, the cell grows and is preparing for dividing by doubling and copying the DNA chromosomes. This phase consists of sub-phases called G1 (first gap), S and G2 (second gap). Briefly, a cell is prevented from going from G1 to the S phase when not all conditions for replications are met (restriction point). Then, the G1 phase is delayed. Otherwise, when conditions are met, the DNA is replicated in the S phase. Afterward, G2 is the phase where it is ensured that the DNA is not damaged and is appropriate for the daughter cells. Secondly, during mitosis (M phase), the nucleus of the cell is divided, and the DNA is segregated. The result of this phase is the two daughter cells. As high precision is needed for this process, it is regulated by an independent control system, which consists of checkpoints. They act as a timer because they activate each event at the appropriate time (in the correct order) and provide enough time for the completion of an event [104]. A visual depiction is displayed in Figure 2.2.

As humans produce 50 to 70 billion cells in one day, the rate of cell death plays also an important role. The programmed cell death is called apoptosis, while in the process of necrosis, the cell is injured and swells and bursts. The difference between them is that apoptosis is more controlled - the cell shrinks and condenses instead of exploding. Moreover, no toxic content is released. Apoptosis is irreversible and follows the all-or-nothing phenomenon [104].

The cancer cell In simple words, the development of cancer has its origin in a cell that does not respond to regulatory signals anymore. The regulation is altered and results in fast and/or excessive cell division. When cells practice cell division uncontrolled, a growing mass of abnormal cells occurs, which is called neoplasm. When this mass is clustered together, it is called benign and noncancerous, because it is incapable of invading other tissue [104].

Hanahan and Weinberg [54] describe the acquired capabilities of cancer. Cancer cells generate many growth signals for them on their own (self-sufficiency in growth signals) and are insensitive to anti-growth signals at the same time. As a consequence, they have limitless replicative potential. Moreover, cancer cells invade tissue and form metastasis. Thirdly, most, but possibly all, cancer cells acquire resistance toward apoptosis. Fourthly, cancer cells seem to sustain angiogenesis, which is to form new blood vessels in order to be nourished with nutrients and oxygen.

2.1.3 Causes of Cancer

The incidence of cancer continues to rise. Possible explanations for this include increased wealth, urbanization and a long life. People survive longer, infectious diseases or accidents are often not life-threatening, so cancer may be developed in later years. Due to wealth, people consume alcohol, tobacco or convenience food, and develop obesity, which are all considered as risk factors for developing carcinoma. Other factors are viruses and past exposure to ionizing radiation [41, 140].

There are also internal predisposing factors like immune conditions and inherited mutations (change of sequence in the genome), which act together with aforementioned external factors to initiate or assist in the progression of neoplasms. A single change in genetics may increase the risk of cancer but is not decisive for malignancies. In fact, its development depends on multiple genetic alterations.
Sporadic cancer is caused by mutating somatic cells. It accounts for the majority of cancers and is often developed at late ages. An example is high exposure to the sun which can lead to skin cancer. Several genes are usually mutated when having sporadic cancer and are then used as parameters or markers in therapy and prognosis.
Hereditary cancer is caused by inheriting cancer-causing mutations from the parents and occurs rather at an early age. The person is born with this change in a single copy of a gene. It is to note that they have one working copy so that an inherited mutation is not guaranteed to develop a malignant tumor [104].

2.1.4 Diagnosis and Treatment

It is vital to determine the stage of the tumor at the time of diagnosis. It influences the prognosis and treatment, based on previous experiences with similar stages. The stage plays also a role in clinical trials and research. Another important factor in determining the extent of cancer is to evaluate the results of the treatment.
There are many staging systems, however, the American Joint Committee on Cancer (AJCC) TNM staging system is considered the most useful one. It classifies cancer by three factors TNM: size/extent of the primary tumor (T), regional lymph node involvement (N) and presence of distant metastasis (M). For each of them, there are categories, most often expressed as numbers (e.g. T1). For each tumor, the criteria for the staging are defined separately, because, for example, prognostic features differ [53].

The combination of each factor results in assigning the present cancer to a stage group. The classification takes place before treatment (clinical staging, cTNM) and after surgery (pathological staging - pTNM) [52].

In general, the following approaches aim to treat malignant tumors: surgery, radiation, drug therapy, palliative care and integrative medicine. Which approach is followed depends on the original location of the tumor, stage and type of cancer and lastly biological factors (e.g. presence of receptors) [104].

2.2 Preoperative Breast Cancer

Female breast cancer is 2020 the most commonly diagnosed cancer with an amount of 11.7% of all diagnoses, estimating the number of new cases to 2.3 million. Additionally, it exceeds the incidence rates of other cancers by far. Further, it is to note that the incidence rates are about 90% higher in transitioned countries than in transitioning countries [138].

The breast consists of fat, connective tissue, milk ducts, lobules, the nipple-areola complex and skin [40]. The terminal duct lobular unit (TDLU) is the functional unit of the breast and changes according to hormone levels. The TDLU consists of the terminal duct and its lobules. Several terminal ducts join to form a large duct that has a dilatation (lactiferous sinus) before they end in the hyperpigmented nipple [97].

This section gives information alongside the preoperative breast cancer journey including surgical treatment.

2.2.1 Prevention and Risk Factors

Effective prevention strategies are necessary to tackle the burden of breast cancer. Some risk factors provide the option to modify people's behavior by implementing such strategies through health education and policy [25]. Other prevention methods are screenings, chemoprevention (for example, blocking DNA damage) and biological prevention (also called monoclonal antibodies) [136].

As defined by the National Cancer Institute, a risk factor is „something that increases the chance of developing a disease"[93]. A protective factor is associated with a lower risk. However, cancer risk factors include for example certain behaviors, while there are also risk factors that cannot be controlled like age or genetics. Both risk and protective factors are identified in epidemiology studies [92]. The following summarizes (non-)modifiable risk factors of breast cancer.

Non-modifiable Risk Factors The patient's age is a basic factor. In fact, breast cancer is significantly less frequent in women younger than 45 years. The disease is predominantly found in women, men contribute 1% to all diagnosed breast cancers [72].

Many risk factors for breast cancer lie in the exposure to ovarian hormones, estradiol and progesterone, over the lifespan. These two hormones drive cellular proliferation (growth), which in return provides the opportunity for errors to develop into breast tumor [5]. As a consequence, the menstrual cycle plays a crucial role in risk calculation. It is known, that early menarche and late menopause increase the risk of breast cancer development [72, 5].

Pregnancy also influences the risk of breast cancer. In an early work by MacMahon et al. [84] in 1970, it was estimated that the risk for women who were younger than 20 at the time of the first confinement is half that for women, who did not give birth at all. Also, a more recent paper summarized that early pregnancy is a protective factor [72].

Sun et al. [136] summarized the genes related to breast cancer. Breastcancer Associated Gene 1 (BRCA1) and Breast Cancer Associated Gene 2 (BRCA2) both encode tumor suppressor proteins. BRCA1 is situated on chromosome 17q21 and its deficiency leads to a dysregulation of the checkpoint, genetic instability, abnormal duplication and apoptosis (see 2.1.2). BRCA2 is located on chromosome 13q12. Its task is to regulate the repair of DNA breaks. It is to note that BRCA1/2 mutations are responsible for about 20% to 25% of hereditary breast cancer cases and are inherited autosomal dominant [136].

Modifiable Risk Factors In addition to reproductive factors, lifestyle-related behaviors are also relevant. Bad dietary habits (i.e. high in fat) and obesity may promote the malignant transformation in mammary gland cells [72]. Furthermore, a literature review by Carmichael and Bates [19] found that the majority of reviewed studies observed a positive association between obesity and tumor size.

Moreover, regular physical activity (3-5 timers per week) reduces breast cancer occurrence by 20-40% [72]. In a literature review by Lynch et al. [83] there was a 25% average decrease in breast cancer risk among physically active women, compared to the least active women, in the reviewed studies. It was also observed that a further risk reduction is possible by prolonging the physical activity.

A reanalysis from 2002 [26] suggests that each additional 10g alcohol intake per day increases the relative risk of breast cancer by around 7%. The cumulative breast cancer incidence for an age of 80 years was estimated to be 8.8 per 100 women for non-drinkers and 10.1 per 100 for the consumption of two alcoholic drinks per day [26]. Recently, an American Cancer Society (ACS) guideline stated that limited evidence suggests that „there is no association of alcohol intake and overall mortality in breast cancer survivors [...]“[118].

2.2.2 Diagnosis

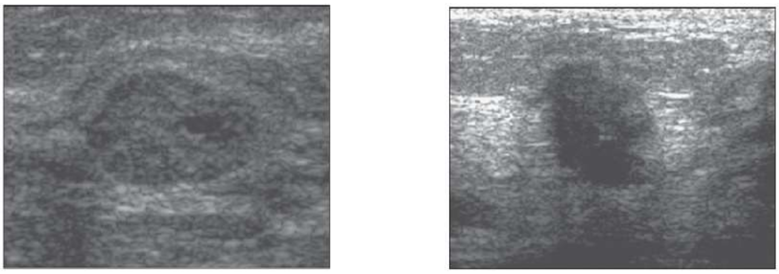
The biennial update of the American Cancer Society stated that about 80% of breast cancer is diagnosed in the age group 50+ years. Additionally, 1 in 8 women will be diagnosed with invasive breast cancer in their lifetime, while the probability of diagnosis is the highest in their 70s [29]. Similarly, an estimate by the European Cancer Information

System revealed that the age group 45 to 69 had the highest number of new cases in 2020 across EU-27 [32].

Screening Programs

Screening is to rapidly apply tests, examinations and other techniques to identify unrecognized diseases presumably [127]. Early detection is vital for increasing survival because tumor metastases are responsible for over 90% of cancer deaths [136, 138]. The World Health Organization (WHO) recommends population-based mammography screening programs for asymptomatic women having an average risk for breast cancer. For (relatively) strong health systems the recommended interval for ages 50 to 69 is two years. This interval showed to balance harms and benefits best, resulting in a breast cancer death reduction of 16% in the mentioned age group. In other age groups, the screening program is not highly recommended, as it may yield to higher false-positive results. For weak health systems, clinical breast examination is recommended [150].

Figure 2.3 depicts the difference between benign and malignant masses in an ultrasound image.



(a) Benign mass (b) Malignant mass

Figure 2.3: Masses on ultrasound: benign mass (a) is a fibroadenoma with oval shape, malignant mass (b) is an invasive ductal carcinoma irregularly shaped [77].

Diagnostic Imaging Mammography uses X-rays and is able to find breast cancer before patients feel a lump. Mammography may reduce mortality but is also known for causing overdiagnosis and overtreatment. This method of screening could be a source of harm and favors the detection of slow-growing tumors. Therefore, survival after a screen-detected cancer diagnosis is very high [51]. Although mammography has a limited sensitivity towards dense breast tissue, it is still the gold standard when it comes to screening in the general population.
Supplemental to mammography, ultrasound and Magnetic Resonance Imaging (MRI) is used, which can detect non-palpable masses even in dense breast tissue [127].
As summarized by Morrow, Waters and Morris [91], MRI has a higher sensitivity for breast cancer detection than mammography. There is strong evidence that BRCA mutation carriers and women with suspected genetic mutation benefit from MRI. Figure 2.4 displays malignant masses in an MRI image.

Figure 2.4: Sagittal breast MRI with an abnormal lymph node (right) and two adjacent malignant masses (left) [77].

Classification and Staging

Breast cancer can be divided into three main groups, which are based on histological and molecular properties:

- ER^+/PR^+: Expression of hormone receptor (HR), that is estrogen or progesterone receptor
- $HER2^+$: Expression of human epidermal receptor 2
- ER^-, PR^-, $HER2^-$: Triple-negative breast cancer (TNP) [3]

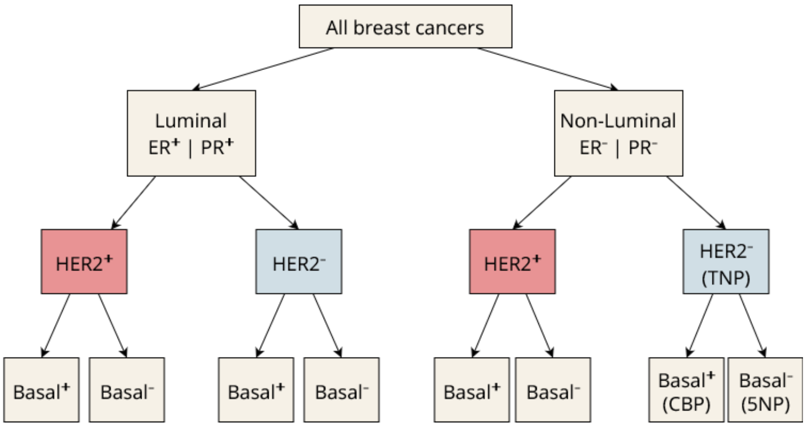


Figure 2.5: Overview of the classification of breast cancer. Figure based on [7].

In particular, tumors in the first group are called luminal, the others are non-luminal. Additionally, the expression of basal markers, cytokinase ($CK5/6$) and epidermal growth factor receptor (EGFR) is used to distinguish types of breast cancer further. Moreover, TNP tumors can be further divided into firstly, 5-negative phenotype (ER^-, PR^-,

$HER2^{-}$, $CK5/6^{-}$, $EGFR^{-}$) and secondly, core basal phenotype (CBP), although it is to say the clinical relevance from this distinction has been questioned previously [7]. Figure 2.5 depicts this classification.

Sun et al. [136], summarizing various papers, stated that HER2 is found to be overexpressed in about 20% of primary cancers, while overexpression of EGFR was detected in more than 30% of inflammatory breast cancer, which is a very aggressive form. Additionally, EGFR-positive cancer has a poorer prognosis than EGFR-negative tumors.

Staging During initial diagnosis, staging is performed which determines the severity and extent of the breast cancer. Moreover, prognosis as well as recurrence and mortality risks are estimated in addition to defining individual care for the patient. The staging influences also the assignment to clinical trials. The TNM system (see 2.1.4) for breast cancer considers primary breast cancer size, its spread to lymph nodes and its spread to other distant sites. When this is assessed, the breast cancer is assigned to one of five stages [105]. An overview is displayed in Table 2.1.

Stage	T N M Classification
Stage 0	Tis N0 M0
Stage I	T1 N0 M0
Stage II	IIA: T0/T1 N1 M0 | T2 N0 M0
	IIB: T2 N1 M0 | T3 N0 M0
Stage III	IIIA: T0/T1 N2 M0 | T2 N2 M0 | T3 N1/N2 M0
	IIIB: T4 N* M0
	IIIC: T* N3 M0
Stage IV	T* N* M1

Table 2.1: List of TNM classifications and their assigned stage. Stage 0 refers to ductal carcinoma in situ (DCIS) and is a non-invasive type of cancer, which is located in place, in situ. Stage I to III are called invasive, while stage IV is metastatic [94]. Symbol (*) means any. Table based on [127].

2.2.3 Surgical Therapy

Surgical intervention is the primary treatment of local and regional breast cancer. In general, there are breast-conserving and non-breast-conserving approaches [85].

During the breast-conserving surgery (BCS), an image-guided localization of the tumor is required. For optimal cosmetic outcomes, the incision placement is a key factor. When the tumor is excised - with normal tissue as borders - the specimen is sent to the pathology, where it is determined whether a re-excision is necessary. In comparison, mastectomy has many forms and may be performed with or without breast reconstruction. A skin-sparing mastectomy preserves the patient's own skin and therefore optimizes cosmetic outcomes.

Nipple-areolar-complex-sparing mastectomy is carried out only in certain patients that meet a set of criteria, for example, tumor located $> 2.5cm$ away from the border of the areola. During a total mastectomy, breast tissue and the nipple-areolar complex are removed, but no lymph nodes. When lymph nodes of level I and II are removed too, this is called a modified radical mastectomy. The radical mastectomy is similar to this but is rarely performed because there is a lack of impact on survival and usually heavily deforms the breast [127].

For DCIS patients, the majority is eligible for breast-conserving therapy. For early-stage breast cancer, factors like tumor-size-breast-size ratio, patient preferences, radiation therapy tolerance and presence of multicentric disease are taken into consideration. Typically, patients with a tumor size $<= 4cm$ get breast-conserving therapy, which is always followed by adjuvant radiation therapy (see section 2.3.1 below). Larger tumor sizes may point to mastectomy because of better cosmetic outcomes. Patients with those larger tumors who wish for breast conservation are candidates for neoadjuvant or adjuvant therapy to decrease tumor size. The presence of multicentric disease usually requires mastectomy, because of the increased recurrence risk after breast-conserving therapy. Patients with locally advanced breast cancer usually undergo a form of mastectomy but sometimes it is also an option to apply neoadjuvant chemotherapy followed by breast-conserving therapy [127].

Axillary staging provides information about the axillary nodal status and delivers therefore important prognostic information while contributing to tailoring adjuvant therapies. For example, lymph node involvement in early breast cancer leads to a recommendation for chemotherapy. When a malignant lymph node is detected, this information is used by surgeons to decide whether to proceed to an axillary lymph node dissection (ALND) or sentinel lymph node biopsy (SLNB). The execution of ALND is associated with functional deficits (see section 2.3.2 below). When patients had undergone ALND for staging of axillary nodes, many had no nodal metastases and therefore suffered from the morbidities without an oncological benefit. In comparison, the SLNB is based on the concept that there is an order of lymph nodes and that specific lymph nodes (sentinel lymph nodes) drain the breast first [127]. The introduction of the SLNB was a major advance and replaced the conventional ALND. Using SLNB, there is a lower risk of lymphedema than with ALND (less than 2%-3% vs. 15%-20%) [85]. Additionally, it was shown that patients who undergo SLNB alone have an improved quality of life and a decreased morbidity compared to ALND patients [127].

2.3 Postoperative Breast Cancer and Survivorship

In 2020, breast cancer caused 685.000 deaths, accounting for 1 in 6 cancer deaths, while the death rate dropped by 40% from 1989 to 2017 [138]. Improvements in treatment and increased mammographic screening led to an increase in the 5-year relative survival rate from 79% (diagnosed 1984-1986) to 91% (diagnosed 2008-2014). Biological factors like stage, tumor grade and hormone receptor status influence breast cancer survival. As estimated in the Cancer Treatment and Survivorship Statistics, about 3.8 million women are living with a history of invasive breast cancer in the US. Notably, more than 150.000 are living with metastatic disease. About 64% of breast cancer survivors have an age of over 64 years [88].

2.3.1 Medical Oncology

The choice of therapy depends on the tumors' characteristics and extent. For early-stage breast cancer, lymph node involvement, tumor size and ER/PR/HER2 status are relevant. For stage IV patients, the locations of metastatic areas and receptor status are factors to be considered [85]. The following introduces the most common forms of therapy.

Chemotherapy Chemotherapy can generally be administered as adjuvant or neoadjuvant therapy. Adjuvant systemic therapy is primarily interesting for early-stage patients. For stage I patients it is to say that the benefits are small because the risk for recurrence and metastases is low. When the presented breast cancer is not operable (for example in locally advanced cancers), neoadjuvant systemic therapy may improve the situation and make tumors operable later, although it can also be used to observe the tumor response in order to get more information (e.g. prognostic information) [30]. Indications for neoadjuvant therapy include tumor size larger than 5 cm in patients desiring breast conservation, inflammatory or locally advanced breast cancer or tumor fixed to the chest wall [85]. In terms of administration, most chemotherapy is given in cycles with treatment, following a period of rest so that the body can recover. The drugs may be liquids that are administered into a vein or subcutaneously, or pills that are swallowed [95].

Radiation therapy Radiation therapy is given alone (invasive cancer), before or after surgery to kill or shrink breast cancer cells or it is used as supportive care to reduce pain and discomfort [94, 95, 96].
It was shown that patient survival and long-term mortality from breast cancer are comparable for mastectomy and for BCS + radiation. Moreover, the administration of radiation after BCS leads to a small survival advantage in patients with invasive breast cancer. In addition, radiation therapy plays a role when considering regional recurrences in patients with positive lymph nodes. For women who have undergone mastectomy and have a medium or high risk of local-regional recurrence, radiation is recommended for adjuvant treatment [85].

Endocrine therapy Endocrine therapy is recommended for a minimum of 5 years and is suitable for patients with ER^- or PR^+ receptors [85]. It targets hormones estrogen, progesterone, luteinizing hormone-releasing hormone (LHRH) and androgen. By that, the growth of tumors is slowed down or the tumor is even shrunken. It is also applied to reduce the risk of recurrence [94, 95, 96].

2.3.2 Side Effects

Due to cancer treatment and side effects, the majority of cancer patients and survivors experience impaired physical and cognitive function [134]. In 2012, it was reported that women are often surprised of side effects continuing after the treatment and persisting for several years. The physical symptoms may be a constant reminder of breast cancer and fuel the fear of recurrence [6].

Side effects may impact the blood (thrombus), bones (fractures, pain), hair (loss), diet (diarrhea, eating habits) or mental health (depression) and are influenced by the length of treatment, drug type and dose and the person. Side effects range from unpleasant to harmful but can also be very serious. When side effects occur months or years after the diagnosis or after the end of the treatment, there are often called late effects [95]. The reported consequences from side effects include problems with social and work commitments and reduced participation in leisure, communication and activity engagement [73].

To optimize cancer care, monitoring and management of psychological and physical symptoms of patients is required, as clinicians need to understand needs and disease experiences. Patient-reported outcomes (PROs) are standardized questionnaires to monitor the well-being and health markers and as such a tool attempting to bridge the gap between clinician understanding and patient experience. The reporting of psychosocial issues, physical symptoms and quality of life informs healthcare professionals on the impact of cancer and its treatment and allows for acting on symptoms [152]. In particular, symptoms like anxiety, worry, nausea, fatigue, pain or physical difficulties may be assessed. Moreover, the use of electronic PRO (ePRO) systems does not require staff to type in data. Instead, patients complete questionnaires and their response is automatically scored and available to clinicians in an easily interpretable form [4]. A systematic review by Yang et al. [152] summarizes the influence of PROs on patient-clinician communication. The authors found that the majority of investigated studies reported increased communication after PRO implementation. Other positive effects were identified for symptom awareness, consolidating consultations and inter-professional communication. Barriers to PRO implementation include a lack of patient/clinician acceptance and the use of a difficult PRO collection interface. Yet it is unknown whether the usage of PROs improves clinical outcomes [152].

The following describes frequent side effects in relation to this master thesis.

Lymphedema The Center for Disease Control and Prevention defines lymphedema as a „swelling due to build-up of lymph fluid in the body [...] which can be caused by cancer or by cancer treatment“[21].
Risk factors include axillary lymph node dissection, overweight or adjuvant therapy. Although not life-threatening, lymphedema usually decreases the quality of life. In fact, it also causes other conditions like frustration, pain, decreased physical activity and

mobility, impaired function or fatigue and stress. It is estimated that lymphedema is developed in more than one in five breast cancer survivors (status 2021) [28].

Upper extremity dysfunction According to a Breast Cancer Survivorship Care Guideline by the ACS and American Society of Clinical Oncology (ASCO) from 2015 [121], difficulties with the upper extremity include decreased range of motion (ROM) (up to 50%), adhesive capsulitis (so-called frozen shoulder) accompanied by stiffness and pain the shoulder joint, rotator cuff injury and axillary web syndrome, where pain and tightness appear as a corded rope in the skin of the inner arm. Other musculoskeletal symptoms like upper limb weakness (up to 23%) and numbness (29%-81%) are also prevalent. These abnormalities may impact employment and lead to a decrease in the ability to perform daily activities [121].

Neuropathy and pain Neuropathy accompanied by burning pain, tingling and numbness was reported in 30% to 40% of patients and is common after surgery and treatment with certain chemotherapy regimens. Reports showed that 25% to 60% of breast cancer survivors suffer from chronic pain, resulting from surgery, chemotherapy, radiation therapy or endocrine therapy, which negatively impacts the quality of life [121]. As predictors young age and ALND have been suggested [131, 147].

Fatigue Fatigue is a persistent feeling of tiredness and lack of energy [154] which cannot be relieved by sleep or rest. It restricts daily activities and therefore changes normal activity patterns [6]. Fatigue may occur as a result of chemotherapy or radiation therapy but are generally very common among patients who were treated for cancer. In fact, the estimated prevalence is 28% to 91%. Treatable causes include cardiac- or thyroid dysfunction and anemia. Other factors that may impact fatigue are mood disorders, pain and sleep disturbances [121].

2.3.3 Rehabilitation

Cancer rehabilitation is the process of helping patients to restore maximum physical, psychological, social, recreational, economic, sexual and vocational functioning [86].

According to [134], rehabilitative intervention is recommended when impairments already minimize the ability to function, for instance, pain, fatigue, cognitive deficits, neuropathy or other side effects. Other indications are lymphedema, sexual dysfunction or musculoskeletal impairment. Furthermore, it was stated that several guidelines recommend referral to rehabilitation at the onset of symptoms, considering the treatment schedule [134].

Generally, it is to note that rehabilitation interventions should evolve over time, according to the progress or lack of progress of patients. Patients shall be empowered to detect functional problems early and to practice self-responsibility [23].

Problems and Barriers

A guideline published by the ACS[134] found that more than 60% of breast cancer survivors suffer from high functional morbidity whereas only 2-9% are referred to rehabilitation services. The authors locate a disparity between use of rehabilitation services and measurable morbidity, so that patients may not get the care they would need to support their functional needs. The reasons for this may be „lack of awareness among oncology providers as to the benefit of rehabilitation services, inadequate integration of rehabilitation services into oncology care, as well as a lack of awareness among patients about the availability and benefit of these services“[134]. Additionally, a lack of specialized healthcare professionals and rehabilitation services in cancer centers have been identified as a problem in this field [23].

Cheville et al. [22] conducted a study to investigate patient-clinician communication regarding functional issues caused by cancer. The documentation by clinicians referred to about 50% of patients' symptoms, 37% of their signs and 6% of their functional issues. The authors suggest that missing rehabilitation service delivery may come from a lack of patient-clinician communication [22].

Miedema and Easley [86] conducted a study to assess breast cancer rehabilitation barriers in survivors under the age of 50 in Atlantic Canada. Systemic barriers included accessibility and availability of services, which showed to be particularly challenging in rural areas. Moreover, costs and travel issues were reported to be barriers. In terms of personal barriers, participants reported that they had already enough to do to get back to normal or did not want to spend any more financial resources. Family or household responsibilities and tiredness from doctor appointments were other reported issues [86].

In a study by Kabak et al. [70] exercise barriers of female breast cancer survivors with lymphedema included being fatigued (65% of participants) and having other responsibilities (60% of participants).

Interventions

There is a variety of interventions available to tackle breast-cancer-related symptoms (side effects) including but not limited to lymphatic drainage, compression therapy, massage, music therapy or yoga [134].

Growing evidence suggests that physical activity, healthy food consumption and avoiding obesity after completing the cancer treatment improve long-term survival. Moreover, there is sufficient evidence stating the beneficial effect of exercising during cancer treatment on several aspects of quality of life. Nevertheless, it is important for cancer patients to seek medical evaluation to discuss an individual exercise program during or shortly after the treatment. In fact, both pre- and postdiagnosis (recreational and total) physical activity was repeatedly found to reduce the risk for breast cancer-specific and all-cause mortality [118].

According to an ACS and ASCO guideline from 2015 [121], primary care clinicians should counsel their patients to (excerpt from category Health Promotion):

- achieve and maintain a healthy weight and increase physical activity to promote and maintain weight loss
- engage in regular physical activity while avoiding inactivity
- return to normal daily activities as soon as possible after the diagnosis
- include strength training at least 2 days per week

About 32% of cancer survivors meet the recommendations for physical activity [121]. Generally, the recommended amount of physical activity is 150 minutes of moderate- or 75 minutes of vigorous-intensity per week, whereas especially activities like walking, stretching, aerobic and resistance training are recommended [118, 134, 121].
Ideally, an individualized exercise prescription is influenced by an assessment of physical fitness (e.g. cardiorespiratory fitness, endurance, flexibility, body composition), although to start low-intensity training like walking, no assessments are required [16].

As stated in [121], physical activity shall be recommended to patients to reduce fatigue and to help patients feel physically and emotionally better and for musculoskeletal health, including tackling pain. Moreover, it was stated that neuropathy was also improved by physical activity.

For patients at risk or diagnosed with lymphedema, exercise is vital and should include stretching to maintain or increase range of motion, weight lifting (resistance training), aerobic exercise and decongestive exercises combined with compression [28]. Moreover, there is a recommendation for obese or overweight individuals. Other areas where physical activity helps include cognitive functioning and hormone-related symptoms [134].

2.4 Prospective Surveillance

Early interventions and surveillance, as well as addressing disabilities before, during and after cancer treatment is recommended. In survivorship it is crucial to identify impairments and introduce interventions in order to minimize functional loss as soon as possible [27].

Oncological prehabilitation is defined as a process occurring between cancer diagnosis and the start of acute treatment which includes psychological and physical assessments. The goal is to establish a baseline for the functional level, identification of impairments and providing targeted interventions. Before treatments of any kind, patients are usually in good physical condition and can assess baseline levels of function that will become targets for post-treatment phases. Moreover, patients who do prehabilitation may feel more in control of their health and treatment outcomes, which may lessen the anxiety of treatments. However, as of 2017, the field was understudied and efforts to improve pretreatment well-being were just about to start [89].

Some NHS hospitals in the UK offer a prehabilitation program (status 2021). According to the *Cancer Research UK Website*, this program consists of four stages screening, assessment, intervention and monitoring. In the screening, weight and physical and mental health are obtained. Next, the results are assessed to refer patients to the correct experts, or if more information is required, carried out other tests like a six minute walk test (6MWT). The intervention shall help patients to cope with and recover from the treatment. There are different programs (universal, targeted, specialist) for a variety of situations. Then, the progress in the prehab activities is monitored in terms of changes, impacts and if an adaption of the program is needed [17].

Prospective surveillance is a proactive approach to examine and assess patients periodically during and after treatment, in order to detect and react to (for cancer typical) physical impairments early [133]. In particular, a Prospective Surveillance Model (PSM) for breast cancer physical rehabilitation was proposed by Stout et al. [133] in 2012, which has the following goals: Surveillance promotion, education of patients, interventions initiation and lastly, promotion of weight management behaviors like physical activity or exercise. The model can be applied throughout the perioperative setting of the breast cancer patient journey and is mostly suited for newly diagnosed patients in stages 0 to III [133].

Phase	Description
Preoperative Rehabilitation	• Baseline creation: ROM, volume, strength, body weight, physical activity/exercise/function/impairments, fatigue • Education: Postoperative activities, adverse effects, weight control
Postoperative Rehabilitation	• Reassessment: Repetition of baseline test/measures • If limitations are present: Initiation of rehabilitation • Education: Healthy behaviors (e.g. weight control)
Ongoing Surveillance	• Reassessment: Repetition of baseline test for detecting changes/impairments • If limitations are present: Initiation of rehabilitation • Ongoing education: Foster awareness and continued healthy behaviors

Table 2.2: The prospective surveillance model consists of three phases: pre- and postoperative rehabilitation which takes place before and after surgery (BCS, mastectomy, with or without reconstruction) and the ongoing surveillance which takes place in each follow-up visit [133].

Within the model, there are three crucial phases: pre- and postoperative phase and the ongoing surveillance phase (see also Table 2.2).
Ideally, rehabilitation starts at the time of diagnosis to assess the baseline functional

performance status and for comparison with re-assessments [132]. In particular, the baseline should assess ROM, volume and strength in extremities, body weight, physical activity/exercises and function as well as physical impairments or fatigue. In this phase, it is also recommended to educate the patient about the postoperative activities, adverse effects, weight control and reintroduction of activities during and after the treatment.
Within the first month of surgery, a reassessment should take place, where baseline tests are repeated and patients are being educated on healthy behaviors (e.g. weight control, return to activity/exercises). This is the occasion to initiate rehabilitation if functional limitations are present. Moreover, an individual exercise program should be prescribed, that can be followed during cancer treatment. The goal is to prevent limitations and to improve function.
In each follow-up visit, baseline tests are repeated to detect changes and impairments. Based on that, rehabilitation may be prescribed. The visits may also be in coordination with the treatment. Ongoing education is important to raise patients' awareness about potential late effects. Additionally, healthy behaviors are continued to be encouraged [133].

Applications of prospective surveillance in breast cancer patients showed the following results.
Zhang et al. [154] divided 300 perioperative breast cancer patients evenly into a control (routine nursing) and a model group (prospective monitoring nursing). The results were that the model group performed better in the disability of arm-shoulder-hand (DASH)) score. The difference regarding upper limb lymphedema was not significant, although a recently published research article by Rafn et al. [115] found that prospective surveillance reduces the risk of chronic arm lymphedema of breast cancer patients.
Singh et al. [128] conducted preoperative education, prospective monitoring, and early physiotherapy on a group, resulting in a maintained shoulder range of motion while the comparison group showed a decreased range at 7 months after surgery. Less arm morbidity was measured in the experimental group, but this was not significant.

CHAPTER 3

Technical Basics

In this chapter, the technical basis is explained. Requirements engineering as a set of activities to develop and understand constraints and requirements from stakeholders is presented. Then, the basics of the related discipline of usability and user-centered design is explained, eventually followed by the definition of serious games and exergames. Here, engines to create games and methods to design games are discussed.

3.1 Requirements Engineering

Before developing a system, application domain, essential system characteristics (for example security), operational constraints and functional requirements from stakeholders must be understood. Requirements Engineering is a set of activities that help develop this understanding [129].

In the International Requirements Engineering Board (IREB) glossary [42], a requirement is defined as a need perceived by a stakeholder, a capability or property from a system, or documented representation of it. A documented requirement shall fulfill the criteria listed in Table 3.1.

There are several activities within requirements engineering:
Elicitation is a process where stakeholders (customers, users) are consulted to discover requirements [130]. *Analysis* is an activity where requirements are checked for completeness, feasibility and consistency. Conflicts are resolved during negotiations, resulting in a compromise set of requirements. *Documentation* is to ensure communication between developers and stakeholders. Within the *Management*, requirements are stored and their change is tracked [103]. During *Validation* it is checked whether the requirements are what is needed [129]. Reported problems are listed along with actions necessary to cope with them [103].

Criteria	Description
Agreed	R was considered as correct and necessary by all stakeholders
Unambiguous	R can be understood in only one way
Necessary	R shall represent facts that are valid in the system context
Consistent	R does not contradict with another or with itself
Verifiable	R must be formulated so that tests can be carried out
Feasible	R must be implementable considering constraints
Traceable	R must be traceable to its origin, its realization and other relations
Complete	R must describe the functionality it specifies completely
Understandable	R must be understandable for all stakeholders

Table 3.1: There are nine criteria that shall be fulfilled by a requirement R [112].

However, these activities are often carried out in a cyclic manner. Finally, a document listing requirements that define what is to be implemented shall be the output [129].

3.1.1 Requirements Elicitation

Generally, there are some challenges approaching during elicitation. Stakeholders tend to not really know what they exactly need or want, at the same time they often have difficulties articulating their requirements. Additionally, their own terms are used, which usually include implicit knowledge which is difficult to understand for people not working in the customers' domain. Analysts must solve these difficulties by expressing requirements in a way that is understandable for every person involved [130].

First of all, sources of requirements must be identified. Besides stakeholders like users or organizations, documents and existing systems may serve as a source of information. Documents can include legal documents, domain-specific documents or even requirements documents of legacy systems. Systems in operation, for example, predecessor systems, may help in gaining insight into what should be changed based on stakeholders' impressions of it [112]. Collecting requirements from more than one stakeholder (and as such from different viewpoints) is essential to meet the needs of all stakeholders and it is a way to prioritize requirements [130].

In the following, techniques for requirements elicitation are presented. Table 3.2 gives an overview of techniques.

Interview Besides requirements elicitation, interviews have the goal to get context information. In a *standardized interview*, questions are prepared beforehand. As the results of this technique are easy to compare, it is especially suitable for assessing the opinions of many stakeholders on the same issue. During an *exploratory interview*, questions are prepared but the interviewer can deviate from the list and adapt the

Technique	Effort	Identification	Elicitation	Innovation
Interview	2-3	✓	✓	✓
Focus group	2-3		✓	✓
Observation	3-4		✓	
Workshop	3-4	✓	✓	✓
Questionnaire	1-2	✓	✓	

Table 3.2: Elicitation techniques and their effort (low (1) to very high (4)) and suitability for the identification of requirements sources, requirements elicitation and developing new and innovative requirements. Based on [111].

interview based on the answers from the stakeholder. As this makes this technique more quantitative than before, the results are difficult to compare. In contrast, no questions are prepared beforehand in an *unstructured interview*. Instead, broad questions are asked and the interviewee may lead the interview in different directions [111].

Focus Group In a focus group, stakeholders come together to identify requirements on a specific topic or item. For instance, participants may focus on problems with the current system. This technique especially fosters the creation of new and innovative ideas and requirements [111].

Observation During observation, an observer observes stakeholders or existing systems to elicit requirements. The advantage of this technique is that stakeholders usually provide more detailed descriptions of their activities while carrying them out [111].

Workshop During a workshop, many stakeholders develop requirements together in a group. It may be a successful technique if prepared well. It was referred to as the most powerful elicitation technique [111], while it may also be seen as an addition to other elicitation techniques in order to balance out weaknesses from other methods [112].

Questionnaire Questionnaires may contain open or closed questions and result in a variety of information in a short time. The downside is that the creation is time-consuming and requires knowledge of the domain. Additionally, only requirements can be gathered which are already expected [112]

3.1.2 Requirements Modeling

Requirements models are used additionally to requirements formulated in natural languages and are usually graphical. Modeling is to abstract reality that is to be created. A model can be descriptive (documentation of existing reality) or prescriptive (a prototype for a fictional reality). In any case, a model reduces reality and is always created within a special context for a special purpose [112].

To model a system in an effective way, a language is needed to describe the model. For that reason, the Unified Model Language (UML) was developed [87]. Using specialized notations leads most likely to fewer misinterpretations than natural languages and is a way of expressing a description in a more concise way [130].

There are different diagram types to model various situations. Below, the most commonly used diagrams are listed. A broader overview is given by Miles and Hamilton [87].

Use case diagram When it comes to object-oriented system design, development, testing and documentation, use cases are the first artifact to create. They describe the value that is delivered to the users and as such touch only the outside looking in view. In addition to use case diagrams, a description of the use case usually accompanies the diagram. Use case specifications are usually captured in a table-like form, however, there are no general rules about which attributes they are holding [87]. For example, the following attributes are included: identification attributes of the use case, preconditions, postconditions, actors, main scenario/flow or trigger event [112, 87].

Class diagram Class diagrams are generally used to model the data perspective of requirements. They consist of classes (rectangles) and their associations (edges) [112], where classes describe different types of objects. There are several defined relationship types in the UML standard, for example, dependency or inheritance [87].

Sequence diagram As there is a diagram to describe what the system must do, and a diagram that describes what different types of objects participate in the structure, there is also a diagram that describes how the interaction works - it is called sequence diagram. It consists of participants and their lifelines, which help to describe the order of interactions but do not give information on duration [87].

Activity diagram The activity diagram describes how a system accomplishes its goals and shows such processes that will occur. As this diagram is similar to a flow diagram, it is easily readable for a broad audience. The start and end of an activity are shown by two nodes, actions are located between these two elements. The flow of an activity is expressed through outgoing/incoming edges [87].

3.2 Usability and User-centered Design

„Usability applies to all aspects of a system with which a human might interact, including installation and maintenance procedures“ [100]. Compared to usability, the term *system acceptability* refers to a larger concept and describes whether a system satisfies all user and stakeholder needs and requirements [100]. As depicted in Figure 3.1, system acceptability is a combination of practical and social acceptability. Usefulness can be broken down to Usability and Utility.

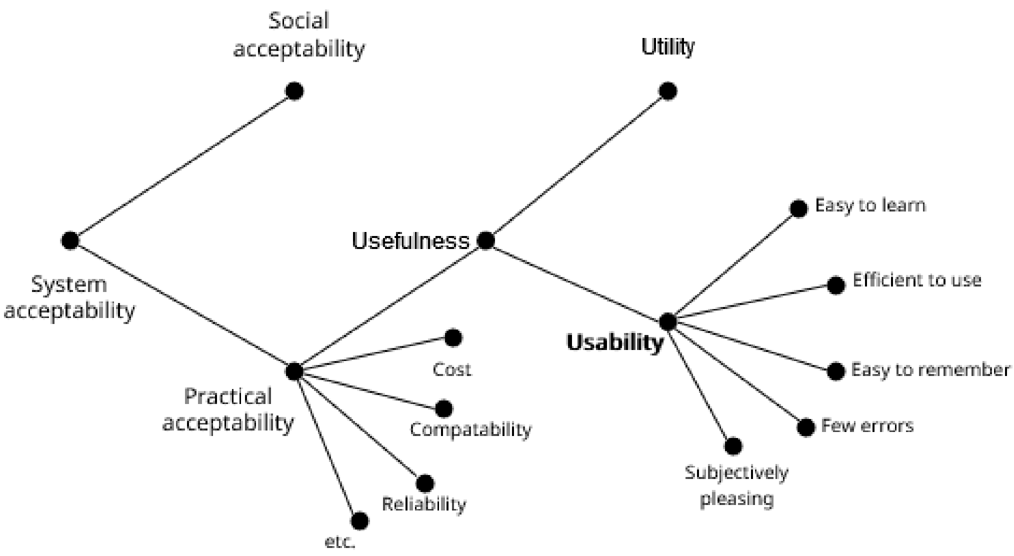


Figure 3.1: Overview of terms related to usability, based on [100].

In ISO standard 9421-11, usability is defined as „the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" [117].

Nielsen [100] states that usability has multiple components and defines the following usability attributes: (1) Learnability, the system should be easy to learn; (2) Efficiency, the system should be efficient to use, to ensure a high level of productivity; (3) Memorability, the system should be easy to remember; (4) Errors, the system should have a low error rate and users shall easily recover from them; and, (5) Satisfaction, the system should be likable by the users.

3.2.1 Usability Engineering Life Cycle

Usability Engineering should take place along the life cycle, rather than just before the release of a product [100].

The following stages were described by Jakob Nielsen in [100] and shall give an overview of important activities, from requirements elicitation to the testing and evaluation of the application.

Firstly, the intended users have to be studied. A visit to the customer site is recommended to get a feeling for how the product will be used. Two important tasks in this stage include assessing individual user characteristics and doing a task analysis. Determining users' age, computer experience, educational level etc. helps to plan the complexity of the future user interface. During task analysis, one analyzes users' goals and information needs as well as how the task is approached currently (weaknesses are identified hereby). Techniques that could be applied in this stage include observation, questionnaires and

interviews.
Secondly, a *Competitive analysis* investigates existing products and user tests may be carried out. The goal is to identify weaknesses and strengths.
Thirdly, a prioritization of usability aspects is recommended. Through *Goal Setting*, usability goals are defined with regard to usability metrics. An example is a system where learnability was a high priority because the company constantly hires new employees. Although reliable measurements cannot always be taken, it is still good to have an idea of the aimed usability level.
Fourthly, *Parallel Design* is an approach where multiple designers work on the same draft of a design in parallel. They do not discuss their ideas until the draft is finished, in order to have multiple possible designs available. *Participatory Design* is about the involvement of users in the design process. A key action is to present current design ideas in an understandable way. Prototypes serve this purpose and can be functional or simple (for instance, paper-based).
The next step is to foster consistency in the total user interface, which includes not only screens but also tutorials, documentation and training classes. As prototypes act as an early statement of what kind of interface is being aimed at, they help to achieve consistency within projects.
Guidelines consist of well-known principles that should be followed during development. In addition, *Heuristic evaluation* is to investigate an interface in order to decide what is good and what is not. Ideally, this is carried out following certain rules, but often the performance is based on common sense and intuition [100]. A common method for a heuristic evaluation was developed by Nielsen and consists of 10 heuristics [99], which are listed in Table 3.3.

The next stage in [100] is called *Prototyping*. Prototypes are faster to develop and cheaper than full-scale implementation, which is why they are the preferred way of displaying or communicating early user interface designs. As already mentioned before, they are easy to understand for customers. There are two dimensions of prototyping. A vertical prototype includes only a few selected features, but they already provide deep functionality for testing real circumstances. In contrast, in a horizontal prototype, the level of functionality is reduced so that no real work can be performed, but it includes the full user interface. An example of a prototype is a scenario (see next section).
An *Interface evaluation* results in a list of usability problems. These need to be prioritized based on the impact, for example, the number of users who will encounter the problem. Usability specialists and other evaluators shall rate each problem for severance.
Later, a new version of the interface can be created. It must be pointed out that the revised design does not always solve the usability problem and could even introduce new issues. Through the application of *Iterative design*, many iterations of designing the user interface are accomplished to get to a good solution.
Lastly, collecting feedback from the field is important for future products (including enhancements to the current product). It shall be assessed how the users interact with the system to carry out their tasks in the real environment [100].

Heuristic	Description
Visibility of system status	The design should always keep users informed about what is going on, by providing feedback within a reasonable amount of time.
Match between system and the real world	The design should speak the users' language, rather than internal jargon. Real-world conventions should be followed.
User control and freedom	Users often perform actions by mistake, so a clearly marked 'emergency exit' is recommended.
Consistency and standards	Users should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform and industry conventions.
Error prevention	The best designs carefully prevent problems from occurring in the first place. It is recommended to present users with a confirmation option before they commit to the action or eliminate error-prone conditions.
Recognition rather than recall	It is recommended to minimize the user's memory load, he/she should not have to remember information from one part of the interface to another.
Flexibility and efficiency of use	The design should support both experienced and inexperienced users, e.g. by providing shortcuts and tailoring of frequent actions.
Aesthetic and minimalist design	An interface should not contain information that is irrelevant or rarely needed.
Help users recognize, diagnose, and recover from errors	Error messages should prefer plain language instead of error codes, state the problem and suggest a solution.
Help and documentation	To foster understanding, a documentation for the system may be provided, however, it is also good if it is not needed.

Table 3.3: Summary of the 10 Usability Heuristics for User Interface Design, based on [99].

3.2.2 User-centered Techniques

There are a number of techniques from requirements engineering (see 3.1.1) which also have applications in usability engineering. From a user-centered standpoint, an observer may discover unexpected ways of how the software is used during an observation. Through interviews and questionnaires, users can be asked about their opinion on user interfaces. One should not take results too literally, and it is recommended that actual behavior shall have precedence over claims. Focus groups can be used to assess user needs before designing the interface or after some time of using it [100].

Personas are archetypal users and typically provide information on user goals, tasks, behavior, knowledge or expectations for the new solution. However, the characteristics to be gathered depend on the product that is developed. The information may come from workshops, contextual inquiry or questionnaires [117].

Scenarios act as a bridge between requirements and the design. Scenarios make use of real-world examples to depict how a future user may interact with the planned system and as such present a specific process. They can be used in various stages in the development process, for instance for specification, validation, UI concept and testing [117].

3.3 Serious Games and Exergames

A game can be defined as „a physical and/or mental contest that is played according to specific rules, with the sole goal of amusing or entertaining the participant(s)“ [75]. This chapter gives information on serious games and one sub-type, exergames.

3.3.1 Serious Games

Serious games are computer games, whose main purpose lies not purely in entertainment [116]. Besides story, art and software, Zyda [155] argues that they also involve pedagogy to incorporate activities that instruct or educate. Laamarti et al. [75] define a serious game as an application having three components experience, entertainment and multimedia. Another definition by Rego et al. [116] see serious games as „games that allow the player to achieve a specific purpose using the entertainment and engagement component provided by the experience of the game“.

In [75], a taxonomy for serious games is suggested, comprising of the characteristics (1) Activity, (2) Modality, (3) Interaction style, (4) Environment and (5) Application area. *Activity* describes functions performed by the player as response or input, *Modality* refers to the channel by which computer and human communicate, *Interaction style* describes how the player interacts with the game, *Environment* defines one or more environments of the game and *Application area* refers to one or more application domains. The particular manifestations for each characteristic are mentioned in Figure 3.2. For more details on each characteristic, this author refers readers to [75].

3.3.2 Exergames

Exergames in the field of well-being have become widespread [110]. A current commercial example is the Nintendo Ring Fit Adventure game as shown in Figure 3.3. However, commercial exergames are considered not suitable to address specific pathological issues. They are designed for the public and primarily for entertainment. As such, they do not provide healthcare professionals with game data on the progress of the patients [65]. Still,

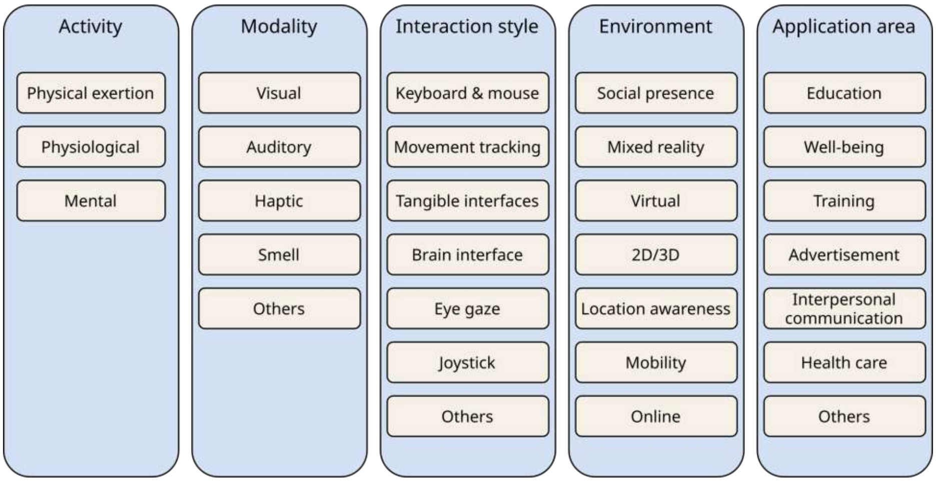


Figure 3.2: Within the serious games taxonomy proposed in [75], each of the five characteristics, (1) to (5), has different manifestations.

it is to note that it was argued that „commercial games are effective, motivating, and engaging for patients [...]“ [79].

Figure 3.3: Screenshot from Nintendo Ring Fit Adventure [151]. On the left-hand side, the user is instructed on the execution of the exercise.

In an early work of Caspersen et al. in 1985 [20] it is stated that exercise „[...] is physical activity that is planned, structured, repetitive, and purposive in the sense that improvement or maintenance of one or more components of physical fitness is an objective.“
An exergame is an exercise and a game at the same time [110]. There are various definitions. Jansen-Kosterink et al. [65] described exergames as „[s]erious games [that] have been developed to be played to exercise and train specific motor skills“, while Pirovano et al. [110] stated that „An exergame is an exercise with a game built into its structure“. Oh and Yang [102] describe an exergame as „[...] a video game that promotes

(either via using or requiring) player's physical movements (exertion) that is generally more than sedentary and includes strength, balance, and flexibility activities."

3.3.3 Design of Games

Pirovano et al. [110] suggest a methodology for the design of therapeutic exergames, consisting of four steps: (1) Exercise definition, (2) Virtualization, (3) Game design and (4) Secondary goals.

In the first step, a set of exercises has to be designed. An exercise can be described by a sequence of actions and is defined by the following: skills to be re-trained, primary goals (type of movement, quality), movement properties (e.g. speed of motion) and output parameters (e.g. reaction time, success rate). In order to be able to add a therapeutic value, secondary goals need also to be defined. Secondary goals are rules that ensure that the exercise is carried out correctly.
The next step is to transfer the exercise into a virtual exercise. To communicate action outcomes to the patient, feedback mechanisms are designed. Additionally, input devices, which track the required movement are identified. It is to note that secondary goals may constrain the choices made in this stage of game development.
After that, the virtual environment is transformed into an exergame with game characteristics. Actions should have meaningful consequences in the game while providing immediate and clear feedback. The introduction of intrinsic and extrinsic motivational factors may foster motivation (e.g. a reward system). At this point, testing with healthy people and with patients afterward is recommended to evaluate usability and compliance.
As a last step, the handling of secondary goals must be designed. This step consists of two parts: One part is to analyze motion data and to identify wrong movements; the second part is to display feedback accordingly and timely, so that patients can correct their movement [110].

In a literature review by Laamarti et al. [75], the identified factors of a successful serious game are music incorporation and multiplayer mode, both to boost motivation. Another factor is that a low performance of the player should not result in negative consequences in the game. Moreover, to maintain the interest of the players, it is necessary to keep just the right level of challenge. The authors recommend to not sacrificing the entertainment component in favor of the serious goal, as enjoyment is a prerequisite for reaching the goal [75].
In contrast, the goal is of importance when it comes to exergames, as in those „ the game [component] should not interfere with the correct execution of the exercise" [110].

Lohse et al. [79] identified motivational factors that are empirically supported by research: Reward, challenge, feedback, choice & interactivity, clear goals and socialization.
When beginning to play a game it is important that users can familiarize themselves with the game, for example through tutorials. The game should gradually change in difficulty to promote positive failure (success was only shortly away). The concept of choice & interaction is vital for engagement, as it increases the connection between the

patient and the game so that patients feel involved in the game. Socialization was shown to increase and stabilize time spent in a game. Aspects of it include presence, feedback (e.g. congratulations) and competition [79].

3.3.4 Development of Games

The following game engines were analyzed in the course of this thesis to research which could be used to develop the exergame. They were identified as the most common in an internet research.

Unity The Unity engine is based in C# and can be deployed to more than 20 platforms. There are different plans, however, there are free plans for personal use and for students [143]. The Unity asset store provides access to different paid and free content, for example, 3D characters, sound assets and add-ons as well as additional tools. As of January 2023, there were over 45000 3D assets available [144].

Godot The Godot Engine is an open-source game engine under the MIT license. It supports 2D as well as 3D and multiple platforms like Android or HTML5 [68]. It includes an editor and plugins can be downloaded additionally in the asset library [69], consisting of 1586 items (January 2023) [141]. For scripting, the python-like GDScript is used, but other languages like C# or Rust are supported, partly provided by the community [69].

SFML *Simple and Fast Multimedia Library* is an open-source library that supports the development of games and multimedia applications while supporting multiple platforms and programming languages. It consists of five modules system, window, network, graphics and audio, which are somewhat independent and are compiled in separate library files. Nevertheless, an application that is drawing will need the libraries system, graphics and window [113, 126]. SFML is licensed under zlib/png license, which allows free usage for any use [125].

Unreal Engine The Unreal Engine is a suite of different creation tools for game development, but also for film and television content or visualizations. It is free to download, however, there is a 5% royalty if the revenue of the product exceeds 1 million US-dollar [35]. It supports multiple platforms, but also VR/AR platforms like Oculus VR [34]. The marketplace offers free and paid content like assets, sound effects, visual effects and other [36].

CHAPTER 4

Related Work

Within the described taxonomy of serious games (see 3.3), the application area *health care* can be further divided into (1) health monitoring, (2) detection and treatment, (3) therapeutic education and prevention, and (4) rehabilitation [75].

Generally, it is to note that the main problem of rehabilitation is the lack of motivation, which is caused by the repetitive character of the exercises, which are often considered boring. It was shown that games do increase motivation, which may lead to an increase in compliance with physical rehabilitation [65, 116]. Additionally, games challenge patients to constantly want to beat their high score, which may lead to an increase in training intensity [65].

This chapter describes related work in the context of breast cancer care, games in rehabilitation and side effect management. The last section highlights the differences and similarities between state-of-the-art papers and this thesis.

4.1 Digital Interventions in Breast Cancer Care

There is a variety of apps available supporting breast cancer patients in tackling issues along their patient journey or even before diagnosis through self-examination. A review of smartphone breast applications by Mobasheri et al. [90] suggests that educational and self-assessment tools are the most common functions of these apps. Further, the authors identified a lack of evidence base and medical professional involvement, in addition to safety concerns in about 16% of the reviewed apps.

In the following, current examples of applications in the breast cancer domain are described.

The mobile app bWell [55] was developed with a user-centered approach to support post-treatment breast cancer patients who suffer from upper limb dysfunction in restoring

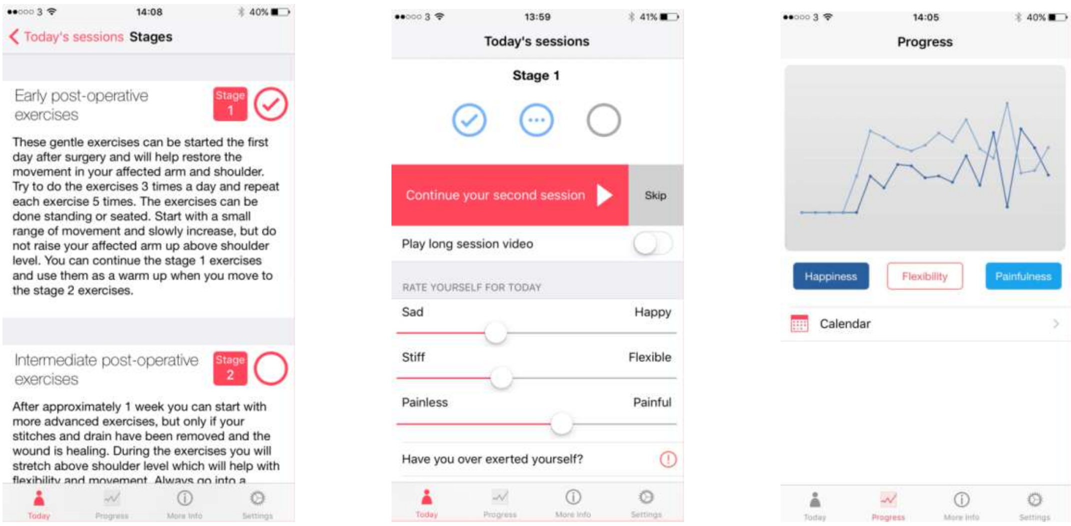


Figure 4.1: Screenshots from bWell application, extracted from poster presentation [56]

full mobility in arms and shoulders. Users watch exercise videos in the early, intermediate and/or late post-operative stage. The exercise program aims at increasing/maintaining the range of motion, promoting lymphatic transport and increasing the strength and stability of shoulders and arms. It was developed with a physiotherapist and a focus group of nine early-stage breast cancer patients. Further, a literature review of current arm and shoulder mobilization programs was carried out showing that there is no consensus on duration, training volume (number of repetitions) or frequency.
The participants questionnaires concluded that reminders, detailed demonstrations, tailored information and tracking exercises/progress are favored features. Clinical effectiveness was not measured. In Figure 4.1, screenshots of the application are presented.

Buscemi et al. [15] conducted a pilot study investigating enrollment, retention and usage of a smartphone-based application MyGuide, which was developed to improve health-related quality of life among Hispanic breast cancer survivors. The application focuses on the enhancement of psycho-social adaption after the disease, stress awareness and management, social support, communication and cancer knowledge. 25 participants who were 3 to 24 months post-active treatment were encouraged to use the application for 4 weeks, 3 hours each. The written content was supplemented with video and audio files. Additionally, telecoaching was offered to facilitate adherence to the application. 45% of the participants requested detailed information on diet and physical activity during survivorship. Around 30% requested additional videos, relaxation exercises and more content on cancer recurrence, respectively. Quality of life was assessed through the FACT-G7 score and improved from week 1 to week 4 but not significantly.

Lengacher et al. [76] developed a mobile mindfulness-based stress reduction iPad application for breast cancer patients. The goal was to improve psychological and physiological symptoms. Participants received a tutorial on how to use the iPad and a user manual.

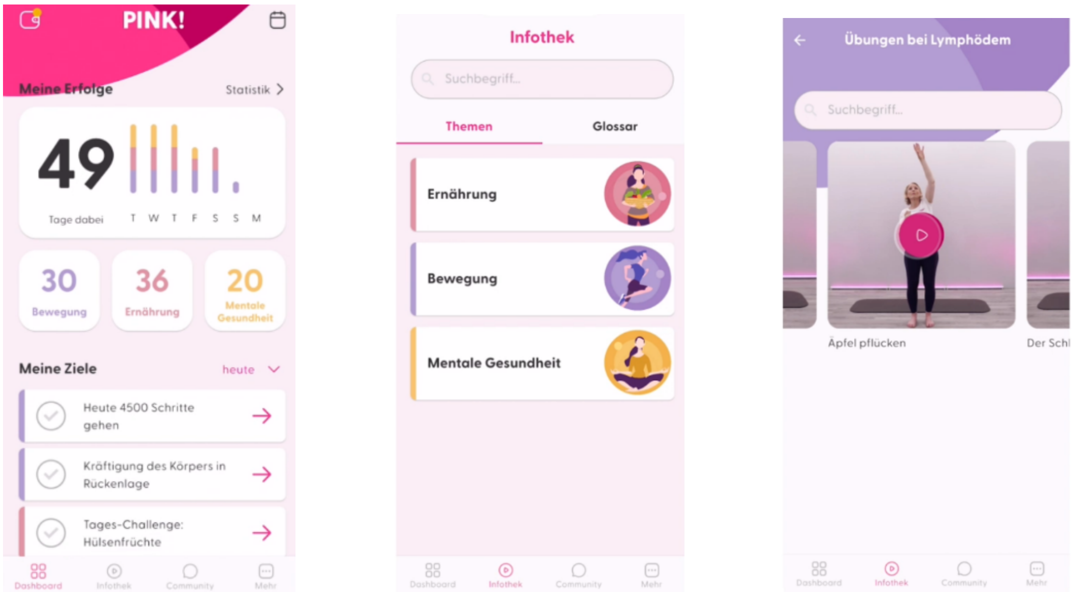
They were asked to access audio and video files to be guided in meditative techniques. Participants were supposed to do weekly 2-hour sessions for 6 weeks. Additionally, they were contacted each week to remind them of the weekly modules and to provide the opportunity to raise questions. The intervention is based on a stress reduction program by Jon Kabat-Zinn [71]. Measurements were taken according to various methods, for instance, the Five Facet Mindfulness Questionnaire or Fatigue Symptom Inventory.
Improvements, compared to the baseline at week 0, were detected in terms of depression, anxiety, stress, fatigue, fear of recurrence, sleep quality and quality of life. In terms of acceptability and usability, participants reported overall positively, while some highlighted their preference for a group setting and lamented about the time effort.

Kim et al. [74] incorporated game-based learning in an approach to improve the psychological status, quality of life and drug compliance during 3 weeks. Additionally, the intention was to promote self-management and reduce the side effects of chemotherapy. Users could chat with others and buy healthy food with their avatars. They were awarded for regular medication intake. When a quest is accomplished, users get heart coins that influence the avatars' health and can be spent on in-game items.
The results were that the game had a positive impact on quality of life and drug compliance. Patients in the study group reported fewer physically adverse effects (e.g. fatigue, numbness) than the control group. No impact on psychological side effects like mood or anxiety was reported.

Recently, Swartz et al. [139] conducted a pilot trial studying the effect of a multicomponent physical activity intervention on breast cancer patients, both on and off treatment.
The intervention group took part in weekly group sessions including behavioral coaching, a breast cancer support group and a video game-based activity demonstration to guide the practice. Sessions allowed for providing feedback as well as promoting self-monitoring and goal setting. Games were played through the consoles Wii (Fit) U and Xbox 360 (Kinect) in the group sessions and were selected in collaboration with an occupational therapist and a lymphedema therapy specialist. The exercises targeted balance, body weight and cardiovascular endurance. Additionally, weekly steps were tracked by the Wii U Fit Meter and served as input for a virtual marathon race. The control group participated in a usual support group and received conventional pedometers.
The results were an increased physical function in the intervention group. The steps per day increased, while there was a decrease in the control group.

Feyzioğlu et al. [37] compared traditional physiotherapy after breast cancer surgery (standard group) to an Xbox Kinect intervention (Kinect group) within a randomized controlled study. Participants underwent breast cancer surgery with axillary dissection. The standard approach consisted of an upper extremity physiotherapy program including passive mobilization scar tissue massage. The Kinect intervention included playing games *Kinect Sports I* and *Dance Central 3: Macarena* as a warm-up. According to the authors, all games required movement in the shoulder (flexion, abduction, extension, rotation), elbow (flexion, extension, supination, pronation) as well as in the wrist (flexion and extension). Both groups received treatment for 2 sessions per week (45 minutes each) for

6 weeks.
The primary outcome measures were pain intensity and ROM. Pain was measured using Visual Analog Scale (VAS), while ROM was measured using a digital goniometer. Secondary outcome measures included upper extremity functionality (measured via DASH), shoulder muscle strength and handgrip strength (using a dynamometer), as well as fear of movement (Tampa kinesiophobia scale (TKS)). The results were that there was a significant decrease in primary and secondary outcomes from baseline to post-intervention in both groups (within-group analysis). Comparing the two groups, the TKS score was found to be significantly higher in the Kinect group, while the mean DASH score was higher in the standard group. The authors conclude that VR-based training using Xbox Kinect may be as effective as standard physiotherapy when it comes to upper limb dysfunctions after breast cancer surgery.



(a) Dashboard (b) Information page (c) Exercise selection

Figure 4.2: Example screenshots from PINK! Coach application, provided in an explanation video [109]. (a) Dashboard showing an overview of the latest activity. (b) Information about diet, physical and mental health. (c) Exercises for specific symptoms in the form of videos.

The goal of the mobile app *PINK! Coach* is to motivate breast cancer patients on the topics of fitness, dietology and mindfulness to establish healthy habits. The exercises include strength, yoga, stretching, coordination and exercises for specific side effects. Moreover, recipes, relaxation techniques and mindfulness-based exercises are available. Additionally, features like appointment management and a digital file storage for health-related documents to be shared with physicians and other people are provided [108]. Figure 4.2 depicts a few features of the application.
The app can be prescribed as a Digitale Gesundheitsanwendung (DiGA) for patients

with a breast cancer diagnosis, which means that health insurance providers bear the costs for the application in Germany. The program is based on approved guidelines and was developed with several experts. Furthermore, the website provides a list of relevant publications [107].

4.2 Rehabilitation in Other Domains

This section describes various applications in the field of rehabilitation in other domains than breast cancer care, or where breast cancer patients are not the primary target group.

4.2.1 Games in Rehabilitation

Jansen-Kosterink et al. [65] evaluated a serious exergame for patients with chronic pain. In *PlayMancer*, users discover an abandoned island and gather artifacts (points) to find out about former inhabitants. It consists of three minigames, each targeting different muscles and movements. A suit with 36 reflective markers served as the game's input. The patients played the game for 4 weeks. After that period, an increase in walking speed, neck mobility and reach height was reported. Game data was used by therapists to get information about progression and lead to an adaption of sessions according to the patient's needs. As such, treatment transparency was highlighted as a positive factor by the authors.

The mobile exergame *MOBIGAME* [62, 61] is an approach to improve motivation to exercise in type 2 diabetes mellitus patients. The primary outcome - physical activity - is measured as steps per day, and motivation is measured via the mobile app (amount of completed exercises, etc.). The game uses the self-determination theory to address both intrinsic and extrinsic motivation and the goal is to restore an abandoned garden to attract animals. The exercises include strength, endurance, balance and flexibility, can be concluded outside or inside, and are rewarded with building materials. There are different variants and levels to support different fitness levels. Instruction videos ensure correct and safe execution. Progression is tracked by repeating the baseline tests, which are the 1-min Sit-to-Stand Test (STS) and the 6-Minute Walk Test. The used sensors are available on a mobile phone, e.g. camera, accelerometer, GPS.
In comparison to the baseline, Intrinsic Motivation Inventory (IMI) increased in the intervention group (and decreased in the control group), while participants trained 143 minutes per week with the app, on average. It is noted that about 82% of workout reminders led to completing a workout on that day. Hoechsmann et al. stated further that step tracking via phone was a limitation, as people might not always have their phone with them and recommended using more "wear-time" compliant devices like an activity wristband. Figure 4.3 shows screenshots from the application.

Sato et al. [122] conducted a study with patients suffering from chronic lower back pain using the Nintendo game Ring Fit Adventure. This game makes use of a controller which is formed as a ring and is used for resistance training. Squeezing and stretching of this

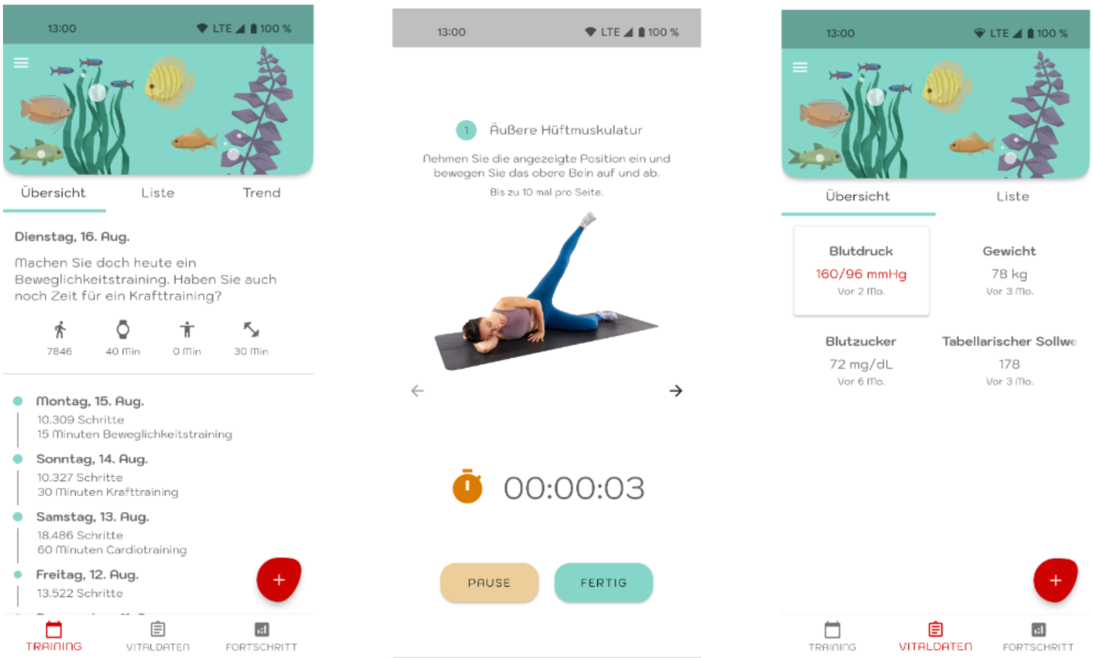
(a) Exercise mode (b) Activity overview (c) Training overview

Figure 4.3: Screenshots from the MOBIGAME applications. (a) Users can view detailed instructions for the exercises and choose a tracking method. (b) Users can view statistics per week, month, or year and day. (c) Total number of completed exercises are shown to the user [62].

controller are detected. The participants did a 40-minute exercise each week for 8 weeks. There was a decrease in lower back and buttock pain, while no effects were shown in terms of lower limb numbness, pain catastrophizing and kinesiophobia (fear of movement).

4.2.2 Non-game-based Approaches

The mobile app *heartfish* provides medical-based training in the field of cardiological rehabilitation, and is available for Android and iOS devices. According to the website, users can create their individual training schedule to exercise endurance, flexibility and strength. Additionally, the app is able to manage fitness and health data and provides information on healthy habits and food. The program is supported by over 70 physicians and 13 institutions in Austria [59]. Other functions include exercise reminders, PDF reports (only Pro-version) and daily training recommendations. External Bluetooth devices can be connected to make data entries easier, however for use cases connected to this, e.g., synchronization, linking accounts, etc., an upgrade to the Pro-version of the app is needed [58] (Apple App Store price 20,49€ for 3 months [57]). According to the manual, the primary target group are patients diagnosed with diabetes type 2, hypertension and chronic ischemic heart disease, but the app is suitable for any person over 18 years old, who undergoes medical treatment and can do exercises on his/her own [58]. On the Apple App Store, other target groups mentioned are generally people with chronic diseases like cancer and multiple sclerosis [57]. Some screenshots of this application are shown in Figure 4.4.



(a) Overview page (b) Record screen (c) Parameter overview

Figure 4.4: Screenshots from heartfish app as provided in the manual. (a) By touching the plus sign, a new manual entry for training can be added. (b) Screen for recording training in the app. (c) Overview of health parameters (vital signs), entered either manually or automatically [58].

4.3 Electronic Management of Side Effects

In a systematic review, Warrington et al. [148] report on features of existing electronic symptom reporting systems. The most commonly implemented features were to make patient-reported data available to healthcare professionals remotely (58%) and to monitor symptoms over time (46%). Two investigated systems demonstrated a positive impact on fatigue, while two others reported a positive effect on self-efficacy.

The internet-based application WebChoice [119] allows for monitoring symptoms and problems while providing tailored information and communication with nurses and other patients. Additionally, patients may keep personal notes in a diary. Participants of this study were diagnosed with or in treatment for breast cancer or prostate cancer. Symptom distress was assessed through the Memorial Symptom Assessment Scale-Short Form (MSAS-SF), while depression was measured using the Center for Epidemiological Studies-Depression Scale and health-related quality of life (HRQoL) was assessed using the 15D HRQoL instrument. Other outcome measures were social support and self-efficacy. Only symptom distress differed significantly between the control and experimental group.

Sundberg et al. [137] conducted a non-randomized controlled study investigating a smartphone application, Interaktor, for prostate cancer patients undergoing radiotherapy. Participants were asked to send reports on a daily basis. The assessment consisted of 15 questions and addressed occurrence, frequency and the distress level of patients. At the clinic, nurses viewed the reports via a web interface. Some answers by patients were supposed to cause yellow or red alerts for nurses, meaning that they should contact the patient during the same day or within an hour. Additionally, data was collected at three time points, in the intervention as well as in the control group. This data was obtained using EORTC QLQ-C30, a 30-item questionnaire asking about functional (e.g. physical), symptom, financial (impact of disease) and quality of life-related topics. Moreover, the SOC scale was used to assess the overall orientation to life.

Lu et al. [82] evaluated mobile apps for PROs in the field of oncology. Of 41 investigated apps, the following features were implemented in the majority of applications: symptom severity rating, annotating symptoms, inclusion of additional symptoms, graphical representation of symptoms over time and send/export data. The majority of the apps were general symptom trackers, while the minority was designed for cancer-specific purposes.

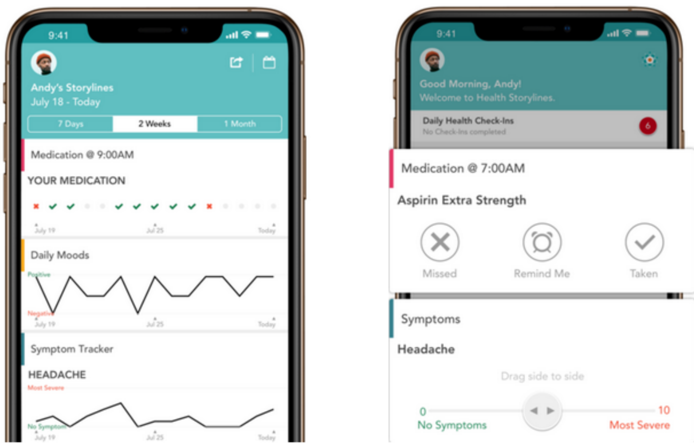


Figure 4.5: The Health Storylines application enables graph representation and tracking of symptoms, medications and more [124].

Among the investigated apps, *Health Storylines* was the only app that was trialed for usability and satisfaction [82]. According to the website [124], the app enables users to track medications, mood, symptoms, weight, blood pressure, sleep patterns, physical activity and more. Additionally, it provides a visual graph of tracked items (both see Figure 4.5). Patients can connect with others to share their progress and create a health report to be shared with healthcare professionals [124].

4.4 Classification of this Master Thesis

Table 4.1 summarizes the differences and similarities between directly comparable state-of-the-art solutions and the solution developed in this master project. Inclusion criteria for being considered as 'directly comparable' are as follows: (1) Solutions for breast cancer rehabilitation or (2) solutions where the main goal is to improve physical health in the context of rehabilitation using a game-based approach.

The first column lists the reference to the analyzed paper. The second and third column (BC and All BCP) gives information on whether the solution was explicitly intended and developed for breast cancer patients and, if yes, whether preoperative breast cancer patients were also addressed.
As can be seen, none of the solutions in the breast cancer care domain explicitly include preoperative or pre-therapeutic patients in a prospective surveillance manner. According to prospective surveillance, a patient's rehabilitation should start even before surgery (see also chapter 2.4). This is the main aspect which differs between state-of-the-art solutions and the solution of this master thesis.

When looking at interventions and their main aims, most of the state-of-the-art solutions focused on physical rehabilitation/exercise, whereas a few targeted mental health, quality of life or even physiological functioning. The author's solution focuses solely on physical fitness. Most papers and this thesis followed a mobile approach. A minority of solutions contain breast cancer-specific/adapted exercises or provide patients with the possibility to define their own goals. At the same time, many solutions allow for progress tracking in some form. Console games fulfill this partly because commercial games usually have some integrating functionality for this in some form, however, this tracking is not connected to the specific disease or affiliated conditions. In the special case of [65], the game data was analyzed to assess the progress of the patients, but in the paper, it was not clearly stated if the results were presented to the users.
The developed solution provides patients with the possibility to define a rehabilitation goal, which is their intrinsic motivation. Every 3 months, they can check how close they feel to accomplishing their goals. Moreover, progress tracking is on the one hand ensured by repeating baseline tests and on the other hand the user can view a history of don exercises to compare results. Both parts act as an additional motivation and may also inform patients about their fitness. The exercises created with this master thesis were adapted to breast cancer patients and the selection of exercises depends on the postoperative week of a patient.

Analyzing the game-based approaches, many solutions support carrying out exercises. Especially in cases where a console was used [37, 122, 139], patients could benefit from well-developed commercial games. As already mentioned in the previous chapter, commercial games come with downsides when it comes to rehabilitation, so this approach was not followed within this thesis. Other solutions focused on information and communication-based features within the digital solution [74] or used a special device setup for capturing motion [65] - an approach which was rejected early in this master thesis work, because

the goal was to build an easy to use application that can be used at home.
Among the game-based approaches, the MOBIGAME app for diabetes patients by Hoechsmann et al. [62, 61] exhibits the most similar approach, compared to this master thesis. It provides possibilities to track progress and set goals. The tests one minute sit to stand test (1STS) and 6MWT are used to create a baseline and can be repeated to make progress visible. Regarding input devices, the recommendation of Hoechsmann et al. was followed in this thesis, that smartphones could not track steps as effectively as activity wristbands, for example. As the game is not intended for breast cancer patients, it does not contain breast cancer-tailored exercises and information.

Just as important is the comparison to the non-game-based approaches. PINK! Coach [108] as well as bWell [55] provide breast-cancer-adapted physical exercises in their application. Both applications use videos to explain exercises. This approach was not considered in this thesis, because the goal was to develop a game, which is by default already more interactive than videos.
While bWell focuses only on the exercises, PINK! Coach, as the name suggests, acts as a coach in other topics too: diet and mental health. In comparison, this master thesis focuses on physical exercises as well but also informs about why the exercises are useful. Nevertheless, as can be seen in the table below, the focus lies mainly on the exercises and management aspects and not providing information, because there are already many sources of information for breast cancer care. Additionally, it has to be highlighted that management among solutions refers to symptom management, therapy management, medication management, stress management and training management. The term *management* in the title of this thesis refers to rehabilitation management and is comprised of symptom management and training management.
Lengacher et al. [76] focuses on meditation and mindfulness-based stress reduction (MBSR) and aims at improving psychological health and quality of life.
Lastly, the heartfish app [59] is dedicated to assisting mainly people with cardiologic diseases in creating a training schedule and exercising, but also provides fitness management and gives information on healthy habits. It is not exactly tailored to breast cancer rehabilitation and does not provide exercises selected based on breast cancer patients' needs. Through addressing the needs of a more broad spectrum of patients, the application follows a more general training approach, which was not the goal of this master thesis and was therefore not considered.

Paper	BC	All BCP	Aim	Intervention	Feature	Device	Game	PT	BC ex.	Goals
bWell [55]	Yes	No	PH	Videos	Ex	Mobile	No	Yes	Yes	No
MyGuide [15]	Yes	No	QoL	Written, audio & video content; telecoaching	Inf, Com, Man	Mobile	No	No	n/a	No
Lengacher [76]	Yes	No	PO, PS	MBSR, meditation, yoga	Mind	Mobile	No	No	n/a	No
Kim [74]	Yes	No	PS, QoL	Serious game	Inf, Com, Man	Mobile	Yes	No	n/a	No
Swartz [139]	Yes	?	PH	Coaching, support group, exergaming	Ex	Console	Yes	Partly	No	No
Feyzioglu [37]	Yes	No	PH	VR therapy	Ex	Console	Yes	Partly	No	No
PlayMancer [65]	No	n/a	PH	Exergame (chronic pain)	Ex	MoCap	Yes	Partly	n/a	Yes
Höchsmann [62], [61]	No	n/a	PH	BCT-based game	Ex	Mobile	Yes	Yes	n/a	Yes
Sato [122]	No	n/a	PH	Exergaming	Ex	Console	Yes	Partly	n/a	No
heartfish [59]	Yes	?	PH	Track exercising & health parameters	Ex, Inf, Man	Mobile	No	Yes	No	Yes
PINK! Coach [108]	Yes	No	PH, PS	Support during therapy & follow-up care	Ex, Inf, Man	Mobile	No	Yes	Yes	No
This thesis	Yes	Yes	PH	Exergaming	Ex, Man	Mobile	Yes	Yes	Yes	Yes

Table 4.1: Comparison of similar state-of-the-art solutions and the solution developed within this thesis. Abbreviations: breast cancer (BC), patients (P), physical health (PH), psychological health (PS), physiological health (PO), quality of Life (QoL), exercise (Ex), information (Inf), community/communication (Com), management (Man), mindfulness (Mind), progress tracking (PT), not provided in the paper (?), not applicable due to the difference in rehabilitation domain (n/a).

CHAPTER 5

Results

In this chapter, the result of the thesis is presented. Additionally, each step that led to the final prototype is described thoroughly as follows.

Firstly, section 5.1 describes the creation of the first prototype which resulted from expert interviews and literature research. Secondly, section 5.2 describes the creation of the second prototype, including the planning, execution and results of a questionnaire for patients and the conduction of a heuristic evaluation. Thirdly, the fully implemented prototype is the subject of description in section 5.3, while section 5.4 deals with the planning, execution and results of the evaluation conducted with experts and from a user perspective. Lastly, section 5.5 presents the final results including screenshots, use case tables and requirements.

For an overview of the iterations and activities, see Figure 5.1.

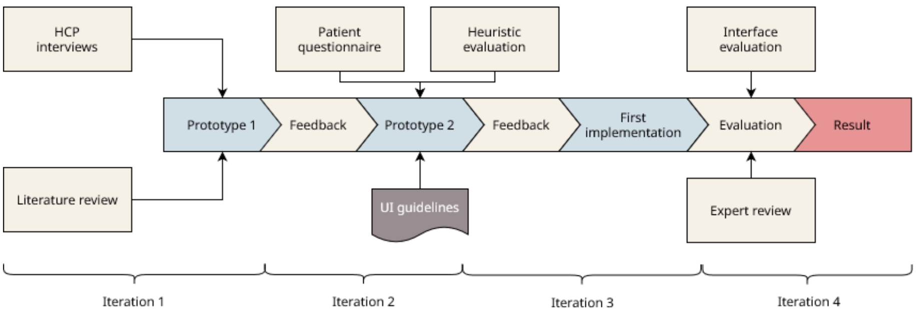


Figure 5.1: Overview of the methodological approach that was followed.

5.1 Iteration 1

Iteration 1 entails finding stakeholders, conducting methods for eliciting basic requirements and identifying possible exercises to be implemented in the application. It was carried out from November 2022 to March 2023.

5.1.1 Stakeholder Acquisition

The strategy to find stakeholders for the project consisted of two parts. First, internet research identified relevant institutions in the field of breast cancer care (e.g. so-called Brustzentren). Where possible, specific healthcare professionals were contacted via E-Mail or telephone, if available, otherwise, the office was contacted. Additionally, acquaintances were asked whether they could recommend someone. While about 14 institutions incl. hospitals were contacted and about 16 individual persons were addressed, 10 responses stated interest and competence in the project and finally 7 healthcare professionals contributed to this master thesis (see Table 5.1), 2 out of 7 being male, with an average age of 44.14 and working in two distinct federal states (Bundesländer).

ID	Age	Sex	Job description
H1	64	Female	Oncologist, radiation therapist
H2	47	Male	Coordination of a breast care center
H3	55	Female	Psychooncologist
H4	34	Female	Specialist for internal medicine
H5	26	Female	Physiotherapist
H6	39	Male	Senior physician in surgery
H7	44	Female	Specialist for internal medicine and oncology

Table 5.1: Anonymized list of healthcare professionals who contributed to the requirements and results of the thesis.

5.1.2 Initial Requirements Elicitation

The conduction of 5 interviews with healthcare professionals H1 to H5 took place between December, 15th 2022 and March, 8th 2023 to find out about the context of the topic. One additional interview was held on the 8th of April (H6). An exploratory interview was carried out each time, consisting of guided and spontaneous questions, as needed. This way, a comparison between answers is possible while taking into account different professions and views of the problem space.
The duration of the interviews ranged between 20 and 50 minutes. The number of questions asked ranged from 12 up to 27, however, both length of questions and expected answers differed. The interviews were recorded either in video and audio or only audio if the meeting was in person and not online. The interviews were held in German so the

author translated the findings into English.

Based on the initial interviews, the context was analyzed and basic requirements were obtained, addressing **RQ1**.

System Context

Figure 5.2 displays a context diagram that highlights the main components of rehabilitation in Austria and is therefore a result of the interviews investigating the system context.

Surgery: First of all, some complications regarding the lymph system were lessened in recent years because of a change in surgical methods. Due to the sentinel lymph node biopsy (see section 2.2) the majority of patients (it was estimated 90%-95%) do not need specialized care for arms and shoulders. Therefore the impact of this topic on the master thesis was also less than estimated based on the literature research. Interestingly, postoperative exercises targeting arms and shoulder are still recommended to all patients (see R-10 and R-11).
Before the surgery, patients usually don't have acute symptoms. The time between biopsy and surgery depends on the organization and the approval of the surgery (OP-Freigabe) but is usually 2 to 3 weeks (see R-01 and R-02). The surgery itself is not a high risk, because it does not affect any organs. After the surgery, patients usually don't face symptoms immediately (besides everyday surgery problems), they acquire them during therapy. Scars are usually not very visible for a long time. It was also stated that the overall quality is very high, because costs do not play a big role, like in other countries, and there is a centralization and specialization.

Follow-up care (Nachsorge): In Austria, there is a fixed schedule for follow-up visits. Content and actions of these visits include physical and mental health, diagnostic findings, gynecological examination, mammography if applicable bone density measurement. Moreover, healthcare professionals ask about what has changed since the last visit, the weight and occurring problems. Also, prescriptions are given and it is discussed what has to be done before the next visit. This is also the time when there is the opportunity to send a patient to a funded rehabilitation.

Rehabilitation: It was estimated that, in their respective institutions, about 20 to 40% of patients make use of the funded rehabilitation offer. After filling out the funded rehabilitation application, according to the interviews, there is usually an approval within 1-3 months, so patients have to wait about 2 months, and no longer than 6 months, to join this program.
Outpatient and stationary rehabilitation offer the same content at different intervals and time schedules. As can be seen in Figure 5.2, the content covers the areas of mental and physical health, dietology and social components (groups), while it does not focus on

very specific parts. The stationary-outpatient ratio was estimated as being 50-50 and 40-60. Generally, it can be said that which type of rehabilitation is chosen depends on age, goals and environment.
On the one hand, outpatient rehabilitation takes 6 weeks and is used by mothers or people who have additional responsibilities like pets or elderly people to care for. Also, people who already want to go back to work make use of this program. Furthermore, it was stated that a few do not consider any form of organized rehabilitation because they want to get to work soon. On the other hand, stationary rehabilitation takes 4 weeks and provides the possibility of being somewhere else and getting away from life as a patient at home. It is often chosen by retired people.

Exercising: The recommendations about exercising were a bit conflicting. One statement was that it is recommended to patients that they should do as much as they can, even when doing chemotherapy. Moreover, when the sentinel technique is used, patients can get back to normal activities or start to exercise after 2 weeks. Another recommendation was to prefer walking over Nordic walking (from 6 weeks post-operative), sports involving throwing (3 months post-operative), horse riding (6 months post-operative) and running (4-6 months post-operative).

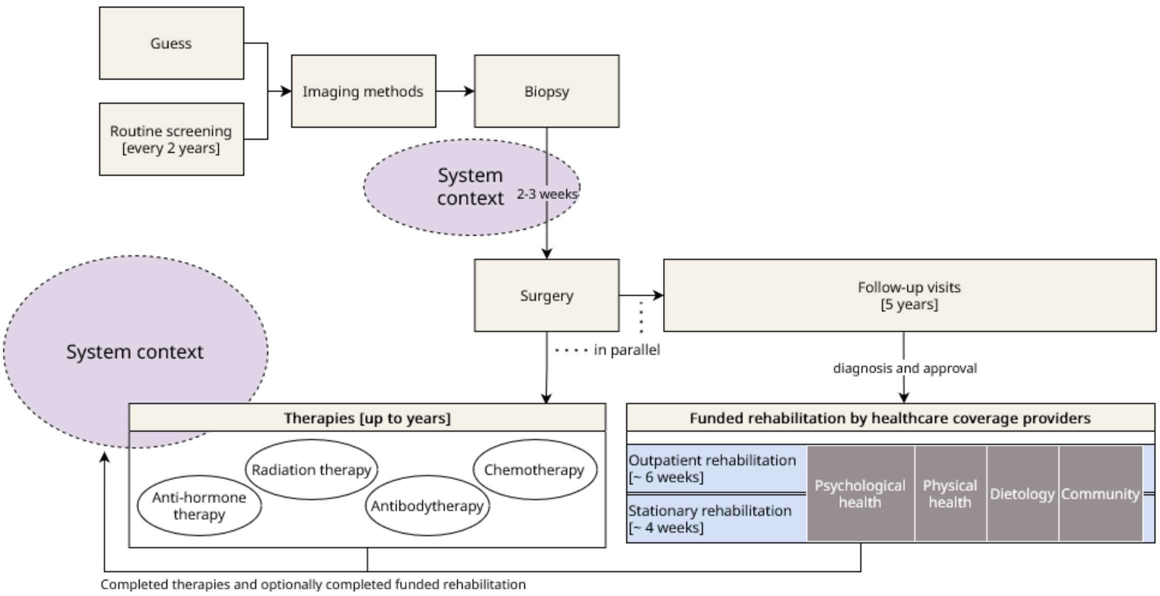


Figure 5.2: Depiction of breast cancer patient journey and embedding of the system context (purple) within this journey.

Compliance: Impressions about this topic differed here. One stated that patients would tend to not do rehabilitation exercises. Another interviewee stated that 30% would comply with the goals of rehabilitation. An explanation would be that daily tasks come again into the lives of patients after the therapy, while before, the diagnosis and therapy rather force patients to abandon their daily 'normal' lives. Moreover, another interviewee stated that patients usually do the recommended exercises because they are happy to be involved and to be able to do something. One interviewee said that the situation with compliance is mixed.

Psychological care: Firstly, all of the asked interviewees stated that they think that doing exercises improves mental health. The most challenging area is to realize and handle the diagnosis and the changes that will come the way. It was mentioned that a comparatively high number of patients make use of mental health consulting, although the prognosis is relatively good for breast cancer. This is because patients use this time to take a look at life to cope with changes. The topics differ. Also, relaxation techniques are covered in psychological sessions.

Resulting system context: As can be seen, the system context is tangent to three parts that lie within a typical patient journey: Firstly, the preoperative phase that is situated between biopsy and surgery; Secondly, there is a small overlapping with therapies, as some therapies allow for easy exercises, typically anti-hormone therapy; and thirdly, the main part of the system context is embedded in the phase after completing therapy. It is noticed that the system context has no overlapping with funded rehabilitation programs organized by healthcare coverage providers, which is explained in the next subsection below (R-03). Furthermore, the follow-up visits ('Nachsorgegespräche') are scheduled in parallel to any therapy.

Initial Requirements

In Table 5.2, basic requirements are listed which were deviated from statements by stakeholders (see Table 5.1). Each requirement is identified by an incremental number consisting of two digits (NN), in the form of R-NN.

R-01, R-02: The concept of prospective surveillance was a result of the literature review. Based on this, some interviewees were asked about it. The reaction towards this concept was very positive. They stated that it sounds like a good option and that patients were happy to be supported early, at the start of the patient journey. Another statement was that patients would be happy to learn they can take an active role in rehabilitation. Additionally, all healthcare professionals said that breast cancer patients are generally well before the surgery (with no acute pain etc.), so they are able to do a preoperative assessment. Taking also into consideration that no state-of-the-art solution provided this feature, it was decided that supporting the prospective surveillance model in some form in the application should be a must-have requirement. The idea was to use the 6MWT and the 1STS for assessing the fitness preoperatively and to call the assessment 'checkpoints'.

R-03: The interviews provided insight into the rehabilitation which is funded by the healthcare coverage providers (Krankenkassen). The goal here was to define the scope of the application with regard to the funded courses and therefore to identify the borders. The result was that both stationary and outpatient rehabilitation requires a diagnosis from a physician and approval from the healthcare coverage provider. After a few weeks, patients can get rehabilitation. As the program itself can be tight, especially for outpatient rehabilitation, while being overall positively rated, no additional actions are necessary here.

R-04: This requirement is connected to R-03 and is also a must-have requirement due to the following reasons. Firstly, the literature research showed that patients often do not want to visit practices after therapy anymore. Secondly, considering the characteristics of the Austrian health system, most people can get rehabilitation for almost no cost if they wish to do that. Thirdly, interviewees estimated that already 20% to 40% visit the funded rehabilitation. Barriers mentioned include uncertainty/inhibitions, laziness, time factors or they prefer to stay at home. It was also mentioned that a few continue going back to their work relatively early, so they don't have time to do a funded rehabilitation.

R-05: Hiking or walking is a common exercise in funded rehabilitation and organized patient groups, as interviews showed. Additionally, walking is an exercise that can be easily practiced, while being not prone to execution errors. It was also mentioned that the moving of the arms is beneficial. It follows that it is a useful feature to support this exercise while being relatively easy to implement and embed into a story in a game.

R-06: It is trivial that patients should get a detailed explanation of how they should carry out an exercise. Additionally, one interview showed that graphical depictions can further foster the understanding of more complex exercises.

R-07: An interview with a physiotherapist showed that communication between patient and physiotherapist can be improved, even before the first meeting, but generally to get information about the patient before each appointment. For example, the physiotherapist can prepare an appointment better, if the rehabilitation goals of a patient are known to him/her beforehand.

R-08: In terms of the 'classic' information which is captured by anamnesis, weight and symptoms are highly related to doing exercises within the app. Moreover, rehabilitation goals shall be defined by each patient and act as instruction for physiotherapists, on what to work.

R-09: Supplementary to R-08, it was stated that a self-assessment of fitness is beneficial because patients shall deal with their own goals and assess how they feel and how they see their own fitness. A physiotherapist is then able to tell if that self-assessment is accurate.

R-10, R-11: The two requirements refer to two postoperative exercises that are beneficial to breast cancer patients. Although the exercises are originally meant for patients where the surgery impacted the lymph system intensively, they are often recommended to every breast cancer patient because patients usually are worried and want to have an active role in recovery.

R-12: The follow-up care visits follow a fixed schedule and deal with how the patient feels, what problems the patient is facing or what the current medical pictures look like. In this context, patients are asked whether they were any changes with regard to the last visit. In this sense, it would be nice to have a summary page as a 'cheat sheet' to support the memory of the patients. When thinking of the working of a baseline, it is a plus if the application can create baselines based on follow-up visits and then deduce a delta between them.

R-13: In the interviews, it was asked what information could be also interesting to obtain in terms of rehabilitation. The job of a patient tells physiotherapists whether movement (e.g. farmer) or prolonged standing (e.g. retail sector) plays a role in their daily lives. This influences the selection of exercises. The socioeconomic environment was considered as a crucial role. For example, for the elderly, it is relevant to know whether they have support in the family. For younger females, it is relevant to know if they have children that they have to look after.

Based on these initial requirements, it was to be decided on which device the application shall be available. It was determined to develop a mobile application for Android devices due to the following reasons:

- R-05: For supporting walking exercises, it would be great and useful to track steps or distance, which is much easier on mobile devices or through smartwatches.
- R-12: For using the application as an aid to memory, it is necessary that patients can take their information wherever they go.
- Mobile apps support a variety of use cases and gained high popularity in recent years.
- Android is a widely used operating system for mobile devices and is not subject to deployment restrictions (iOS/iPadOS can only be developed and deployed with MacOS).

5.1.3 First Prototype

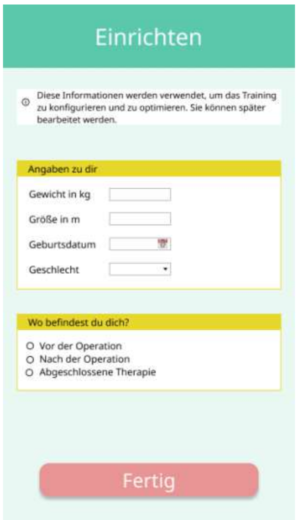
The first prototype was realized in the form of a click-through prototype. This means that various mockups were created and linked with each other to simulate the behavior

ID	Description	P	Source
R-01	The application must support the concept of prospective surveillance.	1	H2 - H5, [133]
R-02	The application must support measuring the fitness of the patient preoperatively.	1	H2 - H5, [33, 133]
R-03	The application does not include functions to be used in parallel to funded rehabilitation (stationary, outpatient).	1	H1, H2, H3
R-04	The patient must be able to use the application at home.	1	H3, H5
R-05	The application must support walking exercises.	1	H1, H3, H5
R-06	Each exercise shall be described in detail and complemented with pictures if necessary.	2	H5
R-07	A physiotherapist shall be able to inform herself/hisself about the patient before appointments, based on the information captured by the application.	3	H5
R-08	The application shall be able to track the following information: symptoms, goals in rehabilitation, weight.	2	H2, H5
R-09	The patients shall be able to do a self-assessment about their fitness, which can be shared optionally with healthcare professionals.	2	H5
R-10	The exercise „Venenpumpe“ consists of opening and closing the hand 30 times. The application shall remind the patient of doing this exercise multiple times a day.	2	H5
R-11	The exercise „Ausstreichen“ consists of moving the right hand from the left hand to the direction of the heart (and vice versa) to increase lymph flow.	2	H5
R-12	The application shall provide a summary page about the patient which can be used e.g. for follow-up visits. It should contain the weight. It may contain the delta of information between now and the last visit (last summary).	3	H4
R-13	The user can provide the following information: job, socio-economic environment.	3	H2, H5

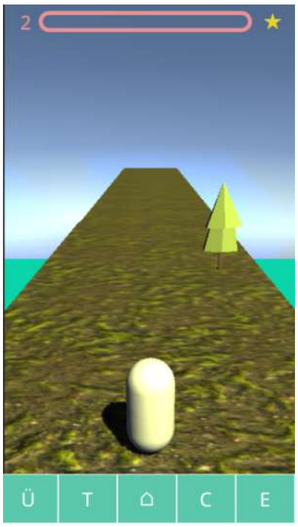
Table 5.2: List of initial requirements based on interviews and literature review. Each requirement consists of (1) Unique identification number; (2) Description; (3) Priority (P), either 1 (must have), 2 (should have) or 3 (nice to have) and (4) Source, based on statements from which stakeholder.

and the user interface interaction (user flow). It was created with the tool Figma[1].

Selected parts from this prototype are displayed in Figure 5.3.

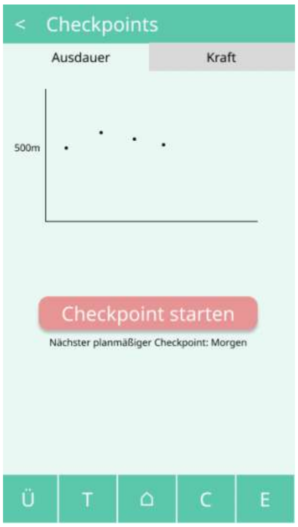


(a) Configuration

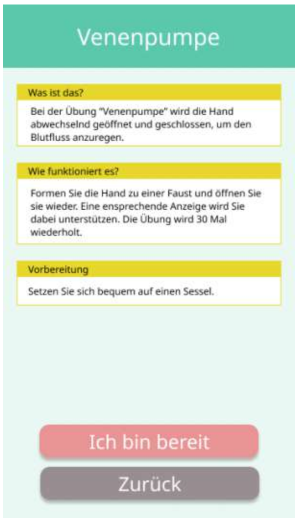


(b) Main screen

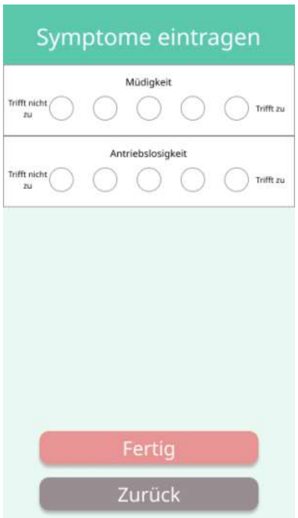
(c) Exercise explanation



(d) History of checkpoints



(e) Exercise explanation



(f) Symptom rating

Figure 5.3: Selected parts of the first prototype. (a) Configuration of the app on first use. (b) Main game displaying a player and a map the player walks. (c) Explanation of the 6MWT before starting the test. (d) Overview of progress with scores and tests. (e) Explanation screen of an exercise before starting it. (f) Symptom tracker with Likert scale.

[1] https://www.figma.com/

5.2 Iteration 2

The second iteration entails gathering feedback for the first prototype, assessing the results of the patient questionnaire and considering UI-related aspects. All results influence the second prototype, which is still a mockup but more detailed than the predecessor. This iteration was carried out in April 2023.

5.2.1 Gathered Feedback

A feedback meeting was conducted on 6 April 2023. The reviewer was a person who was not involved in the creation of the first prototype, stakeholder H7. The planned exercises and the mockups were shown and explained to the reviewer, the duration of the meeting was about 45 minutes. The main goal of this review was to discuss open or difficult issues. The feedback was as follows.

Checkpoints In terms of the checkpoints, it was recommended that the application should request the user to carry it out every 3 months, which is in line with the schedule of the follow-ups in the first three years. Again, the preoperative approach was considered very good.
A brain-storming about how to implement the self-assessment resulted in the following: The user could rate how close he/she feels to the previously defined rehabilitation goals. Rating fitness was considered as being highly subjective from day to day and therefore may not be useful in this interval.
The order of the exercises within the checkpoints was open to discussion. Generally, it was noted that results should not be compared to healthy subjects (e.g. reference values in studies) but only intra-individual. Therefore it would not be very important to stick to a certain order. Furthermore, no exact recommendation was given.
Another subject of the discussion was how to assess the intensity of the checkpoint. The author proposed to use a 10-point rating scale, e.g. the Borg CR-10 scale. This was considered a useful additional parameter. Further, it was noticed that it could motivate patients to see that exertion decreased even though there is no improvement in the distance for example when doing the 6MWT.
An idea by the reviewer was that the user may want to add their current weight to the checkpoints, too.

Goals and Feedback Prototype 1 included an option to edit the parameter "active minutes". It was recommended to not provide this option and instead to give more credit if the goal was exceeded, according to the amount recommended in guidelines. Another point of discussion was on how to communicate with the user on performance and how to give feedback. As mentioned, the consensus was to compare results intra-individually. It was highlighted that users like graphs and colors, where results could be easily viewed. Other than that, it makes no sense to compare results to a reference table that was created using healthy subjects.

Exercises In terms of exercises, it was stated that a display of the pulse would be nice but would not significantly be of value to the users.
Moreover, during a discussion about what exercises should be implemented, the value of difficulty levels was highlighted. According to the reviewer, the application should include the possibility to do all exercises with different difficulties. An example was to do push-ups firstly against a wall, the next time a plank for 20 seconds, and then for 40 seconds. An idea of the reviewer was to assign a patient to a 'fitness group' according to the results of the baseline assessment (checkpoint) to determine the difficulty. It was discussed that the downside of this approach is whether they are reference values available to make this estimate. Another opportunity is to let the user decide the difficulty.
It was stated that the app should contain an exercise targeting the strength. Besides planks, it was suggested to work with a ball that should be moved around the body by the user. Additionally, it was stated that the 1STS is well suited to act as a test but also as an exercise.

Symptom tracker The opportunity to define symptoms was considered useful. It was recommended to use a 10-point VAS instead of a 5-point Likert scale because it is a standard. This could be implemented with colors from green to red, with numbers or different smileys. Another point was on how frequently ask users to track their symptoms. It was stated that this depends on the symptoms, and finally, the consensus was that it could be an option to let the user decide how frequently the application should ask for a rating of a symptom. For example, it was considered not useful to track pain one time per week, but tracking fatigue this way would be indeed useful.

Access of healthcare professionals It was considered positive, to allow treating healthcare professionals access to patient's data, e.g. to enable the assignment of exercises. It was stated that it would be optimal for patients to work together with their clinicians on a schedule that can be met.

System context Also, the timely context of the system was discussed. It was recommended to consider times with no training, e.g. when on funded rehabilitation, explicitly in the app, for example, an opportunity to pause the program for 3 weeks. Additionally, the possibility to add the date of the surgery to influence the app was considered useful.

5.2.2 User Interface Considerations

The following actions were performed in an effort to include the UI perspective in the second prototype. The basis of this analysis was the mockup of prototype 1 (see Figure 5.3), so the feedback for iteration 1 was not included beforehand.

Android Design Guidelines

Google proposes an open-source design system called Material Design 3 [2]. The mockup was analyzed with regard to the following elements.

Styles [50] The Noto font is one of the recommended fonts to be used in Android applications, and was already used in prototype 1. Icons were incorporated into the next prototype, using the Figma design kit [48], with more to follow in the implementation iteration.

Components [49] In terms of buttons, the guideline for rounding edges was considered. The concept of cards was used to design the menu entries for the exercises and other lists. Cards present content and actions about one topic. A navigation bar was included to provide the option to switch between different parts of the app. Although this was already present in the first prototype, this part was reworked. Tabs were also included in prototype 1, however, were reworked, too, to match the style of material design. Additionally, the top app bars in prototype 1 were reworked so that a suitable icon acts as a 'back'-Button. Lastly, the edges of the rectangles (forms) were also rounded according to the guidelines.

Heuristic Evaluation

A heuristic evaluation was performed, according to the recommendation of Jakob Nielsen in [99], see also Figure 3.3 for an explanation of the heuristics to follow. The evaluated subject was prototype 1.

Visibility of system status When an external device gets connected, the status should be visible in the application. For the exercises, the progress should be shown in parallel to the execution of the exercises. For example, a timer is visible and counts down to zero. Another example that is already shown in prototype 1 includes the display of the level and the progress of the player.

Match between system and the real world To not use internal language was already considered in the first drafts: Words like pre- and post-operative are not used and assessment was renamed to the concept of 'checkpoints'. Additionally, the exercises could have more interesting names than their medical names, e.g. a game for stretching could be called 'Reach for the stars'.

User control and freedom The tab bar already provides a way to correct a mistakenly tapped icon. Moreover, there are several ways to go back, which are the back arrow in each menu on the one hand, and the 'back' buttons on screens that start a longer

[2] https://m3.material.io/

interaction. Additionally, this concept could be implemented when doing an exercise by providing the possibility to cancel or start an exercise anew.

Consistency and standards As can be seen in the prototype, screens that start a longer action look the same. Reoccurring elements were already used as templates when creating the mock-ups to foster a unified design and language - this applies to fonts, colors and grouped elements. A way to implement this further would be to use localization during the implementation of the application.

Error prevention The mock-up already shows that much of the data can be edited to correct errors. Another option would be to implement an undo or redo button, but due to the technical effort, this is not an option or priority of this master thesis.

Recognition rather than recall It is indicated that exercises and other long interactions are explained beforehand, but it is added that the description is shown every time to enable users to recognize the guidance. Additionally, it is also captured in the draft that different icons for different menu items shall improve recognition.

Flexibility and efficiency of use Again due to technical effort, alternative touch gestures are not in the scope of this project. In terms of personalization and customization, this is identified as a nice-to-have requirement, although some form of it is already reflected in editing the profile and active minutes per week.

Aesthetic and minimalist design Analyzing the prototype, it is an idea to switch the position of the explanation and the start button of an exercise after one or two times of doing that exercise in an assumption that users will no longer need to read the description as carefully as the first time.

Help users recognize, diagnose, and recover from errors This aspect can be implemented with a proportionate effort, for example when obligatory fields are not filled, there appears an error message containing that some information is missing. As for apps on mobile devices, where the screen does not contain that many fields, it is suitable to generalize this message because it is most of the time clear which field is empty.

Help and documentation The goal within this master thesis is to implement the application as self-explaining as possible, which is also already depicted in the mock-up by explaining the exercises thoroughly.

As a result of the evaluation, the following points, which may be seen as usability requirements, shall be considered in the implementation with a 'should-have' priority:

- Show status of the connection to other devices, game level, exercise execution

- Provide a way to cancel the execution of an exercise
- Use engaging/interesting names for exercises
- Implement helpful, understandable and simple error messages
- Use icons for different functions in the application tab bar (main menu, settings menu, etc.)

Additionally, the following usability requirements shall be considered with a priority of 'nice-to-have':

- Implement the option to start an exercise anew with only one click
- Make instructions for exercises less prominently visible that were already completed several times
- Use localization when implementing the application
- Use different icons for different menu items in a list view

5.2.3 Development of the Game Concept

The game developed in this thesis was designed using the methodology by Pirovano et al. [110] as a guideline, see also chapter 3.3. Especially the first step, Exercise Definition, was necessary to answer **RQ2**.

Exercise Definition

Firstly, a set of exercises was defined. The first draft was created within the second iteration, however during the review of the second iteration, the exercises were slightly amended. The feedback was provided by stakeholder H5 in mid of April. The final exercise definitions are described in Tables 5.3 to 5.10.

As a result of this definition and Iteration 1 (see 5.1), the walking exercise (Table 5.7) is the most present exercise being the content of the main screen.
The exercises 6MWT and 1STS (Table 5.3 and 5.4) are part of the checkpoints, while 1STS is also an exercise that can be carried out anytime, considering the post-operative week, that could be described as a 'mini game'.
Other exercises in this category are the Vein Pump exercise (Table 5.5), the Sweeping exercise (Table 5.6), the Circle Arms exercise (Table 5.8), as well as the Wall plank exercise (Table 5.9) and the Plank exercise (Table 5.10). Figure 5.4 displays an overview of exercises.

For all exercises, people should wear comfortable clothes and shoes, if applicable.

The proposed exercises with balls involved were considered as not in scope of this project because the users would need an additional item beside the watch to do the training program.

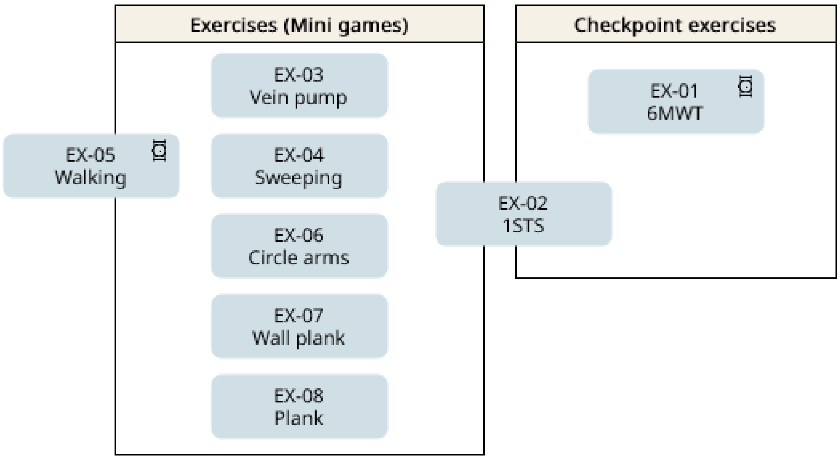


Figure 5.4: Overview of defined exercise and their allocation within the application. EX-01 and EX-02 are exercises within the checkpoints. EX-02 to EX-08 are part of the general exercises, which may be described as mini games. Exercises EX-01 and EX-05 use step tracking.

Name	EX-01: 6MWT
Sequence of actions:	1) Do not execute any exhausting exercise 2 hours before the exercise. 2) Select a route of about 400 to 700 meters, which does not contain many slopes or distractions (e.g. traffic lights on a junction). 3) After an acoustic signal from the app, start to walk. 4) A second signal marks the end of the exercise and the person should stop walking.
Trained skills:	Endurance
Primary goals:	Person should walk 6 minutes.
Secondary goals:	Person should not be accompanied by others. People should not do this test in parallel. The chosen route should not be a circle. The exercise should not be done on a treadmill. Walking aids are allowed.
Details:	The person should walk as far as possible in 6 minutes.
Result (Output):	Amount of steps, subjective perceived exertion
Contraindications:	Unstable angina pectoris, myocardial infarction in the past month, tachycardia (HR rest > 120 beats/min), hypertension, surgery less than two weeks ago, chemotherapy one day ago
Sources:	[9, 33], H5

Table 5.3: Definition of exercise EX-01: Six minute walk test (6MWT).

Virtualization

Secondly, feedback mechanisms to support the defined exercises were developed as follows.

Name	EX-02: 1STS
Sequence of actions:	1) Rest 5 minutes before starting the exercise and do not carry out 6MWT 30 minutes before*. 2) Prepare a chair and sit down. 3) A sound signals the start of the exercise, the person should get up from the chair and sit down again, repeat this for 1 minute. The repetition must be counted by the person. 4) Again, a sound signals the end 5) The number of repetitions should be provided by the person.
Trained skills:	Functional strength of lower extremity
Primary goals:	Person should get up and sit down from/to the chair as fast and as much as possible within one minute.
Secondary goals:	Height of seating surface between 45cm and 48 cm. Chair with no armrest. The chair can be leaned against a wall for stabilization. Hands shall be crossed at the upper body and must not support the movement. Knees shall be at a right angle when sitting and fully extended when standing.
Details:	The movement shall be without delay. However, if a break is necessary, the time does not stop.
Result (Output):	Amount of sit-to-stands, subjective perceived exertion
Contraindications:	surgery less than two weeks ago, chemotherapy one day ago
Sources:	[8], H5, H7. * it was confirmed by H5 and H7 that this is not considered in practice

Table 5.4: Definition of exercise EX-02: One Minute Sit To Stand Test (1STS).

- A timer shall be displayed whenever the time is a relevant component of the exercise
- Acoustic signals shall support time-based exercises
- Visual depictions of movements should help to understand how the exercises have to be carried out

For the input device that is supposed to track the steps, three approaches were investigated.

Firstly, the Fitbit watch [3] was analyzed. Fitbit provides Web APIs that enables developers to retrieve data obtained by Fitbit devices. The authorization works with OAuth 2.0. The steps can be obtained by getting all activities of a day and select all steps from it. Alternatively, distances are provided as a separate data field in the daily activities response. It is also possible to implement the Subscription API to receive updates on

[3]https://www.fitbit.com/

Name	EX-03: Venenpumpe (Vein pump)
Sequence of actions:	1) Person opens and closes a fist with both hands. Alternatively, the person adds to this movement by moving the ankle up and down.
Trained skills:	Increase blood flow
Primary goals:	Increase blood flow in the first and second postoperative week
Secondary goals:	Can be done standing or laying
Details:	Movement shall be done 30 times, especially in the first days after surgery the exercise shall be repeated 3-5 times a day. The speed is of minor importance, but approx. one time per second for opening and closing the fist/hand.
Result (Output):	Implicit: amount
Contraindications:	(No)
Sources:	H5

Table 5.5: Definition of exercise EX-03: Venenpumpe (German title).

Name	EX-04: Ausstreichen (Sweeping)
Sequence of actions:	1) Person moves the right hand along the left arm toward the heart, with soft pressure. 2) This is done vice versa with the other hand.
Trained skills:	Increase lymph flow
Primary goals:	Increase lymph flow, especially postoperative, edema prophylaxis
Secondary goals:	Can be done standing or laying
Details:	10 times per side
Result (Output):	Implicit: amount
Contraindications:	(No)
Sources:	H5

Table 5.6: Definition of exercise EX-04: 'Ausstreichen' (German title).

Name	EX-05: Walking exercise
Sequence of actions:	1) Person connects the smartwatch with the app and wears it. 2) Normal or faster walking, depending on the goal and status of the patient. 3) Steps are shown in the app.
Trained skills:	Endurance, strength, physical resilience
Primary goals:	Normal or fast walking to increase skills
Secondary goals:	Person should be able to talk during training (normal breathing), favor flat/shallow terrains,
Details:	Arms can be moved in addition, supporting items like walking sticks are allowed, recommendation: 20 minutes of training starting from the fourth postoperative day
Result (Output):	Amount of steps
Contraindications:	Problems with circulatory system or general health, 2-3 days postoperative only slowly, carefully, chemotherapy one day ago
Sources:	H5

Table 5.7: Definition of exercise EX-05: Walking exercise or Walking game.

Name	EX-06: Armkreisen (Circle arms)
Sequence of actions:	1) Person sits or stands, relaxed and upright. 2) Arms shall be placed below shoulders and shall be moved in a circle from the back to the front of the body and vice versa.
Trained skills:	Movement of shoulders
Primary goals:	Mobilization of the shoulders with slow movement
Secondary goals:	Person should not place shoulders towards the ears
Details:	Duration of 30 seconds, one minute rest, for 3 times (rounds)
Result (Output):	Implicit: number of rounds
Contraindications:	Surgery less than two weeks ago
Sources:	H5

Table 5.8: Definition of exercise EX-06: Armkreisen (German title).

Name	EX-07: Armstütze leicht (Wall plank)
Sequence of actions:	1) Person stands in front of a wall, approx. a half arm's length away. 2) Both arms are moved towards the wall and touch it. 3) The hands shall carry the weight of the body. 4) The elbows are bent, and the body moves closer to the wall. 5) Using the strength of the arms, the body shall be pressed away from the wall.
Trained skills:	Functional strength
Primary goals:	Strengthening of the upper body, back and abdominal muscles
Secondary goals:	Back must be straight, Heels remain on the ground
Details:	Schedule is 8-10 circles, one minute rest, for 3 times (rounds)
Result (Output):	repetitions/rounds
Contraindications:	surgery less than 6 weeks ago, chemotherapy 2-3 days ago
Sources:	H5, H7

Table 5.9: Definition of exercise EX-07: Armstütze leicht (German title).

Name	EX-08: Armstütze Profi (Plank)
Sequence of actions:	1) Belly, legs and forearms are placed on a mat/ground. 2) Move the pelvis up towards the sky, forearms and legs are carrying the body weight and touch still the ground. 3) Hold this position
Trained skills:	Functional strength
Primary goals:	Strengthening of almost all muscles
Secondary goals:	Buttock in line with the body, shoulders should not be moved towards the ears
Details:	20 seconds duration
Result (Output):	Implicit: duration
Contraindications:	surgery less than 12 weeks ago, chemotherapy 2-3 days ago
Sources:	H5, H7

Table 5.10: Definition of exercise EX-08: Armstütze Profi (German title).

changing data [39]. The price for a Fitbit watch starts at 70£ (May 2023), but an account is required for usage [38].

Secondly, it was analyzed whether to obtain steps by using a service provided by Google. Since the Fit Android API has been deprecated, the new health service, Health Connect was investigated. The Health Connect App is an Android system app starting from Android 14 [47]. It provides an API for both reading and writing health and fitness data on a user's device [46]. If an app requires write or read data access to Health Connect data, a Developer Declaration Form has to be filled out, documenting the reason for access and an use case description [45]. In the end, this approach was not chosen because of the lack of a compatible Android Watch, but would have worked with the Fitbit app.

Finally, a smartwatch called PineTime [4] was selected as an input device to count steps per day. One reason to use this watch is that it can be ordered as a development kit (unsealed) or sealed (ready-to-use) for about only 27$, for more information the author refers to the store page [106]. The firmware of this watch is open-source and is called InfiniTime [5], which works with Bluetooth low energy (BLE). Therefore is not dependent on an internet connection or a Web API and does not require an account.
In the context of android devices, BLE is described as follows. It was made to enable lower power consumption than classic Bluetooth. When using BLE APIs, the use of Bluetooth has to be declared in the manifest file, so that the user grants permission for Bluetooth. The application can then scan nearby BLE devices and when found, the Android device discovers capabilities by connecting to the Generic Attribute Profile Server (GATT-Server) on the BLE device. After that, data can be transferred based on available services and characteristics. The GATT Profile is a specification for sending and receiving data ('attributes') over a BLE link. Each attribute has a unique identifier (UUID) and is formatted as characteristic and service. A service is a collection of characteristics, whereas a characteristic contains a value and a descriptor, which presents the value of the data in a human-readable form [44]. To give an example, when working with the PineTime, the 'motion' service contains the characteristic 'step count' [63, 64].

To be able to implement BLE with Unity, a Unity Android plugin shall be used, which supports the discovery of devices, connecting to BLE devices and, depending on the particular API, even writing and reading abilities. For more information on the technical details of this plugin, the author refers to the Github page [146].

Game Design

In [123] a 'tetrad' of elements is proposed, which identifies four main categories of elements in a game. These four categories were used as a guideline for defining elements of the mobile game.

[4] https://www.pine64.org/pinetime/
[5] https://github.com/InfiniTimeOrg/InfiniTime

Mechanics summarizes rules, goals and processes in a game [123].
As depicted in the first prototype, the space of the game consists of a straight line the player can walk that lies within different environments. The player can only move forward. In fact, the main goal is to walk as far as possible. Goals were divided into short-term, mid-term and long-term goals and are listed in Table 5.11.

	Goal	How	Reward
ST	Gather the first star*	Exercising 1 MET hour	Key
ST	First checkpoint completion*	Do the first (preoperative) checkpoint	Speed is increased permanently
ST	Complete configuration*	Start the app and complete the configuration	Ability to gather chests
ST	Gather 10 stars per week	Accomplish exercises and/or the walking game	Key
MT	Complete stage	Play the walking game	Unlock next stage
MT	Open chests	Combine chests with keys	Artifacts
LT	Complete all stages	Play the walking game	-
LT	Complete 3 checkpoints*	Complete initial checkpoints and two more regular checkpoints	Speed increase

Table 5.11: Short-term (ST), mid-term (MT) and long-term (LT) goals of the game. Goals marked with a * can only be completed once (achievements).

The elements which can be gathered are stars, keys, chests and artifacts. Stars can be obtained through the completion of exercises. Ten stars will be rewarded with a key, as the weekly activity goal, based on the literature research, is 10 MET-hours [118]. Chests are found along the way and will result in finding an artifact when combined with a key. As soon as (at least) one key and (at least) one chest are found, the chest is opened automatically and the artifact text is displayed. When the amount of stars exceeds 10, this does not play a role, the user does not get additional rewards.

To scale the rewards of the exercises and consider the suitability of each exercise, depending on the post-operative week, there is a table for each exercise that rates the reward in dependence on the week. For example, a simple early-postoperative exercise is very suitable in postoperative weeks 1 and 2, but will not be rewarded in later weeks, such as week 6. Vice versa, some exercises are not suitable for the early-postoperative phase and are therefore locked from being played in the first place.

One additional note considers the symptom tracking feature: In meetings with stakeholder H5, the sensibility of features such as symptom tracking was discussed. The recommendation was to not push the symptom tracking too much, as for psychological effects. As a consequence, there is no reward or punishment for tracking or not tracking symptoms, and therefore the symptom management part of the application is not really related to the main game. As such, users are also not informed about possible symptoms.

Story is defined as a sequence of events in the game [123].
The story of the game is as follows. A new land is to be discovered by the player. He/She shall gather artifacts, which are hidden in chests that can be unlocked with keys. Additionally, in order to discover more territories of the land, the player must move forward. The main goal of the game is to walk as far as possible and gather all available artifacts to fully discover the territory and its history.

Aesthetics influences the game experience and includes how the game looks, sounds and feels [123]. These aspects were already considered as a part of UI considerations (see section 5.2.2) and reviewed during mockup presentations of prototype 1. The overall concept of the game was to develop a relatively vivid and colorful world. The inclusion of sounds is planned.

Technology includes instruments and interaction elements that enables the user to play a game [123].
For the implementation, Unity will be used (see also section 3.3.4), because of the many contributions in the asset store, many users in the support forums and the compatibility with the chosen plugin for BLE devices. To create UI elements, the so-called UI Builder can be used, which is a part of the built-in UI Toolkit [6].

Secondary Goals

The handling of secondary goals was considered as not as necessary as in other rehabilitation domains, as the exercises are of a more general nature. Furthermore, the game is intended to be used as an additional offer besides the funded rehabilitation programs, which already allow for face-to-face instructions.

Nevertheless, it was investigated whether to implement a motion tracking approach for detecting the variety of movements in this rehabilitation domain, but this would have impacted the use of mobile devices. Moreover, the researched possibilities (for example, Stereolabs Zed [7]) to track whole body movements would have needed an additional camera, which was not in line with the general idea to build a solution that can be easily used at home, having any budget. Other approaches like deepmotion [8] did manage to capture body movements in real-time, however, it seemed like the output was a video that could be incorporated into a game (beforehand). Additionally, the free version supported 20 seconds of recording, which would have been too less for this project. Furthermore, the use of Virtual or Mixed Reality was investigated. The research showed that these

[6] https://docs.unity3d.com/2021.2/Documentation/Manual/UIElements.html
[7] https://www.stereolabs.com/docs/unity/body-tracking/
[8] https://www.deepmotion.com/3d-body-tracking

technologies could possibly be integrated with Unity [145], but remain relatively costly for the use in research projects.

All in all, it can be noticed that there were a few points hindering the useful tracking of secondary goals, whereas it was discovered during the expert interviews, that exercises are more general than in other rehabilitation domains, so the benefit-cost trade-off favored a more easy approach.

5.2.4 Patient Questionnaire

In addition to the stakeholder interviews, a questionnaire for breast cancer patients was carried out. It consisted of 12 questions in German and was managed through Microsoft Forms[9]. The questions are listed in the appendix, Tables B.2 and B.3. The distribution was managed via acquaintances and healthcare professionals. Hurdles in distributing the questionnaire were 1) a small circle of eligible respondents and 2) disturbance of the topic - a few people refused to take the survey because they were not willing to deal with the topic any more than they do as a patient.
The questionnaire could be answered from March, 14th 2023 to 23 April 2023, and was submitted by 16 participants. The average duration was 5 minutes and a half, not considering an outlier of about 2 hours.

The average age of respondents was 54.16 (min: 32, max: 78). 10 out of 16 (62.5%) patients accomplished a funded rehabilitation by the healthcare coverage providers (krankenkasse-geförderte Rehabilitation), while 6 (37.5%) stated that it was not necessary in their case.

In terms of exercise habits, the following results were obtained: 50% of respondents exercise more than 2 hours per week. The majority (10/16, 62.5%) considered it as a factor of motivation 'when I understand why', while the second highest motivator was 'when I notice my improvements' (7/16, 43.75%), followed by 'when doing sports together' (6/16, 37.5%). Interestingly, only one asked person found doing sport against each other in a competitive manner motivating.
The highest-rated reasons for not doing sports or exercise were: not feeling well enough (8/16, 50%) and that the healthcare professional did not recommend it (6/16, 37.5%). Other reasons were no time and cannot make a habit of it (5/16, 31.25%, respectively). The majority (12/16, 75%) stated that they received information on exercising with breast cancer by healthcare professionals/physicians.

Investigating the use of fitness and health applications in this age and patient group, the respondents were asked if they know and use such apps and whether they find them interesting (multi-selection question). More than half of the questioned patients (9/16, 56.25%) don't use such apps but found this an interesting topic, while 6 participants (37.5%) stated they are not interested in this subject. The mean age of interested patients

[9] https://forms.microsoft.com/

was about 53 years, while the mean age of not-interested respondents was about 60 years. Four participants (25%) selected that they already heard often about digital apps in the health- and fitness domain. Of these, 3 out of 4 participants selected that they are interested in such apps. Interestingly, none of the not-interested respondents said that they had heard often about such apps.

As another part of the questionnaire, the symptoms and health issues were assessed to get a more direct impression of the situation. One question was about the difference in physical health between pre-diagnostic and post-diagnostic time, rated from 1 (no difference) to 5 (big difference). For this question, there was no clear answer, as the answers were very different. The number which was most often chosen was the number in the middle, 3. All in all, 10 respondents (62.5%) answered with 3 or higher.
For the symptoms, there was a similar trend. The participants had to rate the presence of symptoms from 1 (strongly disagree) to 5 (strongly agree). The median values were 2.5 (tiredness/fatigue), 2.5 (psychological impacts), 2 (pain) and 2.5 (reduced ROM in the abdomen). Moreover, each symptom was rated as present (4 or 5) by 3 respondents (18.75%), each, while 8 to 9 respondents (50% for tiredness, psychological impacts, reduced ROM and 56.25% for pain) rated symptoms as not being present (selected 1 or 2).

In terms of preparing for follow-up visits, it was asked whether they could remember all the symptoms they had or how they have been in the past 3 months. Here, half of the respondents said they could remember everything, 7 participants (43.75%) chose neutral, and 1 person agreed that she/he cannot remember well.

Conclusion To sum up, the response rate was a bit too low to investigate all issues in detail. Nevertheless, the questionnaire showed that already many breast cancer patients do the funded rehabilitation or don't need a rehabilitation program. In fact, none of the participants selected that a rehabilitation program would have been necessary but wasn't carried out. This supports the requirement of the app being intended in addition to the funded rehabilitation further.

A surprising result was that 50% already exercise 2 hours or more per week. This is a positive finding, although it could be argued that especially this question tempts a little bit to give a false or too optimistic answer. All in all, it is still a positive result that only 25% do sports almost never or less than 1 hour per week.
In terms of motivation factors, it was clear that it is motivating to understand why exercising is necessary. This finding further highlighted the importance of information. Noticing improvement was considered another motivating factor.
Assessing reasons for not doing sports, the fact that 50% of participants were not feeling well further influenced the importance of a symptom tracking functionality within the app. Additionally, patients who have severe symptoms will still use the app and in return not lose the connection to the fitness program and will have a constant reminder. Also, with the tracking they can see improvements in symptoms which could also be a motivation.

The majority rated the physical health difference (pre-diagnostic vs. post-therapeutic) as neutral. The high number of ratings may come from the situation, that they do not know how the status was before and how it is now. This interpretation highlights the importance of a baseline and retakes of checkpoints. In terms of the symptoms, medians point to the conclusion that the neutral position ('teils-teils') was here very popular, too, although it is to be noted that the median rather emphasizes the not-having-symptoms side. This may also give the hint that patients experience the symptoms very differently for different weeks and days, and therefore they may find use in a symptom tracker.

Therefore, the results of the patient questionnaire influenced the following requirements or highlighted the importance of the following requirements, already existing requirements initially listed in Table 5.2:

- R-03 : Result supported the observation that funded rehabilitation is already widely used.
- R-06: Result supported the importance of good explanations of the exercises so that patients know why an exercise is useful.
- R-12: Result supported the assumption that patients' physical health/fitness differs between the time of diagnosis and the after-treatment phase. This supports the idea of having a comparison at hand.
- R-17 (new, see below): Result supported the assumption that spotting improvements can increase motivation.
- R-18 (new, see below): Result supported the importance of symptom tracking, as 7 to 8 of 16 respondents did not negate that certain symptoms are present.

As only one respondent considered it hard to remember symptoms or general state of health throughout the follow-up visits, this influenced R-12 in changing the focus to checkpoints as support for remembering and not provide a dedicated page (see Table 5.13).

5.2.5 Second Prototype

Based on the feedback and new insights, requirements were updated accordingly. Table 5.12 lists all new requirements while Table 5.13 summarizes the changes to requirements already defined in prototype 1.

Requirements R-10 and R-11 were deleted because exercises were defined separately (see Tables 5.3 to 5.10).

Additionally, use cases were finalized by providing more detailed descriptions. They are listed in section 5.3, Table 5.19 to 5.24, for better readability.

ID	Description	P	Source
R-14	The defined goal of MET is 10 hours (150 minutes moderate or 75 minutes vigorous activity) per week. The points (reward) for this achievement are gathered depending on the action/exercise.	1	H7, [118]
R-15	The schedule of the application shall be influenced by the situation of the patient.	2	H7
R-16	The available exercises are defined by: name, sequence of actions, trained skills, primary and secondary goals and result/output. Optionally, contraindications and difficulty levels can be defined.	1	[110]
R-17	After each checkpoint and non-early-postoperative exercise, the user can optionally rate how exerting the actions have been, using a 10-point scale.	2	H7, [60, 149], PQ
R-18	The user can create symptoms and determine the frequency of the tracking (e.g. once per week). The symptoms shall be tracked using a 10 Point Visual Analogue Scale (VAS).	2	H2, H5, H7, PQ
R-19	A physiotherapist shall be able to assign suitable exercises to supervise patients.	3	H5, H7

Table 5.12: A list of in iteration 2 new requirements.

The mockups from prototype 1 were updated according to the new requirements but also updated in terms of Android guidelines and design. In particular, new pages were added and existing pages were updated. A detailed description of each screen can be found in section 5.5. The following highlights the changes with respect to the previous prototype.

- Profile page added (see Figure 5.5b)
- Game world was updated to be more realistic (see Figure 5.5b)
- Checkpoint was updated to the new requirements and the defined flow (see Figure 5.5a)
- Tab bar and menus were a bit restructured, because of the addition of a profile page
- Tab bar was adapted to the Android guidelines (also, a placeholder for icons was introduced)
- List of symptoms with detail view was prototyped (see Figure 5.5e)
- Symptom tracking rating was changed from buttons to a discrete integer slider (see Figure 5.5f)

ID	Change	Justification
R-03	Source: +PQ	Patient questionnaire as additional input
R-06	Source: +PQ, Priority: 1	Patient questionnaire as additional input
R-08	Description: The application shall be able to track the following information: symptoms and goals in rehabilitation.	Weight is already captured by the checkpoints.
R-09	Description: The patients shall be able to do a self-assessment about their goals, which can be shared optionally with healthcare professionals.	Self-assessment is more useful about goals and not about fitness (feedback by H7).
R-12	Description: Every 3 months, a checkpoint can be accomplished which consists of a 6 minute walk test, a 1 minute sit to stand test, a goal assessment and an opportunity to type in the weight. The history of these checkpoints can be used as a summary for follow-up visits, for example, or to compare performance with time. Source +PQ.	More details defined/change of focus. Patient questionnaire as additional input

Table 5.13: List of in iteration 2 updated requirements, based on provided feedback, more detailed concepts and the outcome of the patient questionnaire

- Concept of cards (android guidelines) was applied to the fitness list and the exercise list (see Figure 5.5c)
- New page for viewing goals was prototyped (see Figure 5.5d)
- Back-Button was removed within the checkpoint pages

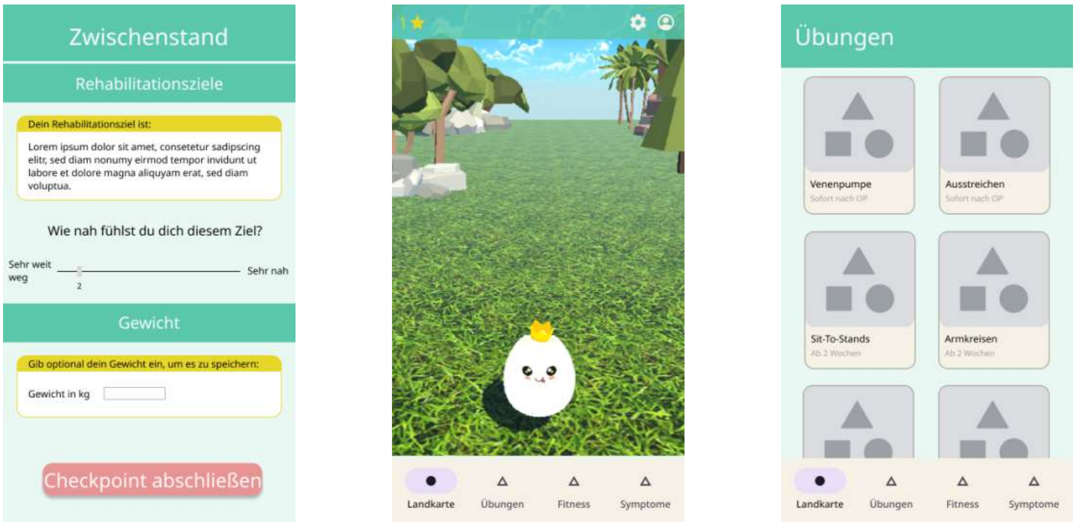
To give examples, Figure 5.5 displays some of the mentioned updates. For the final screenshots, please refer to section 5.5.

5.3 Iteration 3

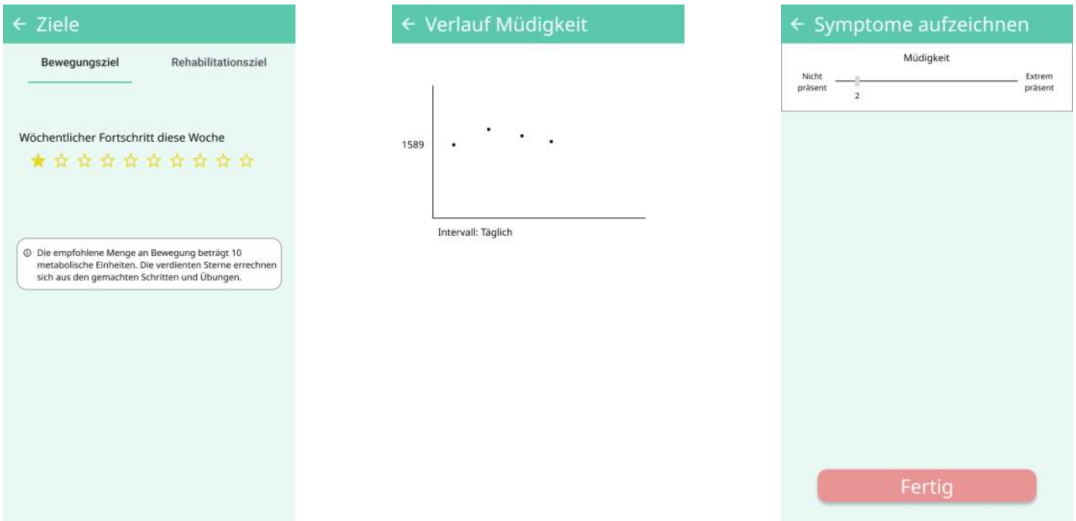
Iteration 3 consists of clarifying open questions, defining the reward system in more detail and finally implementing the solution in Unity.

5.3.1 Gathered Feedback

During the interview that was conducted on April 8 regarding iteration 1 (see section 5.2.1), a first draft of the exercises already existed so the following feedback was provided



(a) Self assessment (b) Main screen (c) Exercise list



(d) Goal page (e) Symptom history (f) Symptom rating

Figure 5.5: Selected parts of the second prototype. (a) Self-assessment part of the checkpoint. (b) Updated game environment, including stars, settings and profile button. (c) List of available exercises in the 'Übungen' tab. (d) Goal page displaying the rehabilitation and the MET-hours goal. (e) Detail view of a symptom. (f) Slider in the symptom tracking dialog.

by stakeholder H7. The exercises vein pump and walking, were considered as good. With regards to the walking exercise, it was recommended to motivate the users not only for walking but also for faster walking, as this is also a good opportunity for breast cancer patients. Other than this, it was confirmed that the vein pump exercise is a good early-postoperative exercise. Furthermore, it was recommended that other exercises should not be done in the first two weeks after the surgery.

In addition, two interviews were conducted on April 18, with stakeholders H2 and H5. The sessions were between 10 and 25 minutes. The mockups of iteration 2 were shown and explained to the stakeholders. The provided feedback was as follows:

- Relevance of the BMI: As it does not consider all or many factors, the BMI is not as important as it was in the past. Therefore, providing the height of the patient makes less sense. (H5)
- Retake of the checkpoint: Taking into consideration that the 1sts test can be done anytime and the walking game can also be played if wanted, a manual retake of checkpoints is not that necessary.(H5 confirmed, already included in prototype 2)
- The VAS rating should be done with colors or smileys, words should be avoided. (H2, H5)
- It would be good if the patient could pause the program, e.g. when on funded rehabilitation. (H5 confirmed work with H7 in previous iteration)

Moreover, the concept of MET-hours and stars as a reward was re-evaluated. The consensus was that the star system shall be adapted at least for the first postoperative week. It was decided that (at least) this week, the 10 stars can be reached more easily. Consequently, easy early postoperative exercise should lose value with each postoperative week, so that users have a challenge. Generally, it was recommended to look at the official MET hours table to determine the amount of rewarded stars.

Additionally, it was stated that rating subjective exertion is a good idea and would be useful and even motivational.

5.3.2 Third Prototype

The remaining feedback was again analyzed. Additionally, the application was implemented.

Reward System

Before the implementation, the reward system had to be more clearly defined, based on the feedback provided for iteration 2 (see above). In fact, a MET-table was researched as recommended to estimate the reward for each exercise.

The following list summarizes constraints for the reward system that have been gathered so far:

- As stated in R-14 (see Table 5.12), the weekly goal of activity is 10 MET-hours. These MET-hours are translated into 10 stars that can be gathered within the game by doing exercises.
- According to the feedback, the difficulty shall be lowered in some form, at least for the first postoperative week.
- Easy exercises shall lose value with each postoperative week
- The reward per exercise should be oriented on literature-backed MET table(s).
- The implementation of the application shall support training and reward system for the first 6 postoperative weeks.

As the reward system is based on estimations, it was subject to expert evaluation later on (see section 5.4). The reward system for the walking exercise was slightly changed during the evaluation, this change is not considered in this chapter.

Walking exercise According to a metabolic equivalents table from 1990 [66], one hour of walking 3 km/h is translated to 1.8 MET-hour, while 5 km/h are 3.2 MET-hours.
When again looking at the physical activity guideline for cancer survivors [118], 10 MET-hours were matched with 180 minutes of walking. Therefore, 18 minutes of walking is one MET-hour. According to this calculation, one hour of walking would be around 3.3 MET-hours.

Now, the step tracking gives no information on the duration, so it had to be estimated how many steps can an early postoperative patient go in 18 minutes.
The calculation was based on the author's smartwatch statistics. For 3542 steps, the smartwatch showed 2.55 km. This means, that about 1390 steps were accomplished per kilometer. Assuming a slow pace of 20 minutes per kilometer for early postoperative patients (author's watch showed 16 minutes/km), it can be estimated that 1000 steps could be awarded with 1 MET-hour.

Early exercising As for the week 0 (= first postoperative week), the recommended amount (stakeholder H5) of vein pump exercise is 5 times per day the first 3 days, then 3 times per day. Additionally, patients can slowly start to walk in a very slow tempo. All these activities shall lead to 10 stars.
All in all, the vein pump shall be carried out at least 27 times. When each exercise is rewarded with 0.3 stars, the user get 8.1 stars for this. This results into 10 stars, if 2000 steps are made during the first week. The reward shall be lowered for each week, as shown in Table 5.14.

Strength exercises General weight training is translated to 10.9 MET-hours [66]. For one minute sit-to-stands this can be translated into 0.2 MET-hours. Because this is a bit too low for early postoperative patients, this was rounded to 0.5 to enhance motivation.
For the wall plank, the duration is not fixed and depends on the speed and repetitions. Nevertheless, the exercise can be challenging for patients. Based on experiments, the duration is estimated to 2 active minutes. This would lead to about 0.4 MET-hours per exercise. As the wall plank is a new exercise in week 5, the reward was still set to 1, with the option to lessen it for further weeks in future approaches.

Table 5.14 presents the reward per exercise, influenced by the postoperative week. For example, doing the vein pump exercise one time would lead to 0.3 MET-hours of reward in postoperative week 0, however the same action would result in 0.1 points of reward in week 4.

Postoper. week	Vein pump	1STS	Wall plank	Walking 1000 steps
0	0.3	0	0	1
1	0.2	0	0	1
2	0.2	0.5	0	1
3	0.1	0.5	0	1
4	0.1	0.5	0	1
5	0.1	0.5	1	1

Table 5.14: Rewarded stars (=MET-h) per exercise and postoperative week. 0 = not allowed.

Checkpoints To make the checkpoints more attractive, the reward for a checkpoint is 1 MET-h.

As a result, the requirement R-14 was updated as displayed in Table 5.15.

ID	Change	Justification
R-14	Description: The defined goal of MET is 10 hours (150 minutes moderate or 75 minutes vigorous activity) per week. The points (reward) for this achievement are gathered depending on the action/exercise and the postoperative week (0-5), as described in Table 5.14. Source: +[66]	More details

Table 5.15: Update of requirement R-14 in iteration 3.

To illustrate possible schedules, appendix Table A.1 presents examples of training distribution from week 0 to 5.

Implementation

The implementation of prototype 3 took place from April 20 to May 10. The implementation was planned in work items, mainly use case-wise. For each work item, time effort in days was estimated. The work items were implemented in the following order:

1. App configuration (UC-01)
2. Walking exercise (UC-04) incl. configuration of smartwatch
3. Exercises (UC-03)
4. Checkpoints (UC-02)
5. Profile page
6. Symptom tracking (UC-06)
7. Bug fixes and other enhancements

The use case UC-07 (Supervise patients) was not implemented, because the inclusion of a healthcare professional in the system turned out to be out of scope. Additionally, data that was intended to be useful for the healthcare professional was not implemented as a data input field (e.g. in the configuration screen).

The following shall summarize the most interesting and note-worthy highlights of implementing the game in Unity.

Version control For version control, a private gitlab [10] repository was used with 1 branch. Imported packages available in the Unity Asset Store and other textures were not checked-in to keep the repository fast and lean.

Unity project Unity Editor was used with version 2021.3.20f1. The project was set up to support Android devices. The following assets were imported from the Unity asset store and used in the project:

- Low Poly Tree Pack, Low Poly Rock Pack and Low Poly Fence Pack by Broken Vector [10, 11, 12]: provided game objects
- Free Casual Game SFX Pack by Dustyroom [31]: provided sound effects
- Fantasy House and Water Texture by Lowlypoly [80, 81]: provided game objects and textures
- Ground textures by Nobiax/Yughues [101]: provided textures

[10] https://about.gitlab.com/

- Kawaii Slimes by Awaii Studio [135]: provided the player object
- Low Poly Nature Forest by Pure Poly [114]: provided game objects
- Simple Low Poly Nature Pack by NeutronCat [98]: provided game objects
- Sky Series Free by Avionx [2]: provided textures for skies
- Gridbox Prototype Materials by Ciathyza [24]: provided materials
- Plank Textures by A dog's life software [1]: provided textures

The game consists of 8 scenes and 8 UI Controllers. There are 4 Manager classes and 14 additional scripts, excluding the scripts for handling ble devices. For defining the UI, about 28 UI Element files (.uxml) were created.

User Interface For the font and the icons, as already discussed, the style guideline (see [50]) was followed. Noto Sans Font was chosen and successfully imported to Unity as a Font Asset, however, a problem appeared during testing because the used tablet could not display this font, possibly because Lineage OS could not cope with it. In the end, the Unity default font was used to support the tablet and the simulator. Furthermore, the icons were exported from the Figma project for the mockups and the Figma Project provided by Google Fonts [48], which is free to use under Apache 2.0. Once downloaded, the SVG files were resized using Inkscape [11].

Unity comes with a built-in editor called UI Builder and there are some pre-defined UI elements that can be used. For the UI elements, the guideline regarding components was followed [49], but had to be manually created to be as close as possible to the recommended elements.
For buttons, the recommendations to have a height of 40dp and a 20dp corner radius could be implemented with the UI Builder, but applying a shadow to a button was not possible so it was faked using bottom and right borders. The so-called cards were created by combining various boxes and labels with a button. This concept was not applied to the exercise list, as the cards did not support a dynamic list in an easy way, because they were hard-coded in the UI files. Regarding images, the guideline of padding of about 16dp was followed, however, the handling of images was a bit difficult as they can only exist as a background of other boxes. Tabs were hand-crafted by manually switching the underline color when a button is pressed. The dialog window is also implemented based on the design guideline, using the recommended shape, width and paddings. For the profile edit menu the full-screen dialog was implemented.
Unfortunately, text fields could not be adapted much, so they do not look as recommended by the Android design guideline. This also applies to scroll bars, sliders and radio buttons.

[11] https://inkscape.org/

Database structure In Unity there are multiple ways to save data of different kinds. However, there is a built-in solution for serializing and deserializing data which is called JsonUtility. The JSON data is saved in a file or over a network [153]. Based on the example repository mentioned in the Unity blog [153], a File Manager, a GameStateManager and a class called GameState were created. As the names suggest, the file manager saves and gets the data to/from a file. The GameState class contains data over a single game state. The GameStateManager can load and save game states by using the File Manager. As mentioned in [153], the Utility is not a fully-featured JSON implementation. Custom classes, for example, the Checkpoint class, cannot be serialized directly and have to be converted into a struct. Luckily, lists can be serialized. For example, a serialized list of finished exercises may look like this:

```
"exercisesFinished":
[{"id":0,"idExercise":0,"date":-8585179652626466044,
"primaryResult":30,"secondaryResult":1},
{"id":1,"idExercise":2,"date":-8585179650095450650,
"primaryResult":3,"secondaryResult":4},
{"id":2,"idExercise":1,"date":-8585179649836359081,
"primaryResult":5,"secondaryResult":2}]
```

As can be seen in the example, the date was converted into JSON-compatible form by using Date.ToBinary.

The corresponding C# code in GameState.cs would look like this:

```
[Serializable]
public struct ExerciseDone
{
        public int id;
        public int idExercise;
        public long date;
        public int primaryResult;
        public int secondaryResult;
}
```

Using JsonUtility was a really simple approach to saving data, although it is to say that saving health-related data to a local file is not the best option. Additionally, the file could be manually modified with each editor, which was very useful for testing the application, but is not a solution to strive for, especially when it comes to games.

Connection to smartwatch As mentioned in section 5.2, a plugin [146] for Unity was used to include BLE-related functionality in the game. The code was downloaded from the GitHub page. After analyzing the example Unity project, the code was integrated into the master thesis Unity project. The plugin provides functionalities to search and connect to BLE devices and to read/write to characteristics. The implemented workflow for connecting the mobile app to the PineTime is as follows:

1. The MAC address of the PineTime is typed in the text field in the settings (during testing and because there was only one watch available, this field was always prefilled)
2. The plugin searches available BLE devices and initiate a connection when the wanted device is found
3. When connected, the plugin is asked to fulfill a read request to get the current amount of steps from the watch to the application
4. After this, a subscription request is scheduled, to get all updates of the steps
5. After starting the app the first time on a new device, the application attempts to automatically reconnect to the watch

During testing, it was noticed that sometimes the watch cannot be found. This was usually fixed by turning Bluetooth on the PineTime off and on again. Also, the distance where a connection is kept upright seems to be not that long. When the PineTime was out of range and then came back, the plugin did not reconnect automatically. However, for a free plugin, which was also developed during a master thesis, it worked pretty well.

Figures and Graphs Unity does not provide a possibility to create graphs and figures, to display the history of results in exercising, for example. Therefore the history was implemented by using lists, so that results look like tables (see also Table 5.12(a)).

Localization Unity does provide localization by providing a package. It turned out that this package is not yet compatible with the UI Builder, which was used to develop the user interface elements, so that localization could not be done. In fact, as of May 2023, it is a planned feature on the Unity product board, for more information see [142].

Testing Unity provides a simulator for Android devices. However, the Bluetooth connection to the smartwatch could of course not be tested with this. The main device which was used to test the application was a tablet, Samsung SM-T815 with Android version 11 (Lineage OS). Unity could load a build or a patch, an apk file, to the device and run it. Additionally, there was the option to run the app remotely on the device using an app by Unity called Unity Remote, but this was not used very often because the quality was blurry. Moreover, it is to say that there were mismatches in the layout between the UI Builder, the device simulator and the 'real' Android device, so only building the apk to the device was the most suitable and useful approach.

5.4 Evaluation

The evaluation iteration was carried out between May 10 and May 24. It consisted of an evaluation with users and an evaluation with experts. It aimed to validate requirements (**RQ1**) and suitable exercises (**RQ2**).

5.4.1 Usability Study

A moderated usability study was carried out with 4 participants. Three breast cancer patients were contacted and invited to do a usability test via E-Mail. Unfortunately, no breast cancer patient could be obtained to test the app, so the users testing the usability were no patients.

Plan For preparation, a *Google UX Design Certificate* e-learning video by Google [43] was watched and used as a first basis.
Participants were recruited through acquaintances and ranged in age and gender. 3 participants were female and 1 was male. The age was between 25 and 81. The usability study was carried out in German.

The usability study plan contained instructions on what was expected from participants, what they have to fill out and which data was obtained from them.
A list of tasks (see Table 5.16 (translated)) was defined in such way that it covers all implemented requirements and use cases. Participants were asked to complete them using the application at hand. Moreover, open and follow-up questions were asked to get more information from the participants, as needed.

In addition, the study was planned to be concluded by answering a questionnaire. The System Usability Scale (SUS) consists of 10 questions which should be rated from 1 (strongly disagree) to 5 (strongly agree) [13]. In addition, the scale has alternating positive and negative items so that response biases are avoided [14]. The questionnaire was translated to German by the author, highly influenced by an existing German translation [120], and is provided in the appendix, Table B.1. However, it is to note that translating the questionnaire for non-English speakers could have implications for reliability and validity [14]. The final score is one number that reflects the overall usability of the system. Scores for individual items are considered as not meaningful. Derived by the rating, the value can be from 0 to 4. For positive items (1, 3, 5, 7, 9), the score is the position minus 1. For negative items (2, 4, 6, 8, 10) the score is calculated by subtracting 5 from the value. The sum of all scores is then multiplied by 2.5, resulting in a range from 0 to 100 [13].

The questions were included in a Google Forms web page [12].

Execution Participants were asked to use the 'think aloud method' by communicating their thoughts in parallel to the test. For note-taking, a spreadsheet was created with

[12] `https://www.google.com/forms/about/`

Usability Study Tasks (Activities)
Configure the application with the following scenario: You type in your weight. You did not get a surgery yet, and you don't have a date for your surgery appointment.
Carry out the activity which is proposed to you by the app, based on the information you just provided.
View the data you provided during configuration.
Edit your surgery date to a date at least 2 months ago.
View your rehabilitation goal before you start with an exercise.
Play the walking game. Do at least 1000 steps.
Do another exercise.
You want to track that your headache is okay today. How can you do that?
Additionally, you want to track your fatigue.
Tell me in what intervals the tracking of those symptoms has been defined.
View your today's achievements, what did you do for your fitness so far?
View how close you are to your weekly goal.
View whether you have to track symptoms left to track today.

Table 5.16: List of tasks that participants were asked to carry out during the usability study.

possible issues and observations in one column, and for each participant, an additional column was created. If an issue or observation came up, a '1' in the cell was noted. The duration of one test was about 30 to 40 minutes. After the completion of tasks, participants were asked to fill out the questionnaire (SUS).

Results Table 5.17 displays 43 observation items, that were noted during the usability study. It is intended that this list contains both 'negative' and 'positive' items. This is due to the note-taking approach: Some items were listed beforehand, because the author supposed participants facing the issue. Other items were creating during the usability test. For example, it was expected, that some participant would have problems to complete an exercise (5.17#42), but in reality no participant was observed facing this issue. For another example, observation #3 and #43 express which part of the app was used by participants to view today's achievements: All viewed the history of exercise, and surprisingly none thought of viewing the goals page.

#	Observation Item	Count
1	Finds the app informative	4
2	Likes the design of the app	4
3	For viewing today's achievements, history of exercises is viewed	4
4	Was not completely sure, if smartwatch is connected (before the checkpoint)	4

5	Did not watched the visual description for an exercise	4
6	Did not kept all instructions in mind	3
7	Difficulty finding weekly goal - confusion with rehabilitation goal	3
8	Liked the 'Pflücken' exercise, was considered as fun	3
9	Difficulty finding the rehabilitation goal (first time)	2
10	Checkpoint exercise was started without a hint	2
11	Would like to have the option to turn on music during the 6MWT	2
12	Did try the 1STS exercise before starting it, as recommended	2
13	Started singing during 6MWT	2
14	Difficulty starting the walking game	2
15	Difficulty creating and rating the first symptom	2
16	Found 'name' for symptom misleading	2
17	Finds the app really easy to use	1
18	Expected profile and settings in the tab bar	1
19	Found the color grey for information boxes slightly misleading	1
20	Found it necessary to learn the app	1
21	Expressed liking of the story	1
22	Did not type in the rehabilitation goal during checkpoint	1
23	Did not recognize changing screens from checkpoint explanation to 6MWT explanation	1
24	Proposed mentioning the exact interval of checkpoints in the checkpoint explanation	1
25	Proposed including hint to not eat before the checkpoint	1
26	Proposed displaying connection state of the smartwatch during the 6MWT	1
27	Did not fully get what the 6MWT was about	1
28	Liked the display of the time during 6MWT	1
29	Would have liked a description/reminder of what to do during an exercise (during the counting)	1
30	Was unclear about what exercise to do	1
31	Carried out one exercise incorrectly	1
32	Did not understand the color scale in the symptom tracking, propose displaying the scale as a whole somewhere	1
33	Could not name the tracking interval of the symptoms	1
34	Proposed displaying what symptom(s) have been tracked today	1
35	Difficulty finding user profile	0
36	Difficulty viewing today's achievements (either way)	0

37	Issues completing the checkpoint	0
38	Did not count or forgot to count repetitions during 1sts	0
39	Did not rate subjective exertion	0
40	Did not rate the rehabilitation goal	0
41	Difficulty finding other exercises than the walking game	0
42	Issues completing an exercise	0
43	For viewing today's achievements, goals page is viewed	0

Table 5.17: List of items (issues, observations) that were present (sorted by the total number of participants who faced this issue or this behavior was observed by the moderator).

Based on the spreadsheet notes and especially the negative feedback, an additional list of planned improvements was created, including priority for each improvement based on the severity (relevance) and the number of participants who faced the issue. For example, Observation Items I#7 and I#43 (see Table 5.17) showed that 3/4 participants confused the weekly goal with the rehabilitation goal, and none of participants used the weekly goals to see what progress has been made today. Improvement #12 *Rename 'Bewegungsziel' label to 'Wöchentliches Bewegungsziel' for clarity* was created in an attempt to make the location of the weekly goal more clearer.
Additionally, general observations on technical behaviors of the app were also included. The list is displayed in Table 5.18.

#	Improvement	Source	Category	P
1	Make game explanations easily accessible anytime	I#6, I#10, I#14	General	1
2	Make the information box more present by not using grey as color	I#19, I#22	General	3
3	Ensure the correct number of steps in 6MWT by including a hint to stay close to the device to tackle disconnection issues (applies esp. to indoors).	T/O	Checkpoint	1
4	Show before the starting of 6mwt whether smartwatch is connected or not	I#4	Checkpoint	1
5	Emphasize the presence of a visual description more so that the user can find it	I#5	Exercises	1
6	Rename 'Name' label to 'Bezeichnung'	I#16	Symptom tracker	1
7	Prevent saving an empty symptom	T/O	Symptom tracker	1

8	Display date in detail view in Austrian format	T/O	Symptom tracker	1
9	Make the tracking vs. creating a symptom system more straightforward	I#15	Symptom tracker	2
10	Show which exact symptoms were tracked today	I#34	Symptom tracker	3
11	Show full color scale anywhere to support interpretation of it	I#32	Symptom tracker	3
12	Rename 'Bewegungsziel' label to 'Wöchentliches Bewegungsziel' for clarity	I#7, I#43	Goals	1
13	Move text prompting to define rehabilitation goal nearer to the input text field	I#22	Checkpoint	2
14	Make more visual differentiation between checkpoint intro and 6mwt intro	I#23	Checkpoint	3
15	Enhance 6MWT exercise by adding the connection status of the smartwatch and the possibility to activate motivational music optionally	I#11, I#26	Checkpoint	3
16	Add hint 'do not eat before' and exact checkpoint intervals to the checkpoint description	I#24, I#25	Checkpoint	3
17	Add revision of what to do during an exercise	I#29	Exercise	3
18	Center text in symptom tracking dialog	T/O	Symptom tracker	1
19	Provide some kind of summary for each exercise	T/O	Exercise	2

Table 5.18: List of derived main issues either based on the observation list (item number #) or based on technical reasons or other observations that were made during the test (T/O). Priority (P) ranges from 1 (must have), to 3 (nice to have).

In addition, the results of the usability questionnaire were analyzed. Using the calculation formula provided in [13], the result of each participant is shown in Figure 5.6.

It is to note that the SUS score is not a percentage. In fact, it was investigated that a SUS score of 70 may be around the 50th percentile. However, it is possible to grade the outcome of SUS scores. The proposed grading was researched by analyzing the relationship between the SUS score and adjectives like 'good' or poor' [14]. According to this classification, two participants found the system 'good', while two participants considered the system as 'excellent'.

Improvements After carrying out the usability study, the list of possible improvements was analyzed for pressing issues that must be corrected. Of the 19 items, 16 (84%)

	P1	P2	P3	P4
Question 1	5	4	4	5
Question 2	1	2	1	1
Question 3	4	5	5	5
Question 4	1	4	3	1
Question 5	5	5	5	5
Question 6	1	3	1	1
Question 7	5	5	5	4
Question 8	1	2	2	1
Question 9	4	5	1	4
Question 10	1	4	1	1
Total score	38	29	32	38
SUS score	**95**	**72,5**	**80**	**95**

Figure 5.6: Calculated SUS scores for each participant that took part in the usability study (screenshot from calculation sheet).

improvements were implemented. For a description of the enhancements, please refer to the next section 5.5. The following items were not implemented:

- Show which exact symptoms were tracked today (improvement #10)
- Enhance 6MWT exercise by adding the connection status of the smartwatch (improvement #15)
- Option to active motivational music during 6MWT (improvement #15)
- Add revision of what to do during an exercise (improvement #17)

Most of the above items represent user issues experienced by one participant each. Additionally, all had an assigned priority of 'nice to have'. However, the reasons for not implementing the above issues are as follows.
To show which exact symptoms were tracked today would have been a good feature. In the end, it was not implemented because it would have been better to get feedback from people who actually have symptoms and want to track them. Moreover, the tracking feature was not the main goal of the master thesis and already provides an overview of how many symptoms were tracked today and if any symptoms are left to track.
The second item was already partly improved by implementing improvements # 3 and #4. Additionally, it would not be that useful to warn about the distance when the user is far away from the Android device.
The option to include motivational music was an idea of two participants, but it is to say that the usability study was carried out indoors (due to bad weather), which is why the situation of an outdoor 6MWT could not be captured. Furthermore, there is already the possibility to turn on music on the phone, etc. so this improvement was considered as not that important and relevant for this master thesis.
For the last improvement on the list of not implemented items, it is to say that patients

are usually getting some kind of introduction to what they can do. Especially when talking to physiotherapist H5, it came clear that patients learn the exercises they are supposed to do at home. So for this point, the authors' impression was that unrelated people (non-breast cancer patients) were at first not completely sure of the exercises. Only one participant did not carry out one exercise completely correctly, which could be considered a good outcome when only hearing once about the exercise in the description. All in all, this improvement could be the subject of investigation in future approaches carried out together with breast cancer patients.

5.4.2 Expert Review

Three reviews by experts were carried out. Firstly, a guided walk-through with the app was shown, similar to tasks in the usability study. The experts were asked to review the shown features. When the review was conducted in person, the experts had the opportunity to investigate the app on their own.

The first review was carried out together with stakeholder H5 on May, 11 and was conducted online for about half an hour. This appointment took place before the usability study.
The overall impression of the app was positive. Especially the following items were highlighted positively: images describing the exercises further and the structure of the app. Additionally, it was again highlighted that it is a good approach to not predefine any symptoms or give information on what symptoms may appear, because of psychological effects. The expert liked how the symptom-tracking feature was implemented. Another feature that was positively pointed out was that patients cannot start exercises not suitable for them based on the given surgery date and the resulting postoperative week. Further, it was stated that it would be useful to make a longer exercise (e.g. 6MWT) skippable for the case that patients want to conclude the exercise earlier because of health-related issues, for example.

The second review was carried out on-site with stakeholder H2 on May 23, so that the implemented improvements from the usability study (and from the first expert reviewer) were included in the presented version of the application.
The overall impression of the application was very positive. Especially positively highlighted were the following functionalities:

- Timer before the exercises start
- Protocol of recent messages (implemented after usability review due to item #1 (see Table 5.18))
- Vein pump exercise was considered more fun than doing the exercise the normal way
- Visual description with images

Additionally, the app was considered 'easy to use' and 'user-friendly'. It was presumed by the reviewer that such mobile games will possibly attract rather younger people because elder people would maybe have problems using the app. It was explained that the usability study was conducted with 2 people aged over 60 years and they would have liked the app and were able to use it.

The third review was carried out on-site with stakeholder H7 on May 24. Also here, the implemented improvements from the usability study (and from the first expert reviewer) were included in the presentation.
The reaction to the application was highly positive.

For the 6MWT, the following points were discussed:

- Impact on usability due to low Bluetooth step tracking range
- Assessment of steps vs. distance
- Usage of 2-Minute Walk Test in future approaches

Moreover, the reward system was discussed. The reviewer expressed concerns about rewarding every 1000 steps with one star. It was stated that patients would surely go more than 1000 steps per day and hence it would be more beneficial to change this behavior. The consensus was that the maximum number of stars that come from walking should be restricted to one per day. However, the virtual distance should not be cut and therefore be as it is. In fact, the background story and the game concept were considered fun and are thought to help a lot in motivating patients.

Again, it was confirmed that BMI is not relevant anymore and that it makes sense to not include the height then. It was confirmed that it is feasible that both ratings, perceived exertion and symptoms, are scaled the same way, 1-10. Moreover, the reviewer considered it positive to not include the tracking of the weight because under therapy it is even recommended to not lose weight. Therefore, an interpretation would have been wrong or unwanted.

To sum up, the following was highlighted as extraordinarily positive:

- Smiley scale and color scale
- Colors in the app
- Game world and character
- Vein pump exercise
- Symptom tracking not part of the game

Overall the app was considered a great initiative towards motivating people for exercising.

5.5 Final Result

The implemented prototype including all improvements, based on the evaluation, will be described step-by-step by explaining each use case and its requirements while providing screenshots from the developed application.

To sum up, 5 of 6 defined use cases (Tables 5.19 to 5.24) were implemented resulting in 14 of 17 implemented requirements. A full list of requirements is displayed in the appendix, Table A.3. Figure 5.7 displays a use case diagram for overview. Regarding the usability requirements obtained in the heuristic evaluation done in iteration 2 (see section 5.2), 5 were fully implemented, 2 were partly implemented and 2 were not implemented.

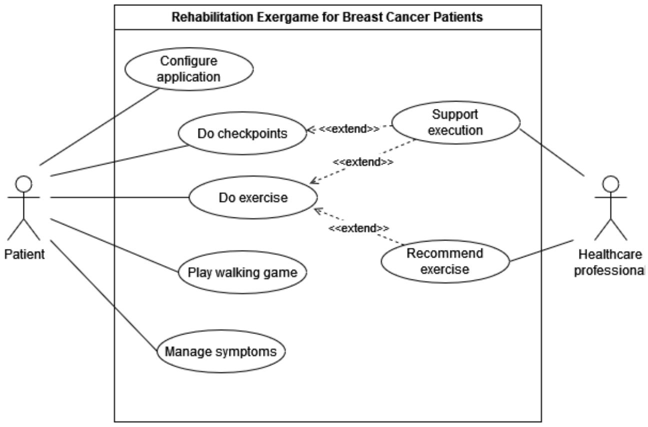


Figure 5.7: Use case diagram of the rehabilitation exergame.

Figure A.1 in the appendix describes the developed application in form of a screenflow diagram.

5.5.1 Starting the App

Configuration

The Configuration use case is about how the user has the possibility to configure the app.

For the use case description, refer to Table 5.19. The following requirements are related to this use case:

- The user can provide the following information: job, socio-economic environment. (R-13: not implemented)
- The schedule of the application shall be influenced by the situation of the patient. (R-15: implemented)

This use case was implemented, but without asking about data relevant for the healthcare professional, as this part was out of scope of this thesis. As can be seen in the screenshot

	UC-01: Configuration of the app
Description	When the user starts the app the first time, information for configuring the app shall be provided.
Trigger event	First starting of the app
Actors	Patient
Precond.	App installed on the device
Post cond.	App is configured
Result	The following information is provided by the user: weight (kg), height (m), gender, birth date, status of patient journey, Optional: date of surgery, Optional: job, Optional: social environment
Main flow	1) The application displays the fields. 2) The user fills in the fields and confirms to continue.
Alternative flow(s)	EF1: If a required field is not filled, the user gets a message communicating the issue.
Priority	1 - MUST HAVE
Related requirements	R-13, R-15

Table 5.19: Use case definition for configuring the mobile app (UC-01).

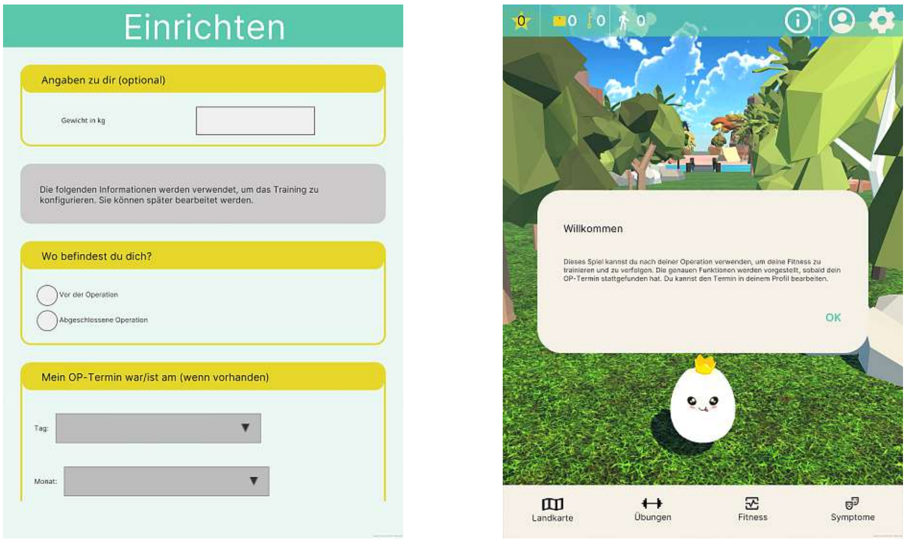
5.8a, the relevant data fields for the usage of the application by the user is limited to weight (optional), status and surgery date (optional).

If no surgery date is provided, it is assumed that the patient was just diagnosed and will have the surgery within the next month. Therefore, all the exercises are free to try out. Within the app, the user is reminded of doing the checkpoint before the surgery.
If a surgery date is provided, only suitable exercises can be started, according to the postoperative week if applicable.

Main Screen

After the configuration screen, the introduction is shown, depending on the status of the patient.
When the patient is preoperative, it is explained that the game starts after the surgery (see screenshot 5.8b) and that the user should now do the first checkpoint to track his/her fitness preoperatively.
When the patient is already postoperative, or the surgery day passed by, the introduction to the game story is presented.

The main screen can be seen in Figures 5.8(b) and 5.16 and contains a top bar with the following information: amount of gathered stars this week so far, number of chests and keys and how many steps were obtained today, if the smartwatch is connected.



(a) Configuration of the app (b) Message after configuration

Figure 5.8: Screenshots of (a) Configuration screen, (b) Introduction message for preoperative patients

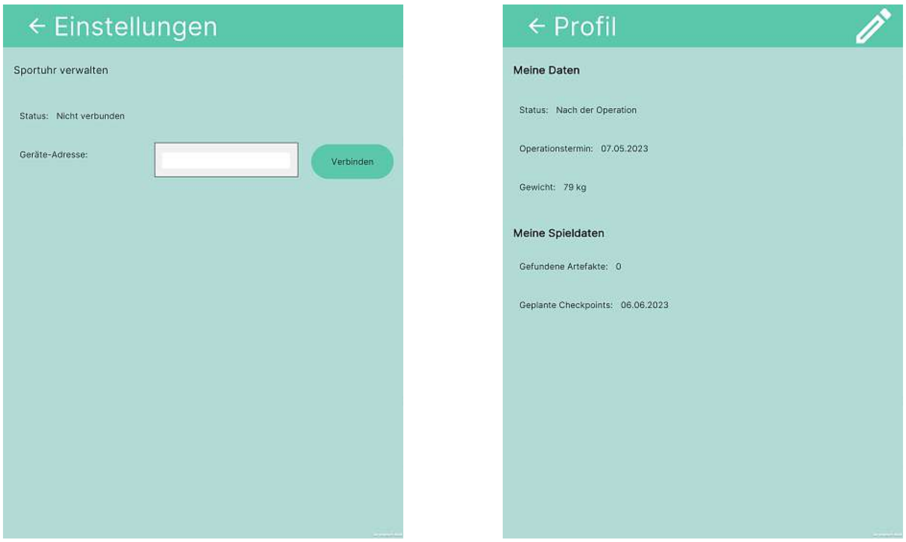
The exact number of stars is shown as the 'weekly activity goal' in the goal screen (see Figure 5.11(b)), where also the expert-based background (MET-h) of the stars is explained. The name was adapted based on the evaluation finding #12 (see Table 5.18).

The smartwatch can be connected by pressing the settings icons in the upper right corner, see Figure 5.9(a). Here, it was implemented that the label beside 'Status' displays the connection status. Other statuses are: 'Device found, waiting for connection...' and 'Connected'. The display of 'level', items and connection status is based on the heuristic evaluation done in iteration 2, see section 5.2.

The profile icon displays the profile, where for example, the surgery date can be edited, see Figure 5.9(b). Other than this, data related to the game is displayed, for example, how many artifacts were obtained. The chosen surgery date influences not only the exercises but also the journey status, which can be preoperative or postoperative.

As a result of the evaluation (see 5.18 #1), an additional icon can be found on the main screen, the information icon. It redirects to a page listing all viewed messages and gathered artifacts. This way, users can reread information given in the messages or the background story of the game.

Similar to the mockups, the bottom tab bar is the main navigation element within the app and follows the heuristic evaluation done in iteration 2 (see section 5.2) by using different icons.



(a) Settings (b) Profile

Figure 5.9: Screenshots of (a) Connecting the smartwatch (MAC address masked) and (b) profile page.

5.5.2 Checkpoints

This use case is about assessing fitness on a regular basis (see Figure 5.10(a)). The first checkpoint is especially relevant as it acts as the 'status quo' assessment, before surgery or any therapies. By providing historical data, the user may compare results.

One checkpoint contains the 6MWT (see Figure 5.10(b)), the 1STS and an additional page showing the current rehabilitation goal. This page also provides the opportunity to rate the goal and give the weight. The screenshot is displayed in Figure 5.11(a). For the two tests, a button was implemented to support ending the exercise early due to health or other reasons, which is also depicted in Screenshot 5.10(b). This can be seen as a partial fulfillment of the usability requirement 'Provide a way to cancel the execution of an exercise', obtained through heuristic evaluation in section 5.2.

The following requirements are connected to this use case:

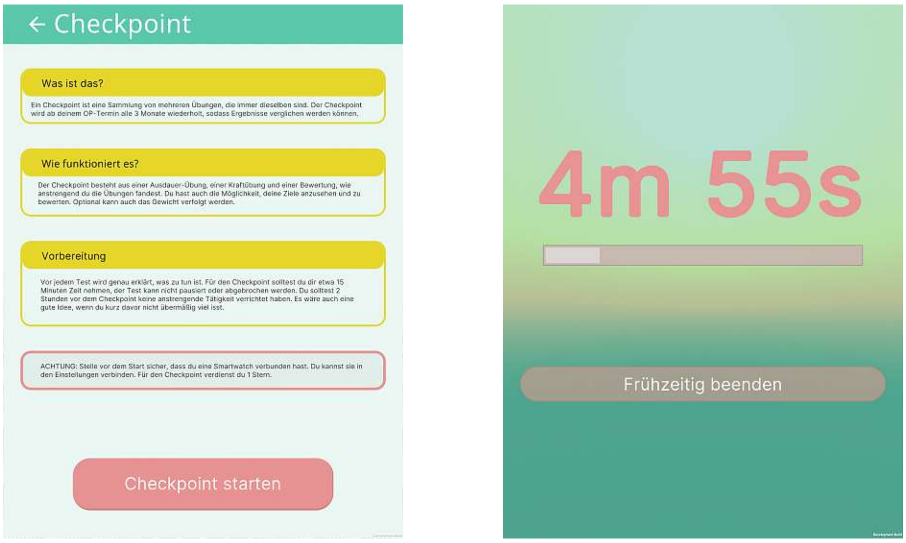
- The application must support the concept of prospective surveillance. (R-01: implemented)
- The application must support measuring the fitness of the patient preoperatively. (R-02: implemented)
- The application shall be able to track the following information: symptoms and goals in rehabilitation. (R-08: implemented)

	UC-02: Take and retake preoperative assessment (Checkpoints)
Description	Before the surgery, the user has the possibility to do a (fitness) assessment. The same tests can be retaken later to compare results. It consists of 6 Minute Walk Test, 1 Minute Sit To Stand Test and a self-assessment.
Trigger event	Press button 'Start checkpoint'.
Actors	Patient, optional healthcare professional
Precond.	Current date matches or is later than the next scheduled checkpoint date.
Post cond.	Assessment saved. Reward gathered, according to the MET definition. Rehabilitation goal is viewed in the goals screen. History of accomplished checkpoints is updated.
Result	The following information is the result of the assessment: achieved steps when walking 6 minutes, amount of sit-to-stands in one minute, goals self-assessment, optionally weight in kg, grade of exertion (1-10) per exercise.
Main flow	1) HCP recommends doing the assessment at home. 2) The user reads the description of 6MWT carefully to avoid mistakes. 3) 6MWT is carried out. 4) The application signals the end of the exercise and the result of the test is shown. 5) The user rates the grade of subjective exertion. 6) User reads the description of 1STS carefully to avoid mistakes. 7) 1STS is carried out. 8) The application signals the end of the exercise and the number of repetitions is provided by the user. 9) The user rates the grade of subjective exertion. 10) Self-assessment is filled out: rehabilitation goal can be edited and must be rated. Providing weight is optional.
Alternative flow(s)	The health care professional carries out the test together with the patient on-site. Step 10: For the first checkpoint, rehabilitation goals are defined.
Priority	1 - MUST HAVE
Related requirements	R-01, R-02, R-08, R-09, R-12, R-14, R-17

Table 5.20: Use case definition for accomplishing checkpoints (UC-02).

- The patients shall be able to do a self-assessment about their goals, which can be shared optionally with healthcare professionals. (R-09: partly implemented)
- Every 3 months, a checkpoint can be accomplished which consists of a 6 minute walk test, a 1 minute sit to stand test, a goal assessment and an opportunity to type in the weight. The history of these checkpoints can be used as a summary for follow-up visits, for example, or to compare performance with time. (R-12: implemented)
- The defined goal of MET is 10 hours (150 minutes moderate or 75 minutes vigorous activity) per week. The points (reward) for this achievement are gathered depending on the action/exercise and the postoperative week (0-5) as follows: Vein pump (0.3, 0.2, 0.2, 0.1, 0.1, 0.1), 1STS (0, 0, 0.5, 0.5, 0.5, 0.5), Wall plank (0,0,0,0,0,1), 1000 steps (1,1,1,1,1,1, max. each per day). (R-14: implemented)
- After each checkpoint and non-early-postoperative exercise, the user can optionally rate how exerting the actions have been, using a 10-point scale. (R-17: implemented)

As already mentioned in the list above, most of the requirements have been implemented. Again, a feature connected to the sharing possibility was not implemented.



(a) Checkpoint introduction (b) Timer during an exercise

Figure 5.10: Screenshots of (a) Checkpoint introduction explaining the flow of actions and what to expect and (b) Countdown to the end of an exercise, in this case during the 6MWT.

As a result of the evaluation (see Table 5.18 #3, #4), the introduction text of the 6MWT was adapted and a label displaying the connection status of the smartwatch was added. Moreover, as can be seen in Figure 5.10(a), the box with the explanation was moved to the top (improvement #13). A back button was added to the 6MWT introduction page to be able to go back and to clarify the menu flow and the label was changed by adding '1st exercise' at the beginning to foster distinguishing it from the previous screen (improvement #14). For the checkpoint introduction text, a hint was added to not eat much beforehand (improvement #16)

Prospective Surveillance

The first two requirements of this use case are connected to the concept of prospective surveillance (see section 2.4). In the preoperative rehabilitation phase, a baseline should be created. The app supports assessing physical functioning (endurance, strength) and weight. Also, symptoms can be tracked anytime, regardless of the status of the patient. During postoperative rehabilitation, the baseline can be repeated. This is done in line with the Austrian follow-up schedule, every 3 months. In the ongoing surveillance phase, again a reassessment of the baseline is recommended. The focus of the application is intended to lie within the assessment of fitness, which is provided by the checkpoint feature.

Other activities of prospective surveillance like education and recognition of impairments were not part of the targeted use cases. Nevertheless, it is noticed that both topics are somewhat included. Exercises are explained in execution but also why they are useful. Additionally, installing the mobile app may create awareness of impairments.

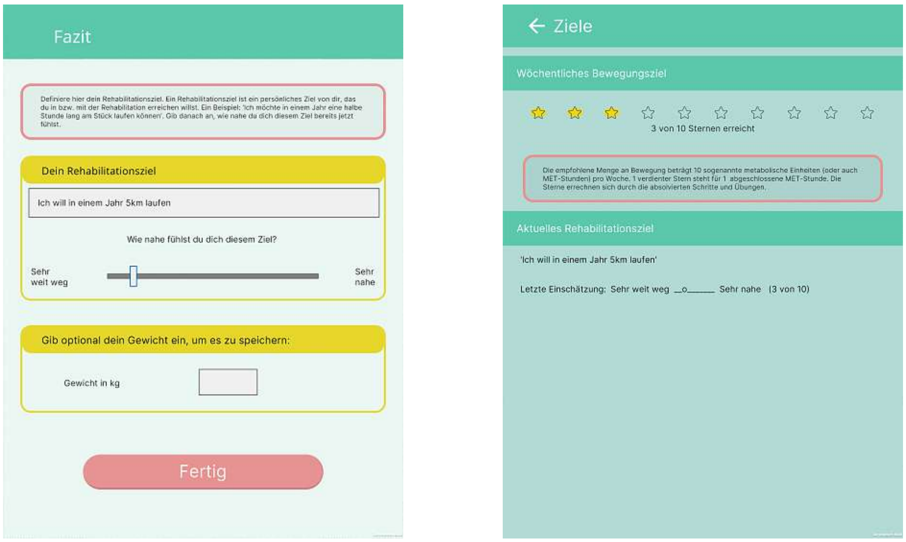
Rehabilitation Goal

Although the rehabilitation goal was first introduced to support the physiotherapist in assessing the goals of the patient, it is still a vital part of the app without the access of a healthcare professional. Patients can visualize their goals and think about how they can achieve them, which can be motivational. Additionally, a rating of how close they feel to achieving this goal may further boost motivation. The input field was implemented as a text field.
Examples of rehabilitation goals include: „I want to be able to run 5km in 50 minutes in 6 months.“ or „I plan to not gain weight or maybe even lose some weight in the next 3 months. Hopefully, I can keep up a healthy exercise schedule with this app.“

As can be seen in Figure 5.11, the appearance of the boxes is transparent with a pink border, based on finding #2 in the evaluation (see 5.18 #2).

Checkpoint History

The history of all accomplished checkpoints shows the achieved value and the perceived exertion so that the user can compare values with time, see Figure 5.12(a). Due to the mixed results in the patient questionnaire regarding a summary page of the last 3 months, there is no dedicated page but users can view the history nevertheless. A full history of weight changes was not implemented, because, due to the lack of patient stakeholders, it



(a) End of a checkpoint (b) Goals screen

Figure 5.11: Screenshots of (a) End of checkpoint screen displaying the rehabilitation goal and allows for providing a goal rating and weight; and (b) Weekly goal and rehabilitation goal are displayed in one screen 'goals'.

could not be assured, that this feature would have caused pressure on the patients. The goal and its assessment can be viewed anytime, but only edited within a checkpoint.

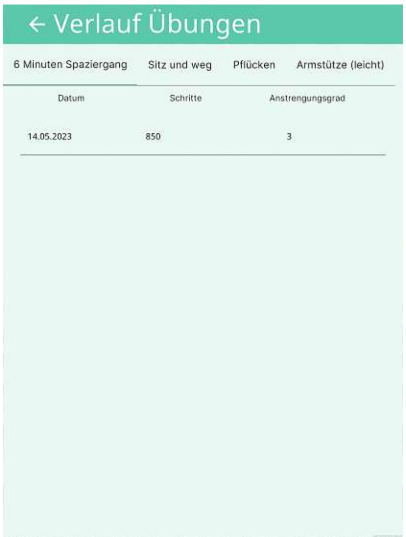
BORG-CR10/VAS Rating

First of all, both VAS and the BORG-CR10 scale are widely used when it comes to measuring subjective perceptions, e.g. for pain or perceived exertion [18]. The BORG-CR10 scale ranges from 0 to 10, but has an additional number available '0.5'. It was researched that the sensitivity and reproducibility of results are very similar when using VAS, BORG or Likert scales [149]. During the research, a slightly modified version of the BORG-CR10 scale was obtained on a web page of a center for cardiovascular diseases, where the rating was simplified to 1-10 (discrete) [60].

Considering all this literature, the symptom rating feature and the subjective exertion rating feature were implemented the same way, using a 10-point scale (1-10), supported by smileys, similar to [60], see Figure 5.12(b).

5.5.3 Exercises

This use case is about guiding the execution of recommended exercises, validated or proposed by literature and experts. The defined exercises are described in section 5.2, however, the following exercises have been implemented: 1 Minute Sit To Stand (see Table 5.4), vein pump (see Table 5.5) and wall plank (see Table 5.9).



(a) History of exercises

(b) Rating exertion after an exercise

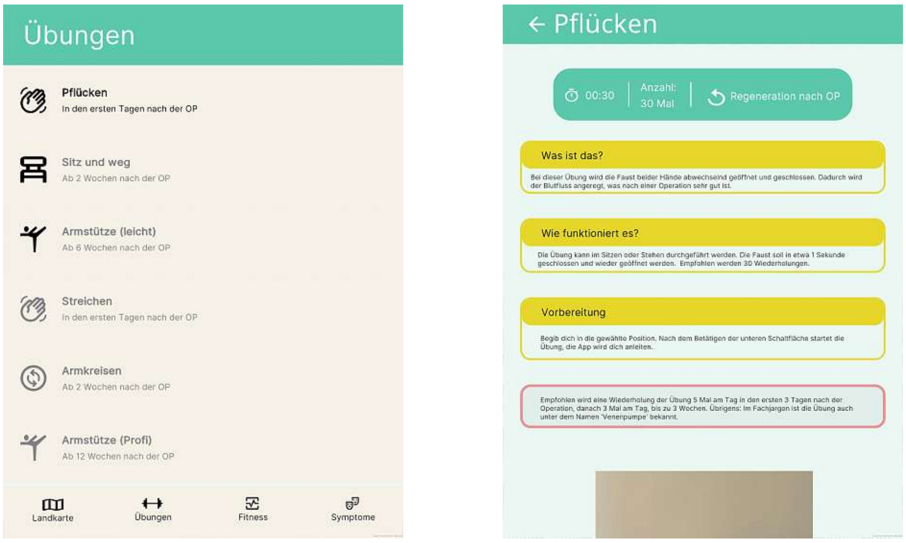
Figure 5.12: Screenshots of (a) History page of exercises and (b) Closing page of 1STS providing a 10-point scale for rating subjective exertion.

The exercises can be viewed through the Exercise Tab.

Based on the heuristic evaluation done in iteration 2 (see section 5.2), the following points have been considered in the implementation:
For all exercises, it has to be mentioned that they were renamed to engaging titles like 'Pflücken' (Gathering) or 'Sitz und weg' (Sit and up). Additionally, although the nice-to-have usability requirement of making instructions less visible with time was not implemented, a green box shall provide the advanced users with the most important facts of the exercise to enable them to recognize already done exercises, see Figure 5.13(b). Also, as can be seen in 5.13(a), the list of exercises was enhanced with icons.

The following requirements are related to this use case:

- The application does not include exercises to be carried out in parallel to funded rehabilitation (stationary, outpatient). (R-03: implemented)
- The patient must be able to use the application at home. (R-04: implemented)
- Each exercise shall be described in detail and complemented with pictures if necessary. (R-06: implemented)
- The defined goal of MET is 10 hours (150 minutes moderate or 75 minutes vigorous activity) per week. The points (reward) for this achievement are gathered depending on the action/exercise and the postoperative week (0-5) as follows: Vein pump (0.3, 0.2, 0.2, 0.1, 0.1, 0.1), 1STS (0, 0, 0.5, 0.5, 0.5, 0.5), Wall plank (0,0,0,0,0,1), 1000 steps (1,1,1,1,1,1, max. each per day). (R-14: implemented)



(a) Exercise selection

(b) Exercise explanation screen

Figure 5.13: Screenshots of (a) overview of available exercises. Grey font means that the postoperative week does not match while grey icons mean that exercises have not been implemented, and (b) Example for a screen introducing an exercise.

- The schedule of the application shall be influenced by the situation of the patient. (R-15: implemented)
- The available exercises are defined by: name, sequence of actions, trained skills, primary and secondary goals and result/output. Optionally, contraindications and difficulty levels can be defined. (R-16: implemented)
- After each checkpoint and non-early-postoperative exercise, the user can optionally rate how exerting the actions have been, using a 10-point scale. (R-17: implemented)
- A physiotherapist shall be able to assign suitable exercises to supervise patients. (R-19: not implemented)
- Exercises implemented: EX-02, EX-03, EX-07

For the description of R-19, please refer to the Supervise Patient use case description below.

The first two requirements describe the intended time and place to use the application. The game is not intended to be used in parallel with a funded rehabilitation program. An explanation was discussed in section 5.1. Moreover, it is constructed so that is possible to do each exercise at home. For information see the system context diagram 5.2, which has not changed throughout the iterations.

	UC-03: Do exercise
Description	The app provides guidance to exercises that may apply to only certain phases of the patient journey. Each exercise is explained thoroughly.
Trigger event	Button selecting the exercise
Actors	Patient, optional healthcare professional
Precond.	Postoperative week of patient >= allowed week of exercise.
Post cond.	Reward gathered, according to the MET definition.
Result	The User accomplished the exercise. Gathered reward is displayed, according to the MET definition.
Main flow	1) User reads the explanation (introduction) of the exercise carefully. 2) User carries out the exercises. 3) If applicable, user enters data about the results of the exercise. 4) User gets feedback on the reward of the exercise.
Alternative flow(s)	The healthcare professional carries out the test together with the patient on-site. The healthcare professional recommends a particular exercise.
Priority	1 - MUST HAVE
Related requirements	R-03, R-04, R-06, R-14, R-15, R-16, R-17, R-19, EX-02, EX-03, EX-04, EX-06, EX-07, EX-08

Table 5.21: Use case definition for accomplishing exercises (UC-03).

The exercises follow the reward mapping (MET-definition, R-14) and, as mentioned earlier, can only be started if the postoperative week is minimum equal to the allowed week of the exercise. Furthermore, each exercise introduction page contains a visual description of the exercise, as shown in Figure 5.15(a). For all exercises where time is a relevant factor, a timer was introduced, following the result of the heuristic evaluation, see section 5.2.

As a result of the evaluation (see Table 5.18), a scroll view was added to each exercise introduction to enable the user to scroll through the description and see the visual description more clearly (improvement #5). Additionally, improvement #19 was implemented by creating summary boxes for each exercise (see Figure 5.13.)

Vein Pump Exercise

The vein pump exercise is defined in Table 5.5. This exercise is the most interactive one because the repetition is fixed and the speed does not vary much. An exception here was to not include a subjective exertion rating because this exercise is for very early-postoperative patients.

As depicted in Figure 5.14, there is an additional introduction to the mini-game, before the game starts. After that, a timer counts backward from 3 to 0, then the player moves

(a) Exercise with in-game explanation (b) Vein pump exercise

Figure 5.14: Screenshots of (a) Page explaining the background story of the interactive mini-game and (b) screen when user walks to gather plants with their hands.

forward. When the player passes a row of plants, the user shall open and close the hand, according to the exercise definition. After the exercise, the user gets feedback on how many stars are gathered.

1 Minute Sit To Stand Exercise

This exercise is defined in Table 5.4 and is a special exercise, being a simple exercise as well as part of the checkpoints. The implementation for both cases is equal. Again, a timer counts backward from 3 to 0, then the timer counts backward from 60 seconds to zero. Afterward, the user can type in how many repetitions were done, and provides the subjective exertion rating (see Figure 5.12(b)).

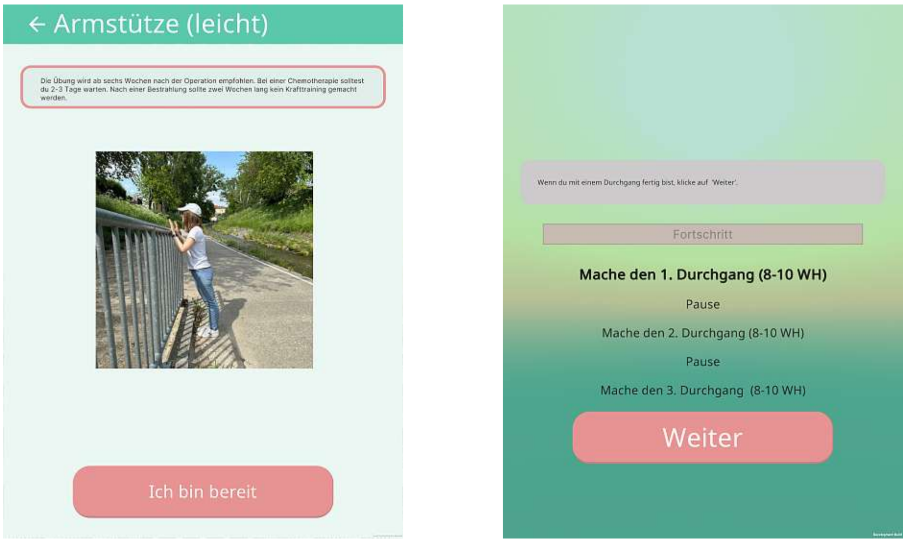
Wall Plank Exercise

The wall plank exercise is defined in Table 5.9 and is an easier version of a normal plank.

This is a less interactive exercise, compared to the vein pump exercise. The application provides a walk-through of the execution of the exercise and has a timer as a support for complying with the pause time of 1 minute. At the end of the exercise, the subjective exertion can be rated.

Walking Game

The walking game is a special case of exercise. It is a central part of the game and heavily influences the progress. The walking game is placed in the main menu, which further



(a) Visual depiction of an exercise

(b) Exercise execution screen

Figure 5.15: Screenshots of (a) Exercise introduction page showing the visual description of an exercise and (b) Guidance to execute wall plank exercise.

highlights the relevance.

The walking game shall motivate patients to walk more. Steps obtained by the PineTime are imported into the application and can be exchanged to virtual distance for the player, to discover the landscape (see Figure 5.16(a)). Additionally, stars are rewarded. The exercise is defined in Table 5.7.

The following requirements are connected to this use case:

- The patient must be able to use the application at home. (R-04: implemented)
- The application must support walking exercises. (R-05: implemented)
- Each exercise shall be described in detail and complemented with pictures if necessary. (R-06: implemented)
- The defined goal of MET is 10 hours (150 minutes moderate or 75 minutes vigorous activity) per week. The points (reward) for this achievement are gathered depending on the action/exercise and the postoperative week (0-5) as follows: Vein pump (0.3, 0.2, 0.2, 0.1, 0.1, 0.1), 1STS (0, 0, 0.5, 0.5, 0.5, 0.5), Wall plank (0,0,0,0,0,1), 1000 steps (1,1,1,1,1,1, max. each per day). (R-14: implemented)
- The schedule of the application shall be influenced by the situation of the patient. (R-15: implemented)

	UC-04: Play walking game
Description	The user plays an avatar that walks through a virtual landscape. Items may appear on the way. The rewarded virtual distance is calculated based on the steps obtained through the smartwatch.
Trigger event	Connection to smartwatch
Actors	Patient
Precond.	By the smartwatch obtained steps are > 0.
Post cond.	Reward gathered, according to the MET definition. Alternative results are saved.
Result	Player is on a new Z-position, which is > old Z-position. Gathered reward is displayed, according to the MET definition. Alternative results are displayed.
Main flow	1) Steps are exchanged to virtual distance. 2) Player in the game moves forward, according to the rewarded distance.
Alternative flow(s)	If a chest is found on the way, this is communicated. If a chest and a key can be matched (one key and one chest), the opening of a chest is immediately communicated and the content of the artifact is shown.
Priority	1 - MUST HAVE
Related requirements	R-04, R-05, R-06, R-14, R-15, R-16, EX-04

Table 5.22: Use case definition for playing the walking game (UC-04).

- The available exercises are defined by: name, sequence of actions, trained skills, primary and secondary goals and result/output. Optionally, contraindications and difficulty levels can be defined. (R-16: implemented)

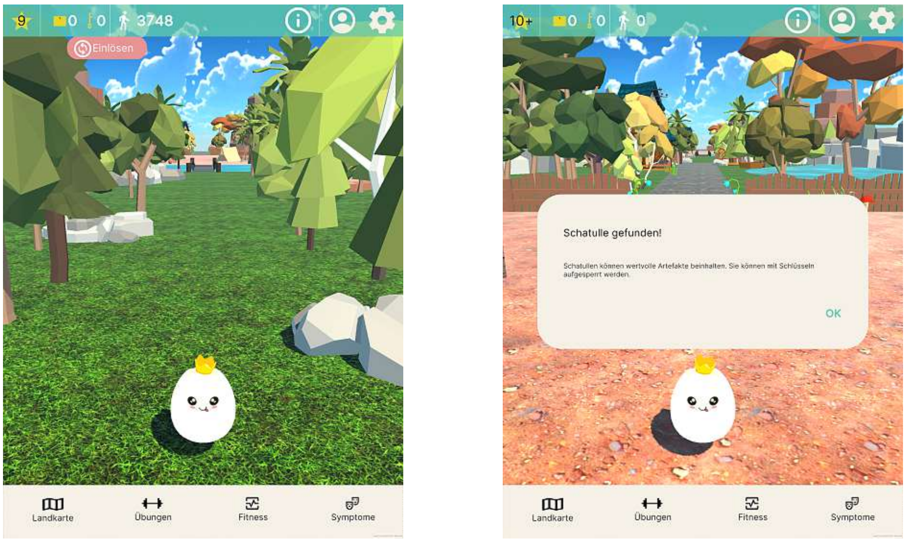
- Exercises implemented: EX-04

On the way, the user can find chests (see Figure 5.16(b)), which contain artifacts that tell the story of the undiscovered landscape.

5.5.4 Symptom Tracking

This use case (see Table 5.23) is about assessing symptoms over time to track the status and is not impacted by the game - on purpose. Users do not get a reward for having or tracking symptoms, nor if they do not want to track or do not have any symptoms. Therefore, this use case is completely optional.

The requirements linked to the use case as shown in Table 5.23 are as follows:



(a) Exchanging of steps

(b) Message to communicate an obtained item

Figure 5.16: Screenshots of (a) Button to exchange real steps to virtual distance and (b) player found a chest along the way.

- The application shall be able to track the following information: symptoms, goals in rehabilitation. (R-08: implemented)
- The user can create symptoms and determine the frequency of the tracking (e.g. once per week). The symptoms shall be tracked using a 10 Point Visual Analogue Scale (VAS). (R-18: implemented)

The user can create a symptom he/she wants to track and determine the interval of asking. This could be daily or weekly, in this current implementation. It is on purpose to not provide any symptoms out of the box. Moreover, based on the heuristic evaluation done in iteration 2 (see section 5.2), a red text shows when a name or an interval was not provided and therefore the symptom cannot be saved.

A created symptom is displayed in the list, and the interval is shown, as shown in Figure 5.17(a). Additionally, there is an overview of the tracking history of the last week, displaying the average rating for each day.

The tracking dialog of symptoms is basically as in the mockups before but the smileys were added. As mentioned, this is equal to the subjective exertion rating.

As a result of the evaluation (see Table 5.18), the save dialog was enhanced by preventing saving an empty symptom and by renaming the label 'name' to 'designation' (improvements #6, #7). Additionally, in the detail view, a display error of the date was fixed (improvement #8) and the color scale describing the symptom rating was added in the

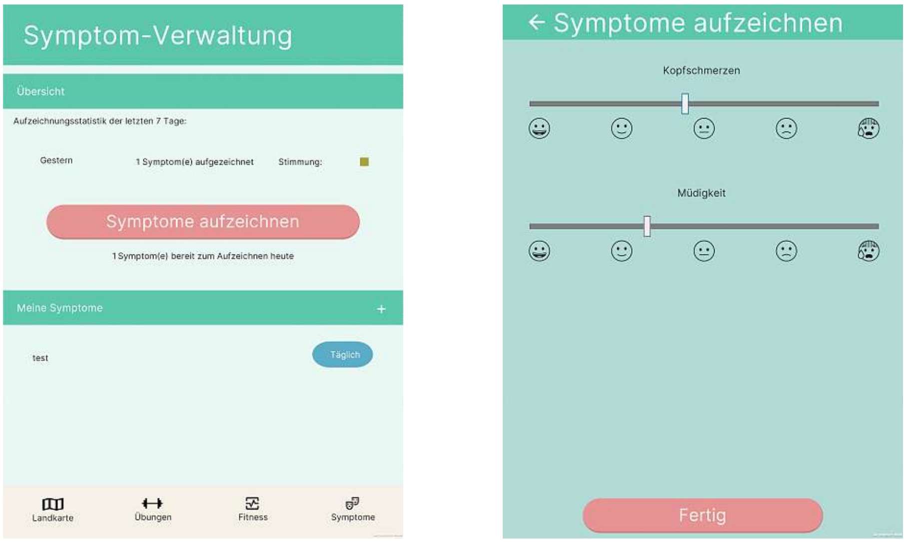
	UC-06: Manage symptoms
Description	The user can create symptoms that can be tracked in defined intervals.
Trigger event	Creation: 'Plus' icon in the list of symptoms. Tracking: 'Track symptom' button.
Actors	Patient
Precond.	Tracking: There is not registered tracking for the particular symptom in the given period (daily, weekly).
Post cond.	Creation: Symptom is saved and can immediately be tracked. Tracking: Symptom assessment is added to the history.
Result	Symptom assessment is saved for that day.
Main flow	1) Symptoms to be tracked are created. 2) The app presents the saved symptoms in a list. 3) The user is prompted to do the tracking, if at least one symptom can be tracked on that day. 4) The user rates each trackable symptom on a scale from 1 to 10, which is supplemented by smileys. 5) The user clicks to conclude the tracking of all on that day trackable symptoms. 6) The detail view of each symptom shows its tracking history.
Alternative flow(s)	-
Priority	2 - SHOULD HAVE
Related requirements	R-08, R-18

Table 5.23: Use case definition for tracking symptoms (UC-06).

form of a foldout (improvement #11). For the tracking, the text displaying the number of symptoms to be tracked was more emphasized (improvement #9) and the symptom designations were formatted centered within the tracking dialog (improvement #18, see also Figure 5.17(b)).

5.5.5 Supervision of Patient

This use case is about enhancing communication between healthcare professionals and patients. As mentioned before, this use case was not implemented because it would have lessened the available time for creating useful exercises on the one hand, on the other hand, as there was no patient available to ask how and if they want to communicate with their doctors in this way, no exact requirements could be obtained.



(a) Symptom overview (b) Symptom rating

Figure 5.17: Screenshots of (a) symptom manager screen, containing a list of symptoms and an overview of the symptom tracking, and (b) symptom tracking dialog containing all symptom eligible for tracking.

Nevertheless, the following requirements were obtained:

- A physiotherapist shall be able to inform herself/himself about the patient before appointments, based on the information captured by the application. (R-07: not implemented)
- A physiotherapist shall be able to assign suitable exercises to supervise patients. (R-19: not implemented)

	UC-07: Supervise patient
Description	Healthcare professionals can assess certain patient data to guide and supervise patients.
Trigger event	Upcoming follow-up appointment. Introducing patient to the app.
Actors	Healthcare professional
Precond.	Patient is using or wants to use the application. Patient allowed sharing of in the app captured data with the assigned healthcare professional.
Post cond.	For exercise assignment: Exercise is assigned to the patient. For gaining an overview of the patient: Performance and achievements of the patient are obtained beforehand.
Result	Healthcare professional informs the patient about suitable exercises. Healthcare professional accesses relevant data about the patient to get an overview before a follow-up visit.
Main flow	For exercise assignment: 1) Discuss useful exercises with the patient. 2) Determine those exercises and assign the patient to them. For gaining an overview of the patient: 1) Access relevant information. 2) Discuss results with the patient at the follow-up visit.
Alternative flow(s)	Assess and discuss achievements together
Priority	3 - NICE TO HAVE
Related requirements	R-07, R-19

Table 5.24: Use case definition for Supervision of patient (UC-07).

CHAPTER 6

Discussion

With this thesis, the following research questions are answered. Firstly, **RQ1:** What are the requirements of health care professionals and breast cancer patients for a software solution that supports the management, tracking and execution of breast cancer rehabilitation? And, secondly, **RQ2:** Which exercises are suitable to be implemented in an exergame?

6.1 Research Question 1

First of all, answering **RQ1**, stakeholder acquisition required much effort and was surprisingly difficult. For healthcare professionals, many did not react to e-mails. A few responded but then could not make time for a meeting. This may be due to a lack of staff in the healthcare sector in recent years or because of the late effects of Covid-19. A few said that they would not feel competent in this particular area. A surprising finding was that no rehabilitation center was interested to support this master thesis. This may come again from a high workload but it is still unexpected that such a center cannot be encouraged to drive digitization in the Austrian health system forward.
Another challenge included finding patients that would participate. Not only was it difficult to find eligible people, but a few refused any involvement, possibly out of fear from dealing with their lives as breast cancer patients.

Both, the expert interviews and the patient questionnaire showed that rehabilitation offered by healthcare coverage providers is consumed by many patients and is considered as positive. Also, the waiting time to start the program is only a few weeks. Additionally, expert interviews highlighted the broad spectrum of topics that are dealt with during rehabilitation. A surprising finding was that the assignment to and the starting of rehabilitation in Austria seems to be less problematic than analyzed by the literature. None of the participants of the questionnaire expressed a need for rehabilitation that has not been fulfilled. The reason for this may be the social nature of the Austrian health system or the variety of locations and offers - possibly a combination of both.

These insights influenced the requirements in the following way. The app does not need to replace or supplement content given in the funded rehabilitation and must therefore act rather complementary, which in return meant to provide an easy solution that can be used at home.

The interviewing of a variety of roles within the field of breast cancer care resulted in a wide understanding of the problem space. Regarding the prospective surveillance, all interviewees stated that, although a preoperative assessment regarding the health situation is a standard, no assessment is currently carried out in terms of fitness. At the same time, all experts were interested in the topic of prospective surveillance and considered the concept as a good idea. This input promoted the idea of considering preoperative users within the requirements.

All in all, the context analysis showed a need for applications like the developed one. Physical activity is a key factor in lowering the risk of cancer recurrence. It is good that patients may install an app on their devices to raise awareness towards regular exercising. Additionally, as the lack of healthcare professionals continues to grow, it is surely useful to introduce new ways of supporting not only patients but also experts in this field.

For the rehabilitation itself, it was interesting to find out that the exercises for breast cancer rehabilitation are not as specific as for other domains rehabilitation. Physical fitness was highly recommended and considered very useful by all experts. However, the mentioned reasons for this were of a general nature: because it is generally healthy and prevents the recurrence of cancer. Furthermore, the assumed relevance of symptoms like reduced ROM or pain was lowered in interviews. Firstly, patients usually do not have symptoms before the surgery. Secondly, usually SLNB can be applied and is applied which leads to fewer or no symptoms after the surgery because there is no impact on the lymph system. This contrasted with the view the literature gave, which can be explained by the age of some papers. In fact, it was due to the interviews that the focus of the application changed from side-effect-based program to a fitness program that suits the breast cancer field better - of general nature, but with breast cancer specialties in mind.

Another finding that influenced the requirements was that different institutions handle breast cancer management differently. This may be further fueled by the fact that each federal state is responsible for its own health system. An example is the inclusion of physiotherapists in the breast cancer journey. In some cases, physiotherapists are consulted before the surgery, in other cases they are involved when the patients need it. The author cannot evaluate which approach would be the best, however, this circumstance influenced the system context as requirements could not be based on the fact that each patient sees a physiotherapist before surgery because some do not.

From a user perspective, the usability study confirmed the usability of the developed app and the usefulness of the gathered requirements. From an expert perspective, the expert review ensured the validity of elicited requirements.

6.2 Research Question 2

Secondly regarding **RQ2**, a set of suitable exercises was created together with stakeholders. An interesting finding was to learn about the general nature of breast cancer rehabilitation exercises which was stated in literature but also in the expert interviews. Due to exercises' characteristics, it was not required to lay a special focus on secondary goals to ensure a completely correct execution, like in other rehabilitation domains, for example, hand rehabilitation. This decision was the basis for providing the application on a mobile device and paved the way for an easy-to-use application. The ensuring of secondary goals via additional devices or motion capturing would have required a more versatile setup. Nevertheless, secondary goals were addressed by visual depictions and throughout descriptions of the exercises. Additionally, one expert stated that patients are instructed on a few exercises when they have their surgery, and, although this may depend on the institution, it is to say that this further boosts the general knowledge of patients as a user group about suitable exercises.

For the translation and integration of exercises to a digital context, exercises were the most suitable where there was a fixed time and movement. This was the case for the vein pump exercise, which was very liked by all usability study participants. Also, the individuals participating in the expert review found this exercise especially fun and engaging. For the other implemented exercises, the app acts as a digital instructor and provides guidance throughout the execution of the exercise.
Exercise which were not considered for the solution contained movements that would have required additional items. An example for this was the idea of introducing a ball, in iteration 2. This was the case because the 6MWT acts as an important and useful instrument within the checkpoints, but already required a device for the step tracking.

Using the PineTime as a device for obtaining steps was really easy and resulted in the expected behavior. Still, it is to say that a Bluetooth connection may not be the best way to obtain such data when thinking of the 6MWT, where users are supposed to go outside and currently have to take their devices with them. This situation would favor the usage of a smartphone rather than a tablet, although a game can be better played on a bigger screen.

Another challenge around defining exercises was to make them quantifiable, so they can be integrated into the reward system. For example, a walking exercise without step tracking would be less useful as there is no indication of the performance of the user and therefore he/she cannot be rewarded accordingly. Another important part of the research was to find out the right amount of reward for players in the game.

From a user perspective, the usability study confirmed not only the usability of the application but also that exercises are explained in a way that is understandable and could be carried out. From a clinical perspective, expert review and literature-based calculations ensured a clinically sufficient exercise program. However, unfortunately, the difficulty of the game could not be assessed, as described in the following section.

6.3 Limitations

In fact, the main limitation in carrying out this master thesis was the lack of breast cancer patients as stakeholders. As mentioned above, no patient could be obtained to give an interview. To still get requirements from this group, a questionnaire was carried out to answer **RQ1**.

On the one hand, this situation had an impact on the usability study. Participants were obtained from acquaintances and were therefore not the intended user group. Nevertheless, this study provided many insights and led to increased usability.

On the other hand, it is clear that this circumstance had an impact on the requirements. As an example, patients would have better known how to display an overview of tracked symptoms. Another topic was also discussed during one expert review. The possibility to track the weight was not implemented in the end. From a clinical perspective, the expert noted that some patients shall lose weight, but during chemotherapy, patients have to be careful to not lose weight. Therefore it is clinically good to not judge or assess the weight within the app, for example by displaying a red arrow facing upward for gaining weight. Still, there would have been the option to display weight values with time in a history. Here, it would have been required to ask patients whether they even want to know or need this feature. It may be possible that this feature would have led to a decrease in motivation.

Another limitation was the factor of time. From a game design perspective, it would have been interesting to see whether the game is too hard or too easy for breast cancer patients in different stages in their patient journey. From a user perspective, it could not be determined what the game would feel like using it long-term, as this would have required additional weeks of testing.

6.4 Future Work

In future approaches, it is crucial to include motivated patients. Only then, user-centered design can be fully applied and deliver a solution that is liked by the user group. Moreover, the game design should be reviewed by studying whether the game is too hard or too easy and for whom. It is clear that there are much more features that would have been useful additions to the application, however, due to the scope of the project not all could be realized. For example, the usage of reminders to exercise is a topic that should be discussed with the intended user group.

As devices in Virtual Reality and motion tracking may become more affordable in the next years, the possibility of using one of these technologies within the field of rehabilitation should definitely be re-evaluated.
In the first case, virtual worlds provide even more possibilities to engage with the user and may increase the motivation for rehabilitation. In the second case, integrating motion

tracking into rehabilitation is generally an interesting topic but it is yet to investigate whether this is a useful approach for ensuring secondary goals in relatively simple and general exercises like in the breast cancer rehabilitation domain.

Furthermore, digitization in the Austrian health system seems to be still a challenge. In the future, it would be an achievement to provide healthcare professionals with certified and validated digital tools to support not only them but also patients and their needs. In fact, both expert reviewers stated an interest in digital solutions that would help patients and considered the developed solution as nice and useful. In fact, they seemed surprised that such things do not exist at the moment. This master thesis confirms that there are indeed experts who are interested in digital projects in the healthcare system and is therefore also an appeal to responsible actors to provide a more digital-friendly environment. For example, as mentioned in this thesis, in Germany, healthcare apps can be prescribed for patients.

Moving away from local circumstances, it would be certainly interesting to include other countries' situations in the breast cancer rehabilitation domain as well. As mentioned multiple times in this thesis, things like work flows, responsibilities, availability of services, healthcare coverage and other practices influence requirements. For future approaches, the scope of context analyses could be broadened so that provided solutions consider not only Austria but also other countries. This would also contribute to a more interoperable digital health system, but will most likely remain a challenge throughout the next years to come.

CHAPTER 7

Summary

Physical activity plays a central role in everybody's daily life, but especially for cancer patients it is crucial to exercise. Physical activity has been shown to reduce the risk of cancer recurrence. It is clear that in-person rehabilitation cannot be replaced by virtual experiences. But, as the lack of healthcare professionals continues to grow, there is a need to find new ways of healthcare services. Additionally, rehabilitation needs more awareness, which may be fueled by such applications.

In this thesis, a prototype was presented that aims to motivate breast cancer patients to engage in physical activity by following a game-based approach. Elements like rewards, items and a vivid world were implemented, while clinically relevant considerations were also made to ensure a safe and useful usage of the application. To achieve this, various expert interviews were carried out to assess the system context and requirements. Additionally, literature served as a basis for many requirements. Furthermore, a questionnaire addressed to breast cancer patients elicited possible requirements from the users. An evaluation was carried out to enhance usability while expert reviews aimed to validate the resulting prototype.

In rehabilitation, early interventions and surveillance are recommended. It is crucial to identify impairments and initiate intervention as soon as possible to minimize functional loss. The prospective surveillance model was used to guide the system context of the application. This model suggests a start of rehabilitation activities even before the surgery. The goal is to promote surveillance, boost the education of patients and the initiation of interventions. Additionally, the promotion of healthy behaviors like regular physical exercise is a key factor. The model should be applied in the pre- and postoperative phases as well as in the ongoing surveillance phase and served as a starting point for this thesis.

The preoperative approach of this thesis contributes to the understudied field of rehabilitation that starts before any cancer treatment. Moreover, the application showcases a solution to digitize early- and late-postoperative exercising in breast cancer patients, which is intended to provide an additional training possibility besides rehabilitation programs offered by healthcare coverage providers.

The main limitation was the lack of breast cancer patients as stakeholders. Despite this limitation, to this author's knowledge, sit the first mobile application to support breast cancer patients in both pre- and postoperative and game-based manner in the execution and management of physical rehabilitation and in the tracking of their symptoms.

APPENDIX A

Development Artifacts

Week	Vein pump	1STS	Wall plank	Walking 1000 steps	Weekly MET-h
0	27	0	0	2	10.1
1	21	0	0	6	10.2
2	12	2	0	7	10.4
3	0	6	0	7	10
4	0	6	0	7	10
5	0	2	2	7	10

Table A.1: Example training schedule for week 0 to 5 displaying the number of exercise repetitions per week and the resulting MET-h, according to the MET-h-Exercise mapping from Table 5.14.

Postoper. week	Vein pump	1STS	Wall plank	Walking 1000 steps
0	0.3	0	0	1
1	0.2	0	0	1
2	0.2	0.5	0	1
3	0.1	0.5	0	1
4	0.1	0.5	0	1
5	0.1	0.5	1	1

Table A.2: Exercise-Reward-Map: Rewarded stars (=MET-h) per exercise and postoperative week. 0 = not allowed.

ID	Description	P	Source
R-01	The application must support the concept of prospective surveillance.	1	H2 - H5, [133]
R-02	The application must support measuring the fitness of the patient preoperatively.	1	H2 - H5, [33, 133]
R-03	The application does not include functions to be used in parallel to funded rehabilitation (stationary, outpatient).	1	H1, H2, H3, PQ
R-04	The patient must be able to use the application at home.	1	H3, H5
R-05	The application must support walking exercises.	1	H1, H3, H5
R-06	Each exercise shall be described in detail and complemented with pictures if necessary.	1	H5, PQ
R-07	A physiotherapist shall be able to inform herself/hisself about the patient before appointments, based on the information captured by the application.	3	H5
R-08	The application shall be able to track the following information: symptoms and goals in rehabilitation.	2	H2, H5
R-09	The patients shall be able to do a self-assessment about their goals, which can be shared optionally with healthcare professionals.	2	H5
R-12	Every 3 months, a checkpoint can be accomplished which consists of a 6 minute walk test, a 1 minute sit to stand test, a goal assessment and an opportunity to type in the weight. The history of these checkpoints can be used as a summary for follow-up visits, for example, or to compare performance with time.	3	H5, PQ
R-13	The user can provide the following information: job, socio-economic environment.	3	H2, H5
R-14	The defined goal of MET is 10 hours (150 minutes moderate or 75 minutes vigorous activity) per week. The points (reward) for this achievement are gathered depending on the action/exercise and the postoperative week (0-5), as described in A.2.	1	H7, [118, 66]
R-15	The schedule of the application shall be influenced by the situation of the patient.	2	H7
R-16	The available exercises are defined by: name, sequence of actions, trained skills, primary and secondary goals and result/output. Optionally, contraindications and difficulty levels can be defined.	1	[110]
R-17	After each checkpoint and non-early-postoperative exercise, the user can optionally rate how exerting the actions have been, using a 10-point scale.	2	H7, [60, 149], PQ
R-18	The user can create symptoms and determine the frequency of the tracking (e.g. once per week). The symptoms shall be tracked using a 10 Point Visual Analogue Scale (VAS).	2	H2, H5, H7, PQ
R-19	A physiotherapist shall be able to assign suitable exercises to supervise patients.	3	H5, H7

Table A.3: A list of all requirements. Each requirement consists of (1) Unique identification number; (2) Description; (3) Priority (P), either 1 (must have), 2 (should have) or 3 (nice to have) and (4) Source, based on statements from which stakeholder/literature.

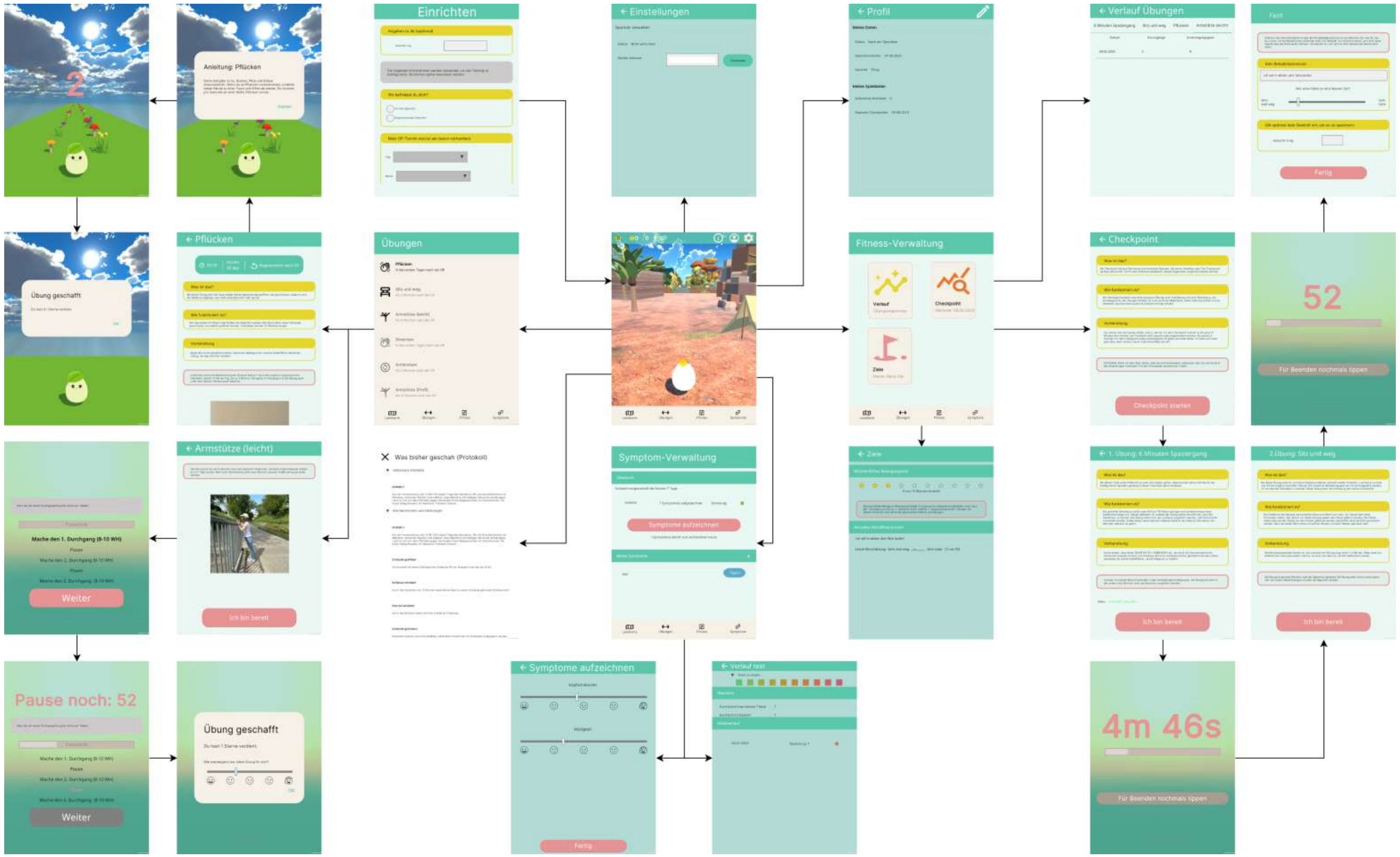


Figure A.1: Flow of actions (screenflow) of the developed application.

APPENDIX B

Methodology Artifacts

Ich denke, ich würde die App (gerne) häufig verwenden.
Stimme überhaupt nicht zu ◯ 1 ◯ 2 ◯ 3 ◯ 4 ◯ 5 Stimme voll zu

Ich fand die App unnötig komplex.
Stimme überhaupt nicht zu ◯ 1 ◯ 2 ◯ 3 ◯ 4 ◯ 5 Stimme voll zu

Ich fand die App einfach zu verwenden.
Stimme überhaupt nicht zu ◯ 1 ◯ 2 ◯ 3 ◯ 4 ◯ 5 Stimme voll zu

Ich glaube, ich würde die Hilfe einer technisch versierten Person brauchen, um die App benutzen zu können.
Stimme überhaupt nicht zu ◯ 1 ◯ 2 ◯ 3 ◯ 4 ◯ 5 Stimme voll zu

Ich fand, dass die verschiedenen Funktionen der App gut integriert waren.
Stimme überhaupt nicht zu ◯ 1 ◯ 2 ◯ 3 ◯ 4 ◯ 5 Stimme voll zu

Ich denke, die App war zu inkonsistent.
Stimme überhaupt nicht zu ◯ 1 ◯ 2 ◯ 3 ◯ 4 ◯ 5 Stimme voll zu

Ich kann mir vorstellen, dass die meisten Menschen den Umgang mit dieser App sehr schnell lernen.
Stimme überhaupt nicht zu ◯ 1 ◯ 2 ◯ 3 ◯ 4 ◯ 5 Stimme voll zu

Ich fand die App sehr umständlich in der Verwendung.
Stimme überhaupt nicht zu ◯ 1 ◯ 2 ◯ 3 ◯ 4 ◯ 5 Stimme voll zu

Ich war mir in der Verwendung der App sehr sicher.
Stimme überhaupt nicht zu ◯ 1 ◯ 2 ◯ 3 ◯ 4 ◯ 5 Stimme voll zu

Ich musste sehr viel lernen, bevor ich mit der App umgehen konnte.
Stimme überhaupt nicht zu ◯ 1 ◯ 2 ◯ 3 ◯ 4 ◯ 5 Stimme voll zu

Table B.1: System Usability Scale [13] translated to German by the author, influenced by [120].

No.	Question	Options
1	Bitte geben Sie Ihr Alter an (optional)	(text field)
2	Haben Sie an einer von Krankenkassen organisierten Rehabilitation teilgenommen?	1) Ja, stationär. 2) Ja, ambulant. 3) Nein, war nicht notwendig. 4) Nein, obwohl ich gerne teilgenommen hätte (ich wurde nicht informiert oder es war wegen anderer Gründe nicht möglich). 5) Andere (text field).
3	Wie oft betreiben Sie Sport? (Yoga, Wandern, Laufen, Schwimmen etc.)?	1) Nie oder selten. 2) weniger als 1 Stunde pro Woche. 3) 1-2 Stunden pro Woche. 4) mehr als 2 Stunden pro Woche
4	Was könnte Sie zum regelmäßigen Sport motivieren bzw. was motiviert Sie? (mehrere Antworten möglich)	1) Wenn man Sport miteinander macht. 2) Wenn man Sport gegeneinander macht. 3) Wenn man die Fortschritte wahrnimmt. 4) Wenn man den Sinn dahinter versteht. 5) Andere (text field).
5	Welche Gründe gibt es bzw. könnte es für Sie geben, keinen Sport zu machen? (mehrere Antworten möglich)	1) Ich fühle mich körperlich zu schwach dafür. 2) Ich finde keine Zeit dafür. 3) Ich komme nicht in die Routine. 4) Ich bin mir nicht sicher, ob und welcher Sport gut für mich ist. 5) Mein Arzt/meine Ärztin hat mir davon abgeraten. 6) Andere (text field).
6	Gab es von Ärztinnen und Ärzten oder anderem medizinischen Fachpersonal Informationen zum Thema Sport/Bewegung bei einer Krebserkrankung (zum Beispiel in Nachsorgegesprächen)?	1) Ja. 2) Nein. 3) Bin mir nicht sicher.
7	Wie stehen Sie zu Apps (oder anderen digitalen Anwendungen, z.B. Spiele) im Fitness- und Gesundheitsbereich? (mehrere Antworten möglich). Beispiele: Nintendo Ring Fit, Xbox Just Dance oder Apps in den Bereichen Sport, Ernährung,Medikamentenmanagement, Meditation etc.	1) Ich habe schon öfter von solchen Apps gehört. 2) Ich verwende solche Apps. 3) Ich verwende solche Apps nicht, finde das Thema aber interessant. 4) Mich interessieren solche Apps nicht.

Table B.2: Questions and option to choose from in the questionnaire eliciting patient requirements. Questions 1 to 7.

No.	Question	Options
8	Wie bewerten Sie den Unterschied Ihrer körperlichen Fitness (Kondition, Gewicht, alltägliche Dinge, ...) zwischen einer Zeit vor der Diagnose und nach der Therapie (z.B. Chemo,Bestrahlung)?	(Rate 1 [„Kein Unterschied“] to 5 [„Großer Unterschied“])
9	Welche Nebenwirkungen sind bei Ihnen seit oder nach der medizinischen Behandlung aufgetreten?	(Rate following items from 1 [„Trifft nicht zu“] to 5 [„Trifft zu“]): 1) Ich fühle mich müde und schlapp. 2) psychische Auswirkungen. 3) Schmerzen. 4) Eingeschränkte Bewegungsfähigkeit im Oberkörper.
10	Wenn ich in Nachsorgegesprächen nach Symptomen oder Befindlichkeiten der letzten paarWochen gefragt werde, kann ich mich nicht mehr genau daran erinnern.	(Rate 1 [„Trifft nicht zu“] to 5 [„Trifft vollkommen zu“])
11	Gibt es Wünsche oder Anmerkungen zur Verbesserung der Rehabilitation? (optional)	(text field)
12	Auf Basis Ihrer Antworten wird eine digitale Lösung zum Thema Sport und Rehabilitation entwickelt. Geben Sie optional und unverbindlich Ihre E-Mail-Adresse an, wenn Sie in Zukunft im Rahmen des Projektes kontaktiert werden wollen, z.B. um die App zu testen:	(text field).

Table B.3: Questions and option to choose from in the questionnaire eliciting patient requirements. Questions 8 to 12.

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Acronyms

1STS one minute sit to stand test. 46, 53, 59, 62, 64, 79, 95, 100, 119, 128

6MWT six minute walk test. 22, 46, 53, 57, 58, 62, 63, 89–91, 95, 97, 113, 128

ACS American Cancer Society. 12, 19–21

AJCC American Joint Committee on Cancer. 10

ALND axillary lymph node dissection. 16, 19

ASCO American Society of Clinical Oncology. 19, 21

BCS breast-conserving surgery. 15, 17, 22, 131

BLE bluetooth low energy. 68, 82

BRCA1 Breastcancer Associated Gene 1. 12

BRCA2 Breast Cancer Associated Gene 2. 12

DASH disability of arm-shoulder-hand. 23, 40

DCIS ductal carcinoma in situ. 15, 16, 131

EGFR epidermal growth factor receptor. 14

HRQoL health-related quality of life. 43

IREB International Requirements Engineering Board. 25

MRI Magnetic Resonance Imaging. 13

PROs patient-reported outcomes. 18, 44

PSM Prospective Surveillance Model. 22

ROM range of motion. 19, 23, 40, 72

SLNB sentinel lymph node biopsy. 16, 112

TDLU terminal duct lobular unit. 11

VAS Visual Analog Scale. 40, 59, 99

WHO World Health Organization. 13

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