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ORIGINAL ARTICLE

Exploring requirements for the development and implementation of VR rehabilitation programs for long/post COVID patients: a qualitative mixed-methods study

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Abstract

An essential step to address persistent symptoms of Long/Post COVID patients lies in the implementation of flexible and accessible respiratory rehabilitation programs. Currently, access to rehabilitation is limited by a lack of available services as well as the physical impairments of those affected by the disease. Virtual reality technologies (VR) offer the potential to support traditional therapies with individualized at home programs. Initial findings on respiratory VR rehabilitation show that the usability and practical applicability of digital programs play an important role in the successful implementation. This study therefore evaluates physiotherapy implemented by a VR application as part of a co-creative, iterative development process with the aim of ensuring usability and acceptance by patients and physiotherapists. Further, requirements for the practical implementation of respective programs as well as the specific needs of the user groups were investigated. Physiotherapists and Long/Post COVID patients evaluated a VR prototype at five stages of development. Feedback was gathered via focus groups and expert interviews. Results then contributed to the further development of the application until relevant requirements for the development of a final prototype could be defined. Overall, it was found that the immersive VR-supported training sessions were well received by patients. However, obstacles which primarily relate to a lack of digital literacy and adverse effects were also reported. Accordingly, prerequisites such as training and technical support for the user groups as well as a target group-oriented design of the applications are necessary for VR rehabilitation to be accepted.

Keywords Long COVID · Post COVID · Rehabilitation · Virtual reality · Co-creation

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1 Introduction

1.1 Background

Virtual reality technologies (VR) provide a promising approach to enable flexible and individualized physical rehabilitation and are therefore increasingly tested in the field of pulmonary rehabilitation, in example for patients with chronic lung diseases (Jung et al. 2020; Naranjo et al. 2018). As part of the establishment of rehabilitation programs for Long/Post COVID patients, too, VR could be a solution to complement traditional therapy measures. In the wake of the COVID-19 pandemic, the rehabilitation of patients in the post-acute phase of the disease is an important measure to address long-term effects, which are commonly known as Long or Post COVID (Davis et al. 2021; Fugazzaro et al.

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2022). and defined as "post COVID-19 condition" by the World Health Organization (WHO 2021).

Available studies on the prevalence of Long and Post COVID present very heterogeneous results. Depending on the included symptoms and methods applied in respective studies, the estimated number of patients vary greatly (Høeg et al. 2023). Still, it is undisputed that a significant number of patients experience restrictions even months after the acute phase of the disease. Patients who report an impact on everyday functioning up to 3 months after testing negative account for 10-50% of the study participants (Rajan et al. 2021). The WHO for instance estimates that patients affected at least three months after testing negative– including patients who were not treated as inpatients– account for up to 20% (WHO 2022). Other available findings from studies relating to cohorts from individual countries show that at least 6,5% of patients report persistent symptoms 6–12 months after a COVID-19 infection (Peter et al. 2022; Thompson et al. 2022). The most common symptoms include fatigue, shortness of breath at rest and on exertion, and muscle pain (Koczulla et al. 2022) as well as concentration difficulties (Alkodaymi et al. 2022). In addition, psychological symptoms caused by the ongoing impact on personal health, such as anxiety and stress, can have a negative impact on the quality of life. If left untreated, this condition can severely impact individuals' ability to return to work or engage in social activities, potentially leading to significant economic repercussions for themselves, their families, and society (Li et al. 2020; Rajan et al. 2021).

In the treatment of respiratory symptoms, physical therapy plays an important role (Ceban et al. 2022; Deutsche Gesellschaft für Neurorehabilitation 2022). In addition to the establishment of outpatient programs, solutions for the implementation of flexible therapies designed for the home environment have to be developed (Candan et al. 2020; Kiekens et al. 2020). While there is still insufficient knowledge about the disease, patients also report a lack of specialized services and therapy programs (Rajan et al. 2021; Stengel et al. 2022). Initial findings suggest that digital approaches such as VR applications enable an accessible implementation of therapies in the home environment and, at the same time, can contribute to increased motivation and adherence to therapy (Groenveld et al. 2022; Jung et al. 2020; Rinn et al. 2023). VR technologies enable the implementation of individual and flexible physical therapy programs in a virtual space through the virtual representation of therapeutic measures. Due to their independent applicability respective programs can therefore increase accessibility. Approaches to integrate immersive VR applications already exist in various areas of rehabilitation as well as in psychotherapy. These are used for instance to alleviate respiratory symptoms (Jung et al. 2020; Naranjo et al. 2018), and to reduce anxiety and stress (Freeman et al. 2018). However, findings from pilot studies on the implementation of VR-assisted rehabilitation programs also show that the technical accessibility and usability of the application in particular can be a barrier to implementation. So far, participatory approaches to the development of VR applications adapted to the needs of the target group have not been established (Dalko et al. 2023). The following study therefore presents a co-creative study design for the participatory development of a VR application to implement respiratory rehabilitation for Long/Post COVID patients for the home setting and investigates requirements and challenges for the implementation of such programs.

1.2 Objectives

With the aim of participatory development, a first version of a VR prototype has been evaluated by future user groups consisting of Long/Post COVID patients and physiotherapists with regard to usability and practicality of the VR therapy program. The focus of this study lies on determining the needs and requirements of user groups. The feedback obtained was further used to adapt and further develop the application. The primary research question that leads the evaluation is the following:

What are the technical requirements for an immersive VR application to be implemented in the respiratory rehabilitation of Long/Post COVID patients?

Secondary research questions are:

How do patients and physiotherapists evaluate the feasibility of the VR application (and VR physiotherapy in general)?

What are the hurdles and specific needs of the user groups to be considered when implementing VR-assisted respiratory rehabilitation programs for Long/Post COVID patients from a professional perspective as well as from a patient perspective?

2 Methods

2.1 Study setting and sampling

The study is designed as a monocentric, non-randomized, exploratory study pursuing a co-creative study design to evaluate and further develop a VR application providing a digital rehabilitation program for Long/Post COVID patients. While new technologies are mostly only tested with a finished prototype, this study integrates the specific needs of target groups already during the development process (Huter et al. 2022). The development of the application is based on the concept of co-creation in the course of a cooperation between nursing science, physiotherapeutic practice and VR designers. The focus of the study, moreover, lies on participatory technology development integrating the future users (Draude et al. 2018; Unger 2014). User-centered development approaches, which provide for the early involvement of user groups already in the iterative process of development, are established in the field of digital health applications and telemedicine in order to achieve a precise adaptation to the needs of user groups as well as to increase the acceptance of new technologies (Gerstbach and Gerstbach 2020; Timmerman et al. 2016; Unger 2014).

In other words, the VR prototype in this study was evaluated by user groups (patients and physiotherapists) in an iterative process at five measurement points (P1–P5). In this paper the qualitative feedback gathered through interviews and focus groups with future user groups will be reported and discussed.

The respective feedback was immediatly incorporated into the further development of the application. Participants of every subsequent feedback round then evaluated an already adapted version (see Fig. 1). There are 4 weeks between each development stage, during which the application is further developed on the basis of the feedback. Only when both steps of a feedback round (e.g. the expert interview with a physiotherapist and the focus group with the core group of patients for P1) have been completed is the further development carried out so that both perspectives are included equally. This process is intended to achieve a continuous increase in the usability of the application.

Subjects in the patient group were divided into one core and three ad hoc groups. The ad hoc groups each tested a version of the prototype at only one point in the study and were able to provide feedback based on their first impressions. The core group, on the other hand, was involved at three measurement points and followed the development of the application. This group gained knowledge about the use of VR applications in the study, so that initial difficulties due to a lack of knowledge or insecurity presumably diminished as the study progressed. On the other hand, the core group acted as a means of validating the results by cross-checking the further development of the application based on the feedback provided.

In this process, each version of the prototype (P1–4)– except for version 5 (P5)– was evaluated by at least two groups: physiotherapists, ad hoc group or core group. Version 5 was only evaluated by the core group, since the focus of this workshop was on the independent setup and handling of the device as well as the individualization of the exercise sets, which is difficult to evaluate by patients who are trying out the application for the first time (see Fig. 1).

The study was conducted according to the principles of the Helsinki Declaration (World Medical Association 2013). The results presented in this article were part of a study registered at the German Clinical Trials Register (DRKS00026077). Ethical approval was obtained by the Ethics Committee of the Medical Faculty of Martin Luther University Halle-Wittenberg in July 2021 (2021−114).

2.2 Participants

Patients with Long/Post COVID and physiotherapists were included as study participants. Eligible patients were recruited through existing Long/Post COVID support groups. Patients with dyspnea levels 3 and 4 on the mMRC scale were excluded.

The sampling for both groups– patients and physiotherapists– was attempted to be as diverse as possible especially in regard to age and gender of participants as well as professional background and the duration of professional activity of physiotherapists (Gläser and Laudel 2006).

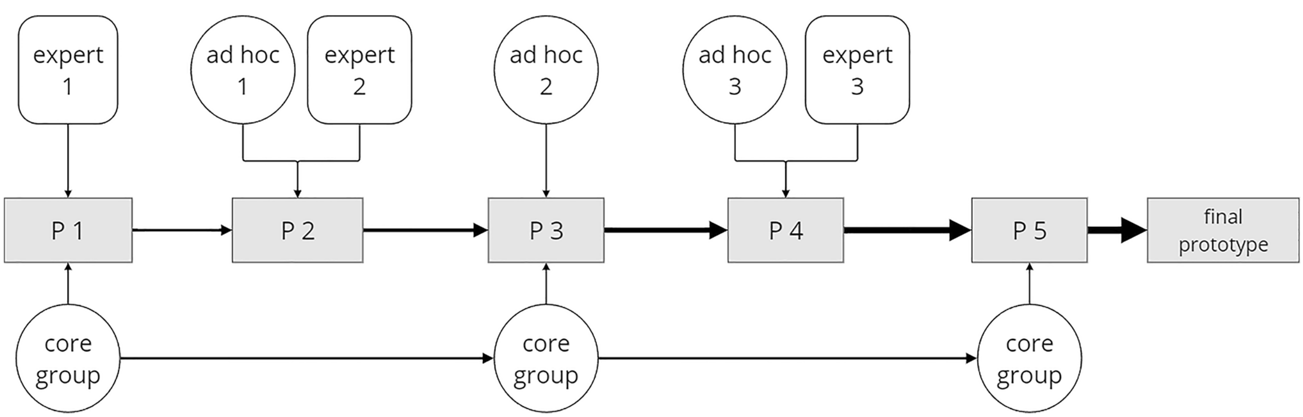

Fig. 1 Process of the iterative evaluation through physiotherapists (expert) and patients (ad hoc and core group) as part of the further development of the VR prototype (P1–P5)

2.3 The VR rehabilitation program

An extensive literature review aimed at identifying existing evidence regarding the implementation of respiratory rehabilitation supported by VR (Dalko et al. 2023) provided the base for the development of a VR prototype in this study. Existing evidence on the rehabilitation of Long/Post COVID patients and patient groups with similar symptoms such as chronic obstructive pulmonary disease (COPD) using VR applications were included in the process.

Initial recommendations concerning the rehabilitation of COVID-19 patients include endurance as well as strength training for the major muscle group, as well as breathing and stretching exercises (Yang and Yang 2020). Liu et al. (2020), in example, conclude that six weeks of lung-specific rehabilitation and the training of proper breathing techniques positively affect lung function as well as physical performance and symptoms such as depression and anxiety (Liu et al. 2020). First systematic reviews also show positive effects of physical rehabilitation– in-person as well as tele-rehabilitation– in terms of dyspnea, physical capacity as well as quality of life (Ahmed et al. 2022; Fugazzaro et al. 2022; Perez et al. 2023). Likewise, the American Thoracic Society and the European Respiratory Society emphasize the need for patient-centered physical therapy interventions that cover both physical and psychological needs (Spruit et al. 2020). Combined with recommendations from therapeutic guidelines, these findings led to the determination of the following goals deemed beneficial for patients suffering from Long/Post COVID (Barker-Davies et al. 2020; Cheng et al. 2021; Glöckl et al. 2020):

1. Alleviation of respiratory distress, both at rest and during exertion.
2. Clearance of mucus from the airways.
3. Strengthening or normalization of the tonus of the respiratory support muscles.
4. Expansion of chest mobility to facilitate deeper breaths.
5. Improvement of cardio-pulmonary endurance.
6. Enhancement of the quality of life by reducing stress and anxiety.

To address these target goals, respiratory therapy exercises were combined with movement exercises for the upper limbs, chest, and neck areas, all of which can be performed in a seated position. These exercises aimed to mobilize the respiratory support muscles, which are often tense in patients suffering from pulmonary conditions, thereby restricting the physiological mobility of the chest during breathing (Kisner and Colby 2010). The therapy commenced with an approximately five-minute warm-up designed to prepare participants for subsequent training. The main training was divided into two intervals, involving dynamic, larger movements and multiple repetitions to enhance patient endurance and mobility. The movement exercises for the intervals were taken from general training theory as well as from the theory of proprioceptive neuromuscular facilitation (PNF). These are well-suited for developing musculoskeletal endurance and strength and promoting overall body stabilization, mobilization, and movement coordination. Respective exercises are also recommended by experts in the treatment of Long/Post COVID (Filipovic et al. 2020). A brief break was included between the two intervals, during which a posture-relieving exercise was introduced to facilitate easier breathing. Following the main exercises, a cool-down phase was conducted, guiding patients through gentle stretching exercises for the chest and spine. Finally, a phase of awareness was implemented to promote relaxation and increase awareness of one's own breath and breathing direction.

To simulate a real therapy session in VR, exercises are demonstrated by a humanoid avatar (virtual therapist) which is supported by virtual objects visualizing movements and breathing techniques. Also, an auditory description of exercise goals is guiding patients through the movements and breathing patterns. During the initial launch, a tutorial takes patients through important functions, such as how to pause, rewind, and how to skip certain actions, as well as introduces them to the controllers. Patients can choose from three difficulty levels of exercise programs, which vary in length and the number of exercises, ranging from ten to 30 min in total runtime. The therapy sessions are presented in a minimalist forest environment with subtle color gradients that change during different exercise phases, enhancing the 'mood' of each phase. Inspired by the Borg scale, after completing the therapy session patients are asked to subjectively assess the level of exertion of the performed exercises using a scale consisting of eleven items, ranging from very light to maximal effort (Borg 1982). The VR prototype was developed to be usable with any VR headset, in this study however we employed the Pico Neo 3 pro.

2.4 Development of the iterative prototype

As illustrated in Fig. 2, the development of the breathing exercise intervention prototype progressed through five distinct iterations, each developed through a co-creative process. The initial prototype (P1) comprised three foundational exercises: mobilization of the shoulder and neck muscles, boxing exercises combined with breathing patterns, and relaxing breathing exercises designed to enhance breathing awareness and depth. The second iteration (P2) building on this foundation by expanding the exercise repertoire to eight. This version included the original exercises of the first iteration and added swimming motions with

Fig. 2 Process of the iterative development of the VR prototype interventions (P1–P5)

the arms combined with breathing patterns, a pause with instructions on pursed-lip breathing, mobilization exercises for the shoulder and arm through proprioceptive neuromuscular facilitation (PNF) patterns combined with breathing, as well as mobilization and stretching of the spine and back muscles in flexion and extension motion, culminating in a longer awareness breathing exercise. The third iteration (P3) retained all exercises from the second iteration but introduced two variations of the boxing exercise and incorporated spine rotational mobilization exercises. Additionally, this iteration featured three difficulty levels, offering exercise programs in durations of 10, 20, or 30 min to accommodate different user needs. The fourth iteration (P4) focused on program stabilization, resulting in enhanced reliability with fewer crashes of the program, and included an updated optical interface to improve user experience. Finally, the fifth iteration (P5) introduced further difficulty options within four exercises: the three boxing variations and the PNF exercises. These enhancements were aimed at tailoring the exercises to meet individual patient needs, providing flexibility to adjust the exercises' difficulty levels as required. These iterative developments aimed to refining and optimizing the breathing exercise intervention prototype, ensuring it is both effective and adaptable to the diverse needs of patients. As can be seen in Fig. 2 the intervention expanded in maximal duration from 8 min of the first iteration to maximal duration of 30 min when all items had been integrated.

2.5 Materials and data collection

Three expert interviews with physiotherapists (27:23 min–31:50 min) and five focus groups with Long/Post COVID patients (19:24–30:46 min) in the region of Saxony and Saxony-Anhalt were conducted in the period from April to November 2023 (KD, HAE). Conducting focus groups with patients results from the aim to give participants the opportunity to express their impressions as freely as possible and to give room to mention aspects that have not been considered in the context of the technical development by the research team. A particular advantage of the focus group methodology is that, in the best case, participants pick up on each other's statements, comment on them and develop them further (Lamnek 2010). The 5 focus groups consisted of 3 ad hoc groups (1 focus group per ad hoc group) and 2 focus groups conducted with the core group. The ad hoc groups were each interviewed at one of the development stages of the prototype (P1–P4), while the core group was asked about their experiences once at the beginning of the study (P1) and once at the end of the study (P5) as part of a focus group. This was done with the aim of picking up on the development of the perception of usability before and after the iterative and co-creative development process. The core group also tested the application at development stage 3 (P3) and evaluated the progress of the development in terms of increasing usability. The main purpose of this evaluation was to verify the integration of the collected feedback into the development of the program. Feedback of this round was therefore only recorded in a protocol, in which feedback on the implementation of the user feedback was documented in particular.

The focus groups were conducted at the facilities of the respective self-help groups following a workshop in which participants learned about the application and had the opportunity to try out the therapy program under guidance of the researchers (KD, HAE). During each testing of the application there was a physical therapist present to watch over the test subjects and intervene if needed. Furthermore, participants were asked not to overexert themselves and to pause or break the testing if necessary. Focus groups and interviews were semi-structured using a guideline to frame the conversation along the research questions addressed in the study (see supplements 1 and 2). The implementation of the test rounds with study participants as well as the guideline were reviewed in a pretest before the start of the study. In addition, protocols were taken to document activities during the workshops and spontaneous statements by the participants (KD, HAE or assistant). These also served as a control instrument to detect any discrepancies with the statements made during the focus group. For example, if participants stated during the interview that they had had no problems with the operation of the VR application during the testing, but difficulties in the independent implementation by participants were recorded at various points in the protocol.

Physiotherapists were given the application to test for one week and their feedback was gathered via one on one expert interviews at their place of work (e.g. practice or clinic). They were asked to test the application at least three times and to take notes on their impressions of the technical implementation and the therapy program as well as difficulties encountered while setting up the VR headset in a short diary. The diary only served to document the impressions during the testing and was primarily intended to ensure that no aspects were forgotten until the interview took place. The diary contained two sections: Notes on the implementation of the therapy program and notes on technical manageability. The focus was on difficulties or problems that occurred during the testing. In addition, with regard to technical problems, it should be stated whether these could be solved independently. Participating physiotherapists were further asked to make individual notes for each test and to record the number and duration of the tests.

Physiotherapists were included in the study due to their professional expertise and their role as a secondary user group being a contact person for patients during the implementation of physiotherapeutic measures. The focus of the interview was therefore the professional assessment of the applicability of the therapy in the daily practice of physiotherapists as well as possible indications for the improvement of the application. Both interview guidelines are developed using the SPSS method according to Helfferich (2011). Questions about difficulties, suggestions for improvement and benefits were deliberately kept open so that respondents were not directed to individual aspects by the phrasing of the question. The guidelines covered three categories: evaluation of the physiotherapy treatment program (focus on selection and compilation of exercises and information), technical usability and implementation of the application in practice. Processes and methods are reported in accordance with the Consolidated criteria for reporting qualitative research checklist (COREQ) (Tong et al. 2007).

2.6 Data analysis

The focus groups and expert interviews were audio recorded and transcribed according to Dresing and Pehl (2015). The analysis followed the guidelines of the structuring qualitative content analysis according to Kuckartz (inhaltlich-strukturierende qualitative Inhaltsanalyse) and served to systematize individual points of criticism and suggestions for improvement as well as the identified hurdles and needs regarding the implementation of the VR application (Kuckartz and Rädiker 2022). The main categories were determined deductively on the basis of the research questions and interview guide. This means that the categories included in the interview guidelines (assessment of technical implementation, evaluation of the therapy program, feasibility in practice) were initially adopted as main categories in the code system. Only after a transcript with all main categories had been coded were subcategories generated inductively from the material. Based on the identified subcategories, the corresponding main categories were revised again. The main category 'necessary preconditions' was thus added in the course of the coding process in order to be able to summarize identified subcategories that contain conditions mentioned by participants for a successful implementation of the VR therapy program. The categories relating to the therapy program and technical implementation were summarized in the categories 'perceived benefits' and 'perceived barriers'. This was followed by a new coding process in which the specific subcategories were assigned to the final main categories and adjusted if necessary until all transcripts were coded and the code system was finalized. In this process, the material was evaluated independently by two researchers and in an iterative process (KD, HAE).

Based on the assessed intention to use the application evaluated here and VR-supported physiotherapy in general, the data sets of the individual interview responses were compared with each other as cases. For this purpose, the identified codes per data set were compared with each other in a cross table. This was done to understand which codes were associated with a rejection of VR applications and which codes were associated with an intention to use VR-supported therapy. Individual cases were then organized into a typology in order to work out chains of reasoning and backgrounds for the acceptance or resistance to VR therapy. For further evaluation of the results, Kuckartz's typology was chosen as a framework to show connections between the identified categories (Kuckartz 2007). Disagreements in interpretation were discussed and resolved with third parties as needed (DP). Protocols and diaries were used as additional material to supplement statements from the interviews in reference to standard techniques of data extraction of content analyses such as those described by Mayring (Mayring 2015). Transcripts were generated as text files and manually coded. The coding and the assignment of quotations were finally summarized in Microsoft Excel tables and visualized in a Miro Board for further evaluation. Data saturation was considered to have been reached when categories could be adequately defined and delimited from one another and no new categories emerged in the course of data analysis.

3 Results

3.1 Characteristics of participants

A total of 20 participants were included in the study. Of these, three are physiotherapists who were interviewed as experts and 17 were Long/Post COVID patients. The physiotherapists were 43 years old on average, two were female and one male (see Table 1). They had ten to 28 years of professional experience. Among them, two worked in a clinical setting and one in an outpatient setting. Two physiotherapists had completed advanced training specifically in the area of respiratory therapy. The patients were 55 years old on average, two were male and 15 female (see Table 1).

The majority of participants had no experience with VR technologies. Existing experience was limited to single occasions of trying out games under the guidance of others.

The core group consisted of six members of a self-help group in Saxony-Anhalt of which one member was male. Participants of the ad hoc groups ranged from two to six members while the final ad hoc group had only two participants due to one drop-out because of a pre-existing condition. Only one ad hoc group included a male participant. The youngest participant was 35 years old, the oldest 62 years. The core group was therefore slightly older on average than participants of the ad hoc groups (see Table 1).

Participants of each focus group were familiar with each other as members of the self-help groups prior to the study. Participants usually knew details about each other's medical conditions as they were openly discussed during their regular meetings.

Table 1 Socio-demographic information on study participants

Physiotherapists			
Number of participants	Gender		Age
1	Female		53
2	Female		34
3	Male		43
Long/Post COVID patients			
Number of participants	Gender	Age	Focus group
1	Female	48	Core
2	Female	66	Core
3	Female	64	Core
4	Male	67	Core
5	Female	56	Core
6	Female	46	Core
7	Female	64	FG1
8	Female	55	FG1
9	Male	57	FG1
10	Female	58	FG2
11	Female	36	FG2
12	Female	62	FG2
13	Female	58	FG2
14	Female	62	FG2
15	Female	54	FG2
16	Female	59	FG3
17	Female	35	FG3
Physiotherapists in total			
Age			34–53
Gender			Male: 1 Female: 2
Patients in total			
Age			35–67
Gender			Male: 2 Female: 15

FG# = numbered focus group

3.2 Qualitative evaluation of VR therapy program and its implementation

In order to illustrate the coding process, an overview of codes, related definitions and examples from the interview transcripts are given in Table 2. The qualitative analysis revealed four main themes in the course of the evaluation of the VR application tested. These include the prerequisites for successful implementation, which primarily concern the technical development of the application, but also outline specifics of the implementation process and accompanying services. On the other hand, the practicability of the therapeutic approach compared to conventional programs was criticized by participants as well as advantages and barriers with regard to the implementation of VR-supported physiotherapy for Long/Post COVID patients identified.

3.2.1 Technical requirements and challenges for the development of the VR therapy program

The main focus of the qualitative evaluation lied on the usability of the developed program and the adaption to needs of future users. In the following technical requirements and challenges identified through the qualitative analysis are reported as part of the results of this study.

The application underwent an iterative development process, evolving from its initial iteration that featured an introduction to the application and three exercises to its last iteration with an expanded exercise repertoire to include eleven exercises, categorized into three sets. In the initial iteration, visual objects guiding users through the therapy program were perceived as having unclear functions. The auditory guidance was also challenging to comprehend. However, in subsequent iterations these issues were addressed by adding more explanations during the tutorial and indicating breathing rhythm through color cues. Also, the inflation and deflation of virtual objects supported the auditory guidance until no irritation in relation to the instructions was mentioned in all three groups (experts, core, and ad hoc group). In the final rounds of evaluation, visual cues and auditory guidance were perceived as clear and easily understandable.

Participants further found it difficult to maintain the prescribed breathing rhythm and direction. Reasons for this included irritation regarding the instructions, but above all difficulties of adapting their own breathing to the instructions. Additional functions such as the ability to pause exercises or skip explanations were requested by participants and implemented in the course of the study. Additionally, the tempo of one of the exercises was found to be too fast, making it challenging for them to keep up which was addressed by incorporating three different speed levels for users to choose from. Two out of the three physical therapists suggested adding extra gamification elements to make the exercises more enjoyable. Notably, one of the subjects had to stop during testing due to sensory overload.

The most requested feature of the application was the ability to personalize the training program (12 out of 20 cases) and the option to perform the exercises without using controllers (13 out of 20 cases). Overall, there was the common perception that the controllers were obstructive to the immersive experience of the application. Furthermore, difficulties in using the hardware such as the browser crashing or problems with setting the game area were reported. Technophobia was an occasional issue, particularly among patients.

Table 2 Overview of results of the coding process

Code	Definition	Example	Sub-level codes
1. Necessary preconditions and requirements	*Settings and components necessary for the successful implementation of the VR therapy program. These components may include the availability of technical support and training for users, as well as the design of the software to ensure usability, accessibility, and the overall effectiveness of the therapy program*	"With enough practice, it might be doable. But I think I would definitely need help the first few times. It's not something that works after just being shown once. […] At least in the beginning, you need additional guidance. Someone you can ask questions, talk to again, and revisit things with." *Case 17 (Patient)*	**1.1 Implementation process and resources** 1.1.1 Implementation of the VR program as part of regular therapy 1.1.2 Knowledge transfer to all stakeholders (therapists, physicians,…) 1.1.3 Availability of (individual) technical support/training for patients and therapists
		"What might bother me during relaxation is this: You're holding the sticks in your hands and are supposed to rest your hands on your legs. But where do you put these things? […] You see, it feels different to relax in this way compared to other ways. […] And if you relax your hands, the sticks just fall. […] So, you have to focus on keeping them in your hands, which means you can't fully relax. In that moment, you're already distracted again." *Case 7 (Patient)* "Yes, I really liked the technical implementation. My only point of reference is Wii Sports, which is a bit older now. What I didn't like as much—well, I have asthma. For me, the timing between inhaling and exhaling was sometimes too long. I had to hold my breath for too long, and I started feeling lightheaded—you know, lightheaded (laughs). But I think that's something that is depending on the patient. Others might not have experienced it the same way." *Case 15 (Patient)*	**1.2 Design of VR program** 1.2.1 Usability 1.2.1.1 Comprehensive guidance of patients to ensure accurate execution of exercises 1.2.1.2 One-Click solution to start session 1.2.1.3 Usable without controller 1.2.2 Therapy program 1.2.2.1 Interactive feedback/Monitoring 1.2.2.2 Diversified therapy program 1.2.2.3 Individualization of training and program
2. Practicality in (professional) everyday life and compared to other therapy programs	*Participants' subjective assessment of the feasibility of integrating the VR therapy program into their professional or everyday routines, including comparisons with other therapy programs (digital or traditional) and considerations of the suitability of the program for specific patient groups*	"Yes, but there are already videos on YouTube for that. You don't need the headset. […] And the AOK also offers similar programs. They have exercise programs that explain what to do—specifically tailored for people like us." *Case 8 (Patient)*	**2.1 Comparison with other digital therapy options** 2.1.1 Non-immersive approaches (Video, Tele-Reha) as favorable
		"That small figure (…) isn't quite optimal. It tries to demonstrate the exercises, but I think it would be much more effective if a realistic, human-like figure demonstrated them instead. And as I already mentioned, it's challenging when, for example, I need to grab something and place it down to the right. I might do one part of the task—maybe some can manage this without looking—but I kept wanting to check what the figure was doing, whether it was breathing or not. As a result, I probably didn't place the ball exactly where it should have gone, which might not deliver the desired therapeutic effect, right? […] it's possible to perform physiotherapy exercises completely wrong, even with the best intentions. That's why having someone to correct you in real-time […] is so important." *Case 10 (Patient)*	**2.2 In-person therapy as favorable** 2.2.1 Digital solutions as complicated in comparison to regular therapy options 2.2.2 Lack of personal contact 2.2.3 Cannot substitute individual feedback from real person
		"You also have to consider that the patients using this have certain limitations, right? And in that regard, it was actually well done. Subtle. Not too fast, not too overwhelming. It works well like that." *Case 5 (Patient)*	**2.3 Suitability of the program in respect to patient group**

Table 2 (continued)

Code	Definition	Example	Sub-level codes
3. Perceived benefits	*Participants' subjective assessment of the advantages of the VR therapy program, including practical benefits (such as eliminating commuting, providing flexibility in timing and location, and enabling independent use at home), as well as psychological and technical benefits*	"There are also people who can't leave their homes. […] For them, such headsets provide an opportunity to exercise and a viable option, especially since getting a home visit from a physiotherapist is likely even harder than securing an appointment." *Case 8 (Patient)*	**3.1 Implementation of therapy** 3.1.1 Independence (from appointments, daily form) 3.1.2 Easier access to therapy 3.1.3 Detailed instructions for the home environment
		"Especially in the post-COVID context, you can't just do something once and hope everything will improve and get better. You really need to do something every day—not huge efforts, but small, consistent steps. And for that, something like this is actually quite useful, at least in my opinion. I mean, I can't set up a home gym if I don't have the space. A headset like this is much easier to use in that regard, definitely." *Case 12 (Patient)*	**3.2 Psychological factors** 3.2.1 Increase of motivation 3.2.2 Increase of adherence
		"I actually liked the background music. Personally, I thought it was good—others might feel differently. But it helps you relax a bit and focus more on what you're supposed to be doing, rather than on everything else. Yeah, I think technology isn't suitable for everyone. But for this generation, I believe it works well. (laughs)" *Case 12 (Patient)*	**3.3 Technical benefits** 3.3.1 Relaxation/Breathing techniques in immersive environment

Table 2 (continued)

Code	Definition	Example	Sub-level codes
4. Perceived barriers	*Participants' subjective assessment of barriers, disadvantages, and limitations to the implementation of the VR therapy program. These barriers include challenges related to digital infrastructure, difficulties in the implementation process, specific preconditions of the patient group, and negative effects associated with the technical aspects of immersive VR*	"I am now struggling with the telematics infrastructure. […] Maybe this is also a bad time to talk to me about technical things, it could be. Because everything always sounds so simple and then it's so complicated sometimes. Complicated in a different way to paper and a live meeting." *Case 2 (Therapist)*	**4.1 Digital Infrastructure as insufficient**
		"The question is, when this becomes available on the market: Who will cover the costs? Will it be something patients have to pay for themselves, or will insurance cover it for six months, for example? […] How much would such a headset cost? Can we even ask that? Like physiotherapy—these are all hypothetical thoughts for now, right? […] And the programs? […] How much does a device like this cost?" *Case 9 (Patient)*	**4.2 Implementation process** 4.2.1 Cost/Prescription 4.2.2 Skepticism whether physicians would (want to) actually prescribe application 4.2.3 Therapists lack of time for patient monitoring
		"Well, I don't have memory problems, but I do struggle with concentration and fatigue. Someone else might say,'I only have concentration issues, but I'm physically fit.' We all have something different here. All 15 of us, each with a unique combination of issues. And everyone is trying to help themselves. […] Well, everyone experiences it differently because everyone has their own mix of problems. It's really challenging." *Case 8 (Patient)*	**4.3 Preconditions of the user groups** 4.3.1 Symptoms of patient group affecting usability of VR program 4.3.1.1 General heterogeneity of patient group (focus on symptoms) 4.3.1.2 Breathing after COVID19/ need to "relearn to breath correctly" 4.3.1.3 Cognitive impairment of patients affects ability to follow program
		"Yeah. (sighs) If it had been in a NATURAL setting, like at the edge of a forest or by the sea, on a beach, and with a REAL person sitting there demonstrating the exercises, for me—well, I haven't tried it, but I think it would have been easier for me to engage with." *Case 9 (Patient)*	4.3.2 Attitude and knowledge of the user groups 4.3.2.1 Lack of digital literacy 4.3.2.2 Technology perceived as strange because of unfamiliarity 4.3.2.3 Design of program as unnatural
		"I'd be worried about dropping the expensive device, I think. […] At some point, I thought,'Well, actually no, it's secure—the headset itself is firmly in place.' But still, there was this slight feeling of,'Oh, I hope it doesn't slip or fall off.' Especially when I tilted my head downward, I kept thinking (laughing),'I really hope it stays on.' (laughs)" *Case 17 (Patient)*	**4.4 Adverse effects of immersive VR** 4.4.1 Adverse effects caused by Headset 4.4.2 Claustrophobia' 4.4.3 Fear and insecurity while in immersive VR in regard to making mistakes, dropping things, falling, etc 4.4.4 Dizziness 4.4.5 Visual, auditory overload 4.4.6 Fear of overexertion

3.2.2 Intention to use and associated benefits and challenges of VR therapy

As an indicator of the feasibility of the application and VR in general, the test subjects' intention of use was assessed (Davis 1989). With regard to the intended use of the VR application and VR physiotherapy in general as well as the main reason relating to this decision, four types were identified. The group of those who intend to use VR and the application tested in the study can be divided into (1) clear intention to use and (2) intention to use under certain conditions. Participants without the intention to use VR were either opposed to (3) the application presented or (4) VR as a technology for implementing physiotherapy in general. Approximately one third of the cases among patients and physiotherapists can be categorized as resistant to the implementation of VR for physiotherapeutic programs (type 3 and 4). Other participants are evenly distributed between types 1 and 2.

Participating patients and physiotherapists (Type 1) stated perceived advantages over conventional therapy as reasons for their intention to use the system, which they consider to be beneficial despite hurdles such as the lack of social contact and cognitive limitations of the target group of Long/Post COVID patients. On the one hand, the focus is on the possibility of individualizing therapy programs and the increased motivation as well as the autonomy gained in the implementation of flexible training units. The application provides detailed instructions for the use at home, simplifying access to therapy as the program can be carried out regardless of location and appointments. Users can also organize their own training times, considering their daily form. In addition, immersion was found to be particularly beneficial for relaxation and breathing exercises.

> Patient 17: You're no longer restricted to finding a therapist [...]. You're no longer chasing appointments. You can plan it individually at home [...] if you have a bad day and then at lunchtime you're telling yourself: "[...] now you're feeling better. Come on, let's start now. Let's do a little exercise."

Type 2 cases also stated the above-mentioned advantages, but rejected VR for certain exercises, scenarios or patient groups. Thus, physiotherapy implemented in VR should only take place under the guidance of physiotherapists. Independent use of the application for physical training was rejected due to the lack of individual feedback from trained staff, but relaxation exercises were still considered a good option as they offered less risk of injury and potential for incorrect use. Physiotherapists did not mention these concerns in the interviews.

The decisive criterion for rejecting the VR application developed here was adverse effects such as dizziness, a feeling of constraint and sweating under the VR headset (Type 3) which were reported by nearly a third of participants. This meant that even some participants who were generally positive about VR physiotherapy were ultimately unable to use the application.

> Patient 6: I would like to use it [...] But: For me, the graphics are simply too overwhelming. The colors, the 3D [...] I'm overwhelmed by it and it's made me dizzy.

In addition, overstrain with audiovisual stimuli was reported as a result of immersion, which could be related to the reported cognitive impairments of the patient group. Uncertainty due to a lack of digital skills and the desire for therapy programs conducted personally by therapists were also reported in this group.

Finally, there were single cases of general rejection of VR used for therapeutic purposes (Type 4). The preference here were face-to-face services, social interaction, and receiving direct, personalized feedback. Both patients and physiotherapists also noted the complexity of the technology compared to conventional therapies, including telerehabilitation, and expressed general frustration with the slow pace of digital transformation.

> Therapist 2: I am now struggling with the telematics infrastructure. [...] Maybe this is also a bad time to talk to me about technical things, it could be. Because everything always sounds so simple and then it's so complicated sometimes. Complicated in a different way to paper and a live meeting.

3.2.3 General preconditions: infrastructure, digital literacy and costs

In addition, several obstacles were identified across all above-mentioned types (Type 1–4) that generally need to be considered when developing VR-supported physiotherapy. First of all, these relate to the costs and implementation of the application and the VR headset in the context of the healthcare system. Test subjects were not willing to purchase technology and software used in the study privately. Equally, none of them had access to VR technology.

The lack of digital literacy and inadequate infrastructure should also be mentioned. Physiotherapists in particular cited a lack of or unstable internet connection as an obstacle to the integration of innovative technologies into everyday practice. Both user groups require comprehensive training in order to be able to use the technology or provide adequate guidance. Technical support is also required during therapy to assist with acute problems and regular maintenance tasks such as necessary updates.

The supervision of VR therapy by physiotherapists was also discussed and generally desired by both therapists and patients. This was viewed as necessary in order to determine whether therapy is not merely being carried out, but above all whether it is done correctly. Nevertheless, the physiotherapists expressed concerns about how monitoring can be implemented in terms of time resources in the context of everyday practice.

While patients particularly emphasized the flexibility in implementation and the detailed instructions for use, physiotherapists assumed increased adherence due to increased motivation. However, both groups emphasized that digitally supported therapy offers for the home environment cannot completely replace a therapy session carried out in person by the therapist and should only be offered as a supplement to conventional therapy. This is because the personal exchange between patient and therapist was the main focus for both groups.

4 Discussion

4.1 Principal findings

The VR application for the implementation of virtual physiotherapy for Long/Post COVID patients evaluated in this study was generally accepted and assessed as feasible. The qualitative evaluation focused on the program's usability and adaptability. Early issues with unclear visual and auditory guidance were resolved through added instructions and visual cues, improving user experience. Additionally, breathing synchronization challenges were addressed by implementing pause functions and varying speed levels. Participants generally expressed a strong desire for personalization and controller-free exercises, as controllers were seen as disruptive. The requirements for hardware and software include stability as well as ease of use in terms of weight and other possible physical discomforts caused by the VR headset. Overall, the iterative development process led to significant improvements, making the program more user-friendly and adaptable.

The expected benefits related particularly to increased motivation, autonomy and accessibility of physiotherapy through providing detailed and engaging instructions for the home environment. The study assessed the intention of use as an indicator of VR feasibility in physiotherapy, identifying four types of users. About a third of participants were resistant to VR (Types 3 and 4), citing adverse effects like dizziness and a preference for in-person therapy. Participants with a clear intention to use VR (Type 1) valued its flexibility, autonomy, and potential for individualized therapy, despite concerns about social isolation and cognitive limitations. Type 2 users saw VR as beneficial for relaxation but felt physical exercises required therapist guidance.

Further, obstacles such as digital literacy and the costs associated with hardware and software were also reported. Mainly, there is an urgent need to train physiotherapists as well as patients to ensure adequate use of the innovative technology and to offer ongoing support in the event of technical problems and maintenance for both groups.

4.2 Comparison with prior work

Compared to existing studies on VR therapy programs focusing on the rehabilitation of pulmonary function as well as breathing exercises, the present evaluation and co-creative development of an immersive VR application showed similar outcomes in relation to perceived increase in motivation, flexibility and autonomy (see e.g. Jung et al. 2020; Moorhouse et al. 2019; Gabriel et al. 2023). However, while the studies in question focused primarily on evaluating physical and psychological parameters (see e.g. Jung et al. 2020; Groenveld et al. 2022), the co-creative approach of joint application development allows further and, above all, concrete statements to be made about the technical needs of the user groups. For example, as part of this study the concept for the audiovisual guidance of the exercises was developed in cooperation with those affected. In addition, the study identified which factors can have a positive (flexibility and independence) or negative (adverse effects) impact on the user acceptance of Long/Post COVID patients. Apart from patients, physiotherapists were also included as a user group, who had previously only been surveyed as part of one other study.

As the study further looked at conditions and requirements for a successful implementation of VR therapy programs, costs and benefits of implementing VR as an innovative technology for the rehabilitation of Long/Post COVID patients can be discussed based on reported results (see 4.3). This is another point that has hardly been addressed by previous studies.

With regard to comparability with the current state of research, it can be stated that a very individual and heterogeneous diversity of results was achieved in this study. This confirms that there is still considerable catch-up potential for reliable data on the explicit subject of research. In particular, it is clear that the framework conditions for financing and integration into existing processes are decisive for application.

4.3 Considering costs and benefits

While the reported, various perceived benefits of implementing VR-supported physiotherapy were mentioned by the majority of both patients and physiotherapists, some barriers must also be considered. Adverse effects were reported by one-third of the participants in this study. Previous studies on immersive VR physiotherapy had also reported motion sickness, dizziness and headaches as negative effects of using VR headsets as common side effects of immersive VR technologies which can only be reduced to a limited extent by the design of respective applications (Baniasadi et al. 2020).

In light of the reluctance to pay for the application privately and the simultaneous lack of access to the required hardware by both user groups, approaches to the implementation of VR-supported therapy programs must also ensure that access is provided free of charge for patients respectively. This means that costs are covered by health insurance companies for instance through programs as the German Digital Health Application (DiGA). Access to VR headsets should also be made available, moreover, through rental devices. Furthermore, therapists especially have to spend more time and effort not only training patients in the use of the technology, but also, they must ensure their availability as a contact person during the course of therapy to provide constant support. This applies in particular when measures to monitor the progress of therapy are implemented.

The costs and benefits of the innovative technology therefore stand in contrast to each other, whereby the question is evident as to whether the reported benefits of immersive VR applications such as motivation and autonomy are proportionate to the resources necessary to implement the technology. The consideration of costs and benefits is a factor that has a significant influence on the acceptance of new technologies. A lack of usability as well as high costs in terms of monetary and human resources can prevent the actual use of new technologies (Schäfer and Keppler 2013). Following Gartner's hype cycle model, which is describing the phases of the establishment of innovative technology, however, it is to be expected that new, promising technologies will initially receive a setback when individual use cases prove to be too difficult to implement in practice. As the technology and conditions develop and awareness of strengths and weaknesses increases, suitable application scenarios may emerge (van Lente et al. 2013). Nevertheless, further research is still required for the case of immersive physiotherapy, which includes a long-term intevention under real conditions as well as VR programs with alternative approaches.

4.4 Limitations

This study uses a qualitative research design to reveal important aspects that are necessary for the long-term integration of VR applications in rehabilitation. The approach and survey methodology proved to be very well suited to achieving the objectives of the study, so that there is a high degree of coverage here. In addition, a certain degree of data saturation was achieved through the approach. However, some methodological limitations must be considered when interpreting the present results. With regard to the age and gender distribution, the sample cannot be categorized as representative due to the recruitment of participants via existing self-help groups, which consisted mainly of female participants over the age of 50. The age range does not show a contrasting sampling structure. The majority of the people included in the study were female. Nevertheless, there is a fundamental tendency toward a clear effect, which is evident despite the small sample size. Furthermore, it cannot be entirely ruled out that participants are similar in other characteristics, such as a general affinity and curiosity towards digital technologies, which could have been a decisive factor in their decision to participate (Elston 2021).

4.5 Indication for practice and future research

The fact that critical feedback regarding the usability in terms of navigation within the application and the instruction of the exercises by audiovisual impulses subsided in the course of the study in all three groups (experts, ad hoc, and core group) shows firstly that the participatory development of innovative technologies is useful to adapt technologies to the needs of the target group. Secondly, we were able to demonstrate that the present study design is suitable to improve the usability of an immersive VR application.

However, long-term studies under real-life conditions are necessary to prove the actual benefits of the therapy program. Additional data for evaluating the effectiveness of the intervention is also necessary in order to establish comparability with other digital and conventional interventions. With regard to the implementation processes discussed above, it is also necessary to involve medical professionals who are to prescribe the applications in future.

5 Conclusion

The VR therapy program evaluated in this study is accepted and positively evaluated by the majority of participating Long/Post COVID patients and physiotherapists. Requirements for the development of an intuitive VR application tailored to the needs and requirements of the target group relate in particular to the reduced and calm design, a close guidance of users through the application at all times and an individualized composition of the therapy program in terms of training units and levels of difficulty. But there are still obstacles that would require enormous effort to implement respective VR rehabilitation or that individual projects are simply not able to overcome. This includes, for example, training of physiotherapists and patients to reduce fear of technology and increase digital literacy, which is an essential prerequisite for the implementation of VR-assisted physiotherapy but also adequate infrastructure in order to implement digital technologies. For this reason, it is very important for future research to think and plan co-creative technological developments in the long term in order to implement the hurdles but also opportunities revealed here in the study in the patient care process in the long term.

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Declarations

Conflict of interest The authors declare no competing interests.

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