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A virtual reality-based pre-discharge home assessment for inpatient rehabilitation: co-creation, feasibility and user perception

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Abstract

Background Pre-discharge home assessments (PDHAs) in inpatient rehabilitation help healthcare professionals evaluate patients' home environments before discharge, ensuring accessibility, safety, and independent living. These visits improve patient adherence to recommendations and patient involvement but are resource-intensive. Ward based assessments using a virtual representation of the patient´s home might overcome these obstacles. This study aims to develop and test a virtual reality (VR)-based PDHA prototype based on healthcare professionals' (HCP) needs, assessing its impact on therapy and home adaptation planning from both provider and patient perspectives.

Results In the needs assessment and prototyping phase, a VR-based home environment assessment tool (VR PDHA) was developed based on feedback from HCPs such as physiotherapists and occupational therapists. The tool was developed to assess patients' home environments, measure rooms and share information. The IT infrastructure consisted of a smartphone with LIDAR technology and an app for scanning and exporting the data to a content management system, where the data can be calculated and edited. Users can also navigate, measure, comment and export spatial data at the frontend and also move around and measure in the VR environment.

The intervention was tested in a real-world setting with 12 patients. Feedback showed that the VR tool improved communication, supported discharge planning and improved understanding the challenges at home. While therapists rated the usefulness of the tool highly, some patients had difficulty visualising the changes. Overall, the intervention supported the therapeutic goals and provided workable recommendations for home adaptations and aids. Further technical improvements were suggested to increase its usefulness.

Conclusions This study demonstrates the development of a VR PDHA, which is accepted by users. The prototype exceeds the capabilities of existing virtual home assessment applications. It provides benefits of a home visit without necessitating extensive personnel or time resources, thereby enhancing both counselling and the provision of aids and modifications. The previously unconsidered user requirements of other user groups outside the rehabilitation clinic, who are also involved in the PDHA process, offer potential for the technical expansion of future prototypes.

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Trial registration Study registration of the pilot study occurred prior to inclusion of the first study participant as DRKS00025836 on August 24, 2021 in a publicly accessible study registry (German Clinical Trials Register).

Keywords Pre-discharge home visit, Home assessment, Rehabilitation, Participation, Virtual reality, Digital healthcare

Background

Persistent limitations are a common challenge for patients in neurological and geriatric rehabilitation. In order to be able to live independently after discharge, patients require training during rehabilitation, alongside home modifications and assistive devices. Pre-discharge home assessments (PDHAs) are home visits, which are conducted by healthcare professionals (HCP) while patients are in inpatient rehabilitation or hospital, and which support patient discharge and therapy planning [11, 22].

PDHAs are utilised to obtain information regarding potential issues within the home environment, including aspects such as accessibility, safety, and independent living [7, 11]. The patient's mobility and activities are assessed, tripping hazards and barriers in the environment are identified, and measurements are taken to recommend appropriate home modifications and strategies for safe and independent living [7, 11]

A study by Lockwood and colleagues revealed that PDHAs improved adherence to recommendations [29]. Moreover, a home visit provides a valuable opportunity for therapists and patients to evaluate the practical applicability and sufficiency of the techniques learned in the clinic within the patient´s real home environment [12].

Conducting PDHAs demands a considerable amount of resources [34, 35, 41]. For instance, several authors reported an average duration of between 45 and 80 min for a single home visit, excluding travel time [24, 25]. Including travel time, the average duration of home visits is at least 68 min, but can be up to four hours overall [23, 25].

A comparative analysis was conducted of the time and travel costs of occupational therapists in relation to PDHA interventions involving home visits and those conducted in a ward setting. The findings revealed a discrepancy in costs of $290.88 (SD $134.01) for home visits and $82.98 ($95.73) for interventions conducted in a ward setting [39].

A lack of resources, encompassing the unavailability of staff, vehicles and time, in addition to excessive travelling distances, impedes the conducting of a PDHA, even when deemed necessary for patients [16, 42].

The utilisation of a virtual PDHA has been suggested as a potential solution to the challenges posed by limited resources, while maintaining the core functionalities of a physical PDHA. This is facilitated by the provision of comprehensive information regarding the patient's home environment and the facilitation of communication between patients and healthcare providers.

In recent years, a number of publications have emerged that explore the potential of virtual reality (VR) tools to support PDHAs. The characteristics of VR are diverse and can be broadly classified as non-immersive and immersive. Non-immersive VR environments permit the user to interact with the virtual environment by using 2D interaction devices, including sets of screens for viewing, as well as keyboards, computer mice, or joysticks [15]. While the user moves around in three-dimensional spaces on the screen or moves three-dimensionally displayed objects, the real environment can be fully experienced by the user at the same time. Immersive VR systems facilitate complete immersion of the user in the virtual environment. The sensation of immersion is created by the user being surrounded by a 3D computer-generated system that represents the reality and delivers real-time changes in sensory information in response to the user's head and body movements, as if they were in an equivalent physical environment [14, 33]. This phenomenon is facilitated by visual displays such as Head-Mounted Displays (VR glasses), which are designed to restrict the user's perception of the real environment, thereby promoting a sense of immersion in the virtual world and its perception as the real world. The degree of immersion is further increased by the extent of interaction with the virtual space. For instance, one is able to navigate the virtual environment, rotate, and observe the surroundings; however, it is not possible to move within the virtual space (three degrees of freedom) or to move along the three translation axes (six degrees of freedom), thereby altering one's physical position.

In some published tools, the non-immersive representation of three-dimensional ("virtual") living spaces is conducted exclusively as a preconfigured default environment (e.g., [4, 30],). However, these tools cannot provide individualised information and therefore do not enable individual recommendations or planning. Other tools are based on interior design applications to create individual floor plans (e.g. [30, 31, 37]). To be able to use these tools at a rehabilitation facility, the team would first need to have specific detailed information such as room dimensions, door widths and the presence and dimensions of furniture in order to model and equip the rooms using the tool. The question that arises from this is how therapists can obtain sufficiently detailed and accurate information for a virtual home assessment.

The advent of smartphone technology with integrated LiDAR sensor in 2020 marked a significant technological advancement for end users [2]. This development enabled the facilitation of basic 3D scanning operations directly through the smartphone.

The three-dimensional models of the actual home environment generated in this way appeared to the authors to be a promising approach for carrying out a virtual PDHA within the rehabilitation facility.

The authors of this article suggest that the utilization of the 3D model not only on screen, but also as an immersive "home visit" using VR goggles, could facilitate an efficacious way to perform PDHAs through the immersive grasp of the home environment. As in the actual home, therapists would be able to gain an immediate understanding of the dimensions and spatial structure, thus facilitating the formulation of individually tailored recommendations and planning.

Studies in the field of technical applications for PDHA often focus on "views", "perceptions", and "potential" from the perspective of users and interest holders, without experiment in real world setting. Others pilot-tested the virtual PDHA intervention in terms of health outcomes on the target patient population in order to generate evidence on the effect of the new technology [4, 35, 36]. Our study has been planned in the sense of a clinical proof of concept, which lies between a purely technical or laboratory proof of concept and a full clinical study [6].

The objective of this study was to develop and refine a technical system to conduct home visits within the virtual twin of the home using a 3D model and VR goggles, based on the user needs and perceptions. We aimed to investigate what the initial demands of HCPs on the design of a prototype for conducting PDHAs were, and how the use of the prototype influenced the clinical processes and mechanisms of impact of a therapeutic home visit from the perspectives of both HCPs and patients.

Methods

The overall approach was guided by the UK Medical Research Council (MRC) framework and integrated existing evidence from a recent literature review [22], developing a theory, and modelling processes and outcomes within an underlying logic intervention model [8, 32]. The technology development was guided by the process cycle of Design Thinking (DT) [1]. Key principles of DT are 1) to describe user needs in the context of use and 2) to involve iterative prototype testing of the intervention with user feedback, and 3) to test the intervention with intended users while implementing and continuing to refine it on the basis of user feedback. In this study, the implementation phase was designed as a real-world experiment with the focus on testing feasibility. This requires a working prototype of the necessary functionality and infrastructure in sufficient quality, which is used for an appropriate period of time with a limited but relevant group of people serving as test subjects [6, 40]. The approach and methods of development and feasibility testing are shown in Fig. 1.

The development and feasibility testing took place in an inpatient rehabilitation clinic (MEDIAN Saale Klinik Bad Kösen II) in the Departments of Neurology and Geriatrics. The rehabilitation clinic is located in a rural area in Germany with a large catchment area of up to 400 km.

Development phase

The intervention was developed between November 2020 and September 2021.

First, user demands on usability and context for the VR –PDHA were identified in two expert workshops with HCPs involved in clinical discharge planning processes, as well as one researcher and one developer. In workshop a, the basic technical design components of the first low fidelity prototype were the starting point for discussion of user needs and the development of the application (Fig. 2).

The users were asked about their tasks in the discharge preparation process. They were also asked to assess in which way the software component would be useful for the visualization and clinical use of the data. Necessary technical functions were derived by the developer and implemented in the next prototype stage. Since not all of the functions requested by users could be implemented within the project's resources, the technical functions were prioritized. The prioritization was guided by defining the main and secondary users. Physiotherapists and occupational therapists were identified as main users, as they are typically in charge of home assessments. Therefore, these professional groups considered themselves to be the ones interacting with the technical system and the developer implemented the corresponding technical functions.

Furthermore, information was obtained from the main users and potential secondary users regarding the context of use (e.g. organisational structures, spatial conditions, clinical processes). This information was used to adapt the technical hardware and software system to the setting. For example, external sensors could be selected for the VR component if a room was pre-set.

In workshop b, a general feedback loop was initiated to ascertain the potential usefulness and ease of use of VR visualization. This was deemed a crucial step, given that the utilization of VR technology was not yet a common practice among therapists. Furthermore, the objective was to assess whether patients should adopt the visualization as secondary users within the VR-PDHA.

Low fidelity-prototypes (e. g. non-immersive 3D visualization) were continuously evaluated in weekly sessions

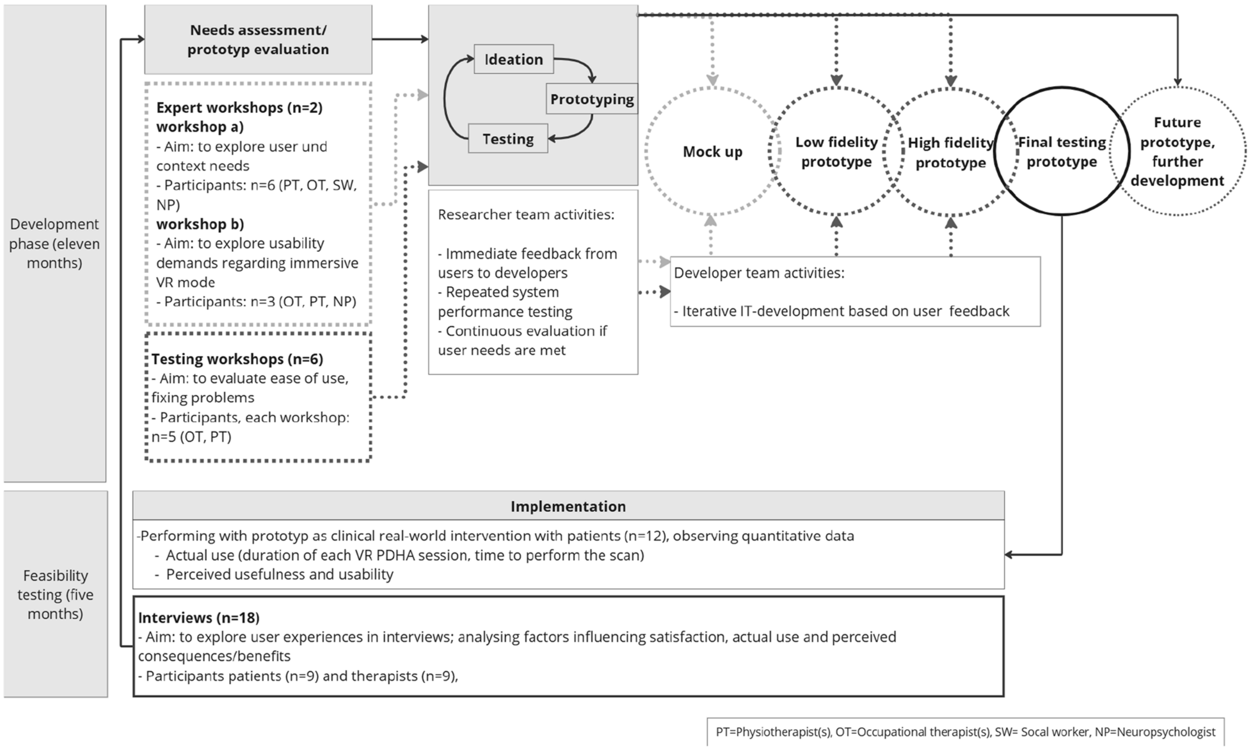

Fig. 1 The process and methods of iterative development and feasibility testing

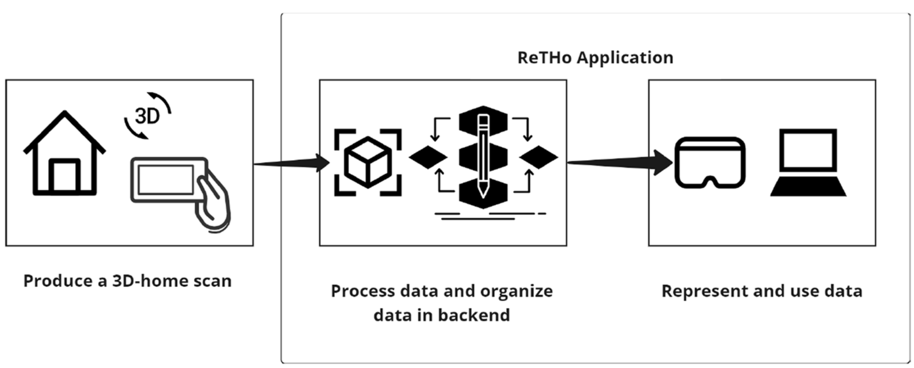

Fig. 2 Components of the technical system

with the IT-developer and a researcher. The iteratively developed high fidelity prototype was finally tested in six testing workshops with therapists (who were identified as the main user group). Main user feedback regarding ease of use was obtained in order to finalize the prototype for the feasibility testing phase.

In workshop a, user feedback was audio recorded and transcribed verbatim.

In workshop b and testing workshops users were additionally asked to think aloud while using the technology and prompts were written down [13].

In addition, relevant contextual factors were explored, using clinical standard operation procedures and consultations with the therapist team leader (e.g., work processes, role tasks, and users' physical environment).

Datasets were produced and analysed subsequently with each iteration step of the development phase and informed the overall intervention protocol implementation activities.

Qualitative data from workshops were analysed according to concept, using "perceived usefulness" and "perceived ease of use" of the "technology acceptance model" according to Venkatesh and Hillol [38] as main categories for coding (Schreier 2012). In order to draw conclusions about necessary implementation measures for everyday clinical practice, the information on context was structured in accordance with a consolidated framework for advancing implementation science [10]. All qualitative data, including data from the following feasibility testing, were analysed with the same technique using a mixed deductive-inductive approach based on the structured approach of directed content analysis (Malterud 2012).

The organisation of qualitative data was facilitated by MAXQDA software and Excel. In order to ensure the rigour of the coding process, the coding was performed by two independent scientists.

Feasibility testing

After a high fidelity prototype had been set up, we implemented and evaluated the VR-based home assessment system in the Departments of Neurology and Geriatrics of an inpatient rehabilitation clinic (MEDIAN Saale Klinik Bad Kösen II) as an exploratory single-arm feasibility study.

Inclusion criteria were: (i) age of at least 18 years, (ii) any neurological diagnosis or geriatric syndrome (defined as "multimorbidity with impending risk of loss of autonomy in activities of daily living"), (iii) anticipated persistent functional limitation(s) associated with increased risk of falls in the home environment and/or need for environmental adaptations, and (iv) discharge destination home or uncertain. Exclusion criteria can be found in the supplement.

Patients had to receive the VR PDHA at least once during the rehabilitation phase. The actual use of the technique during the implementation of the VR PDHA (for example, whether VR was used or not) depended on the therapist. However, assessment of home barriers was structured using a therapeutic interview assessment instrument (Canadian Occupational Performance Measure, COPM) [27].

The actual use of VR PDHA was assessed in terms of duration of each VR PDHA session, including preparationtime (documented by the HCPs) as well as the time for performing the scan at the patient's home (documented by the researcher).

HCPs' views on usefulness and usability were assessed by rating the following questions at the time the VR PDHA was performed: 1) feeling supported by technology when discussing home issues with the patient and pursuing therapeutic goals, 2) perceived overall effort in using the tool, 3) level of enjoyment when using the technology (ranging from 0 = totally dissatisfied to 10 = absolutely satisfied).

Quantitative data were analysed and presented descriptively. Continuous characteristics are presented as the mean and standard deviation, and categorical variables are presented as absolute and percentage frequencies.

Patients' and HCPs' experiences of the intervention were explored by semi-structured interviews.

Interview data were analysed regarding factors influencing satisfaction, the actual use and perceived consequences/benefits of the VR PDHA as well as suggestions for technical improvements, which informed the categories for the analysis focus.

Interview guides were developed specifically for this study and agreed on by the research team prior to use. (Please see supplements for interview guides.) Interviews with HCPs were conducted face to face and interviews with patients via telephone, one call per patient, and were carried out exclusively by one researcher (UKH) who was trained and involved in the project. Interviews were audio-recorded and transcribed verbatim.

Results

User needs assessment and prototyping phase

In a total of eight workshops, user feedback from physiotherapists, occupational therapists, a social worker and a psychologist as well as the IT-developer and one researcher was collected and iteratively incorporated into the prototypes. A detailed description of the characteristics of the workshop participants is shown in the supplement. A total of 45 individual usability demands were derived.

The initial and overarching user demands to perform a VR PDHA while the patient stays in the clinic were:

- To gain a general impression of the home environment
- To measure the home and objects within it
- To gather and share information.

All 19 sub-themes are displayed in detail in the supplement. Due to limited time and financial constraints, some of the technical features of the application suggested by the HCPs were initially postponed in the project (e.g. 'meeting in virtual space with participants').

Components of the system, IT-infrastructures and implemented functions and clinical use scenarios of the final prototype are shown in Figs. 3, 4 and 5.

The home scan was performed using a commercially available smartphone device with an integrated lidar sensor. We purchased the necessary scanning app from the iOS App store. Several apps were available, which we tested in order to select the one that performed best at the time. The hardware and software were used without modification. Although the research team considered the scan to be technically and physically easy for relatives to perform, it was nevertheless decided that the scan should be carried out by a member of the research team, as the initial focus of testing and evaluation was on the technical feasibility of the VR PDHA in the clinic. In addition, there were concerns that logistical processes for shipping the smartphone would have led to delays. Patients normally only stayed in the clinic for three weeks, and the clinic's operation of the VR PDHA should not be put at risk.

	Prototype components			
	3D home scan	**Backend**	**Frontend (desktop)**	**Frontend (VR)**
IT-infra-structure	• Smartphone with LIDAR technology • Smartphone LIDAR app	• Content management system	• Screens to display ReTho-application • Keyboard, mouse	• VR glassess, controller • (Screen to share VR environment)
Functions	• Scanning room by room • Exporting anonymous 3D data to cloud	System: • Storing data • Computing data model dynamically Technical writing: • Login • creating a new patient folder with folder ID-number • Importing and categorising scan data	• Showing rooms as 3D models / floor plan • Navigating 3D-models in three dimensions • Measuring with virtual folding ruler • Entering free text, commenting in chat, adding pregonfigured hazard items from list • Exporting Excel spreadsheets with room-based lists of measurements and/or detected home hazards	• Showing rooms in fully immersive VR • Navigating in VR (by physical or visual motion, 6 Degrees of Freedom) • Measuring with two distance meters (laser meter and folding ruler)

Fig. 3 Use scenario, IT-infrastructure and functions of the application

Fig. 4 VR frontend. Left picture: Room dimensions in the VR room (distance from the door to the balcony); middle: room dimensions in the VR room (width of the balcony door); right: typical application scenario, the first therapist is in the virtual room while the patient and a second therapist see what the first therapist sees and measures, using the screen. The image shows a staged scene with the first author, another research colleage and an actress in a model home

A Data Management System was integrated into a Windows-based application to process and organize 3D scans of patients´ homes in a data-backend (ReTHo) and to visualize and edit the individual 3D data in order to prepare the VR PDHA.

The main functions of the final prototype according to the overarching user demands are displayed in Fig. 3. The intervention procedure for the clinical use of the final prototype was defined a priori. The intervention is described in detail in the supplement according to TIDieR-Checklist [20]

Feasibility testing

Feasibility testing was conducted from October 2020 to February 2021. A total of 19 patients consented to participate, of which 12 patients received the intervention (see patient flow chart in Fig. 6 for details). Reasons for non-participation after consenting were as follows: One inpatient no longer met the inclusion criteria due to a deterioration of his condition, and in six cases, the relatives refused to have anyone at home for the scanning.

The patients were on average 68.83 years old, 57.1% male. Half of the patients (50%) lived at home alone. Diagnoses were: stroke or other neurological diagnose with symptomatic hemiparesis or hemiplegia (50%) or paraparesis (41.7%) and one patient was included who had a geriatric diagnosis. It was assumed by the therapists that patients who were suddenly disabled are more motivated to use the device.

In the case of geriatric patients, the obstacle to an intention to use the device could also be a partner living at home who is also in need of care and who should not be burdened by the scan.

A total of nine HCPs participated in the interviews at the end of the intervention period: OTs ($n = 5$), PTs ($n = 3$) and one rehabilitation technician (RT) who was not an

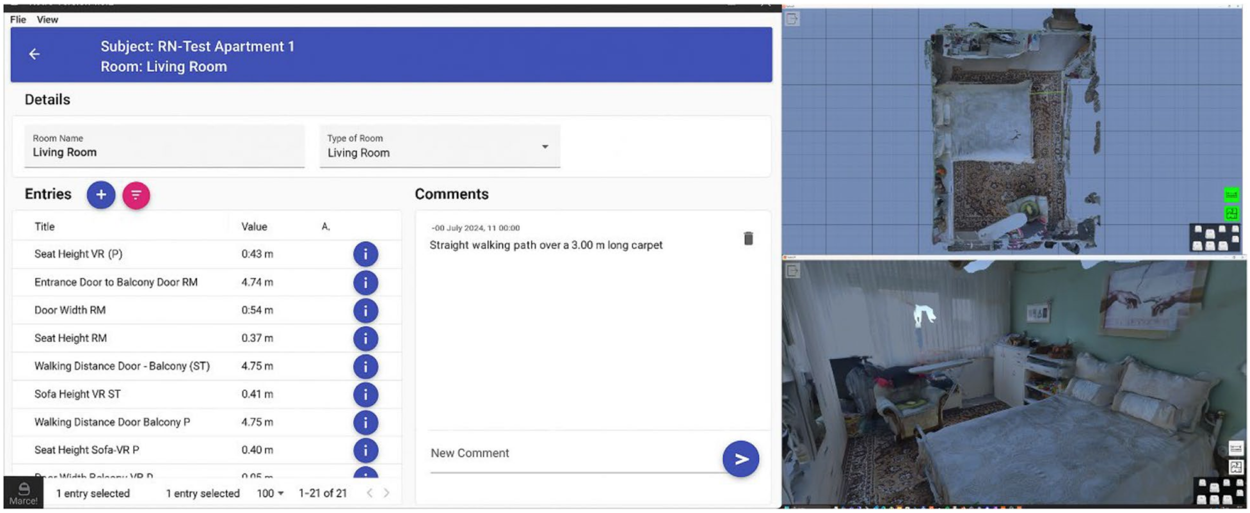

Fig. 5 Desktop frontend. Left picture: View of measurements, free notes, and comments within a specific room. Right picture, top: Top view of a bedroom with button to activate the measuring tape (top right edge of image), button to change views (centre right edge of image) and optional control buttons to move the 3D model (bottom right edge of image). Right picture, bottom: perspective view

employee of the rehabilitation facility but who worked closely with the therapists.

Of the 12 patients receiving the intervention, a total of nine patients reported on their experiences with the intervention in semi-structured telephone interviews. Relatives took part in the interviews in some cases ($n = 4$).

Interviewee characteristics (HCPs and patients) are shown in detail in the supplement.

Actual use

VR PDHA Each of the patients ($n = 12$) received the intervention once.

Per VR PDHA an average of 7.76 (SD 1.97) rooms were assessed and 12.3 (SD 5.02) recommendations were entered in the application interface during the assessment.

Therapy sessions took 43.67 min (SD 10.52, range from 25 to 65) all in all. The time between the start of the therapy session and the start of using the tool for the virtual visit took on average 11.17 (SD 5.57, range from 5 to 20) minutes. However, the VR-based part of the home assessment took 23.33 min (SD 9.31, range from 13 to 42).

The intervention was delivered in different constellations of participants with PTs, OTs, patients, one relative and one rehabilitation technician (see supplement for details). In most cases the therapists used the VR headset and the 3D screen ($n = 9$), or only the screen ($n = 3$). The rehabilitation patients did not put the VR headset on, but used the screen to view the home ($n = 11$).

Scan For nine patients a study team member performed the home scan; in three cases, relatives performed the scan in the team member´s presence. Each room was scanned within a few minutes (3—10 min). An average of 8.67 rooms per patient were scanned. The entire scanning process for all rooms took between 40 and 90 min each time.

Usefulness, usability, satisfaction

Therapists rated usability and usefulness of the tool overall as very good (VAS ranging from 0 = totally dissatisfied to 10 = absolutely satisfied). Satisfaction in feeling supported by technology was rated on average with 9.83 (SD 0.58) and in pursuing therapeutic goals with 9.67 (SD 0.78). Satisfaction with the perceived overall effort in using the tool was rated at 8.25 (SD 2.34) and the level of enjoyment in using the technology was rated at 9.5 (SD 0.90).

As key mechanisms of impact were identified

VR PDHA facilitated communication and comprehensive understanding The visualization of the home supported a trustful discussion between therapists and patients in some cases.

> *"So just having a conversation, like "Gee, but you have a nice carpet." Simply to build up a basis of trust about it. That works out great." (HCP 1). Further, she stated: "So many patients have these fears about returning home. And I think it's perfect for taking away that fear." (HCP 1).*

From the patient's perspective, the virtual assessment facilitated communication between therapist and patient, as it allowed both parties to gain a comprehensive understanding of the patient's environment. This approach enabled a more efficient exchange of information, particularly in cases where verbal communication was

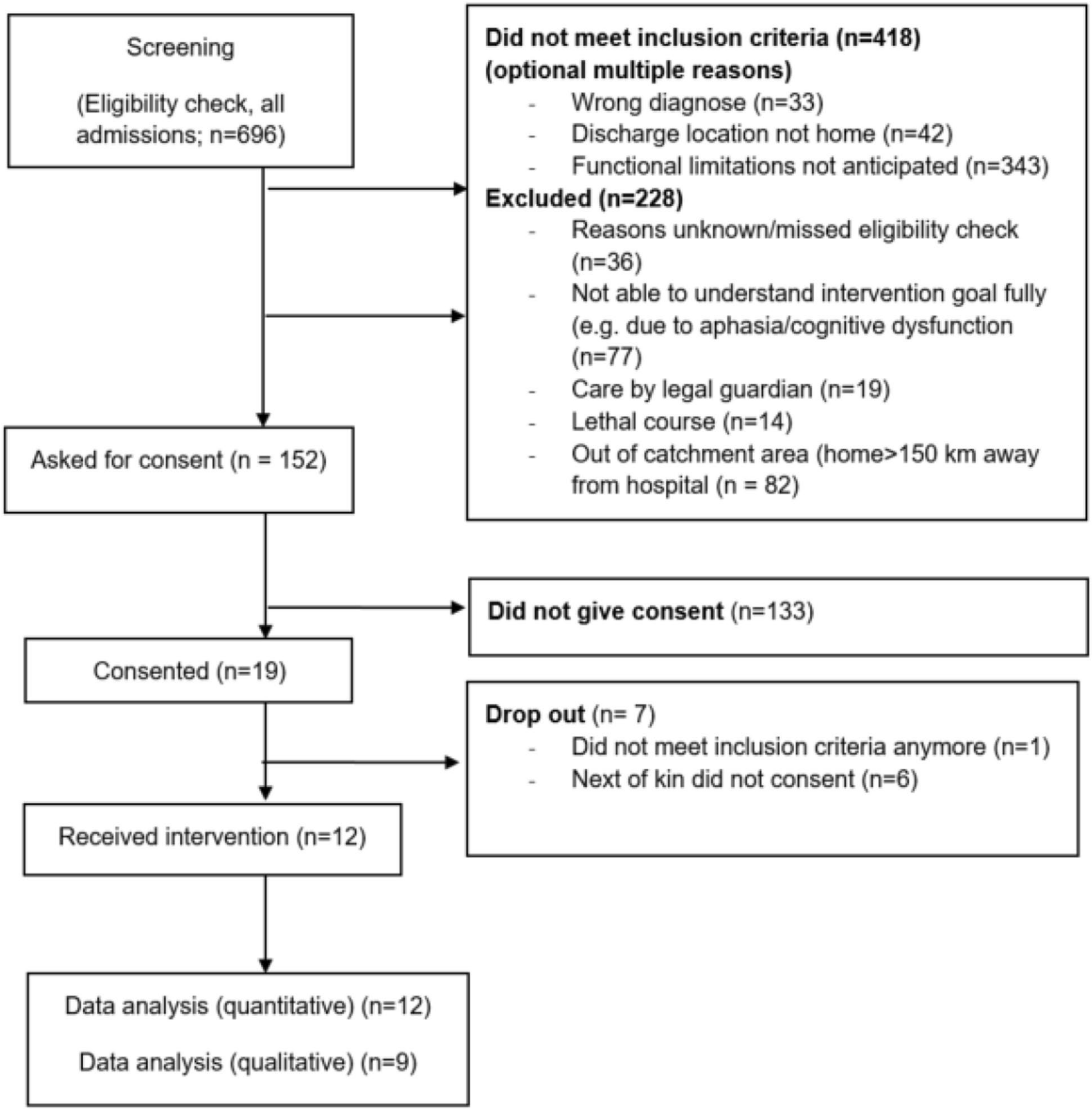

Fig. 6 Patient flow in feasibility study

challenging due to the complexity of the subject matter. One patient said:

> *"[...] it's easier to imagine....and understand with the stairs and all that. Otherwise I would have had to make sketches or something. And so I was able to refer to the screen." (Patient 3)*

One patient stated:

> *"Yes, you don't even know the individual problem areas in your home. And you don't know the condition you'll be in when you get home. So I would recommend having it [VR PDHA] done, right." (Patient 11)*

However, it was not possible to enhance the ability to envision the home in all patients. Despite one patient having access to a 3D model of the house, she found herself unable to envision modifications.

> *"We have built a lot at home, and it is always better when you can stand inside and imagine it in nature. However, I'm a person who has to see it in the real*

> *world. So my husband, who used to be a technical draftsman, made a sketch of it. Well, I could always imagine very little about that." (Patient 9)*

VR PDHA triggered confidence, but also unpleasant feelings One patient stated:

> *"Yes, because when you get to the real world, you're on your own. It's a good feeling to be able to foresee that things can work [...]" (Patient 8).*

Another patient could not return to his old home, and a new home was furnished by relatives. He stated:

> *"I was informed beforehand about what it would look like. I was able to anticipate it and see what might need to be modified." (Patient 4)*

Another patient experienced the virtual-based home assessment as an emotionally stressful situation, being aware that returning home might not be possible:

> *"You get too worked up again and you know you cannot handle it. Have to let it all go." (Patient 2)*

VR PDHA was appreciated for reliable information The therapists perceived the intervention as being supportive for all participating inpatients. Reliable information about the home environment helped to prepare the discharge. Therapists felt that they could give more precise recommendations and prescribe aids that fit into the patient's home.

> *"Therefore, for me as a therapist, it is simply the best possible way to prepare the patient for discharge at home. [....] That's because it (standard approach) is only about a verbal piece of information, right? And the intervention here had a solid foundation because you saw the situation at home. The right things were prescribed and given." (HCP 6)*

Therapists and patients improved recommendations for activity goals (tailored, participation-oriented and operationalized) The assessment supported the goal-setting process for activity training related to everyday life: *"We want to be able to walk from the living room to the kitchen, right? And we are now recreating that in the therapy room. Then it's no longer just: "We'll walk down the hall in the clinic," but: "We'll walk from the kitchen to the living room. And now I'm going to put something in between and you have to step over the edge.*

[...]and that gives a boost to the therapy, so that the patient once again knows what they are doing it for and what they still need to practice specifically." (HCP 3)

Having the real furniture dimensions, the therapists started to simulate home activities in training sessions, such as getting in and out of the shower tub, lifting the leg to the necessary height or climbing narrow stairs. *"We discussed it with the therapist, for the first four or five steps, I can walk up by pulling on the handrail. And where the spiral staircase begins, I walk a bit on all fours. And then, when it's straight again, I stand back up. (...) And that's what we practiced. We simulated it, so to speak." (Patient 3).*

Suggestions for further technical development The RT suggested that additional visual representation of technical aids within the tool would be helpful to further increase the acceptance of necessary aids.

Furthermore, an interface between tool–software infrastructures and IT devices in the facility must be provided to enable a data output within the clinic (e.g., to store or print Excel sheets or share sheets or photographs via e-mail). Furthermore, an interface between the software of the IT system and the local software could connect the electronic patient documentation.

Discussion

This study aimed to develop and test a VR-based PDHA prototype based on healthcare professionals' (HCP) needs, assessing its impact on therapy planning and home adaptation planning from both provider and patient perspectives.

The technical product constituted a system encompassing a screen interface for the organisation of patient data within the patient's home environment, complemented by the capacity to display the patient's home in an immersive or non-immersive manner. This enables the team in the clinic to carry out a home assessment independently of support from remote participants. This approach may offer certain advantages in the clinical process when compared to technical solutions such as video conferencing, as have previously been investigated by other authors [26].

Compared to a technical solution for a home scan based PDHA, published in 2021, our prototype offers the possibility of immersive movement in the home environment [17]. However, the therapists who tested it employed immersion only to a certain extent. The potential advantages of immersion are an improved spatial impression with the opportunity of an immediate motor response from the user. Thus, it can be hypothesised that an immersive PDHA is overall easier and faster for therapists to perform. This hypothesis should be investigated in future studies with more users in order to set the course for the future technical development of our prototype and the future training of users. The potential benefits of immersion in terms of an enhanced impression of the room as part of a VR PDHA should be investigated in future studies.

In clinical practice the original functions of home visits are assessing the environment with regard to safety and recommending adaptions. In this context, measurements of the home environment are taken and the recommendations for adapting the environment are discussed with the patients. Furthermore, the performance of specific activities, such as transfers or self-care are assessed and practised [11]. Disadvantages of home visits are described as using up resources, needing extensive preparation and causing stress for patients and therapists [3, 19].

In the course of testing the prototype in everyday clinical practice, it was possible to investigate the extent to which the VR-PDHA is able to fulfil the original functions of a physical home visit and at the same time eliminate its disadvantages:

Involved therapists emphasized that measurements (e.g. room size and step height) allow for more reliable advice. Therefore, a VR solution could be superior to any other ward-based PDHA that relies only on the patient's or relative's information about the home, especially if required measurements are not available in the counselling situation. Using the true-to-scale visualization of the home, the therapists felt that recommendations for aids and home adaptations could be made and discussed with the patients in a more precise manner.

From the perspective of the patient, the visualization of the home environment facilitated communication of home construction scenarios that were otherwise challenging to articulate. Our results showed that, from a therapist's point of view, being able to discuss recommendations with the patients is in line with [17] who found that therapists perceived a better understanding and ability to facilitate and explain recommendations when using a visual support [17].

Results of a previous review indicated that the use of visualization as a joint basis for discussion of home modifications is a facilitator to include patients in the decisions about home modifications and aids. Giving them a chance to give immediate feedback on proposed changes might lead to improved shared decision-making [22].

Some patients found the PDHA emotionally encouraging, others found it stressful. The same reactions also occur with physical PDHA [5]. This strain might not be preventable, no matter what PDHA is used. A patient being confronted with handicaps that restrict independent living in the familiar home—whether in VR or in reality—always requires the communicative support of the therapist carrying out the PDHA.

Physical home visits are regarded by therapists as a valuable opportunity to assess patients' ability to cope in their own homes [5, 9, 11]. The therapists in our study did not use VR to test or train the patients' functional ability in the virtual twin of the home. The patients themselves did not experience VR immersively with the goggles.

However, the VR environment gave the therapists a precise idea of the home, so they began to rebuild challenges of the home in the therapy room. This allowed them to carry out an assessment of activity capacity in relation to the real home requirements. The VR-PDHA facilitated the adaptation of specific exercises and activity strategies to the unique requirements of the patient's home environments. This enabled an individual participation-oriented goal setting for the inpatient rehabilitation period.

The capacity to undertake precise measurements, identify barriers, and engage in discourse with patients has enabled HCPs in our study to formulate recommendations for home modifications, which is an important task and outcome in PDHA [5, 11].

However, it is also conceivable to carry out training and assessment with patients in the virtual (home) space. The literature generally shows the feasibility and good effects on health outcomes in the field of VR-based stroke therapy [21]. Then again, this training would also necessitate technical enhancements to the prototype, primarily a VR multiuser scenario.

The duration of the intervention (excluding the scan) did not exceed the duration of a regular therapy session (which is 45 min in Germany) and is likely to be well below the effort and duration of a physical home assessment visit, which could take up to 4 h in total [23]. The virtual assessment could be delivered in clinical processes without strain for the therapists. A good fit between clinical routine and study intervention processes was integrated into the intervention design. The therapists could always access the scan in time to carry out the virtual PDHA during the rehabilitation interval, which often lasts just three weeks.

ReTHo was equipped with one potential interface for data transfer by providing the opportunity to export data in Excel sheets and transfer them by mail or cloud or via a USB-slot as a data storage medium. However, these did not fit the clinical IT structures and processes. For future use, the fit between IT-systems should be provided and tested.

HCPs expressed that the implementation of visual representations of aids would be helpful. A 3D application for therapeutic home adaptation was previously evaluated by other research groups in 2014. This evaluation comprised a furniture catalogue and an occupational therapy object library [4]. Implementing aid avatars in VR to support the selection of aids during the VR PDHA could be a useful additional function of our software in the future.

Despite the positive effects of the VR-based home visit on tailored advice, training and patient acceptance of recommendations, there were ongoing issues e.g. about providing aids after discharge. In our study setting, collaboration between a rehabilitation technician and therapists during home assessment was beneficial. This user group should therefore also be taken into account in the future development of a VR PDHA. Given the virtual PDHA's location within the ward, it is notable that the experts responsible for assistive devices (e.g. rehabilitation technicians) are frequently not available on the ward during routine clinical practice. The software could be developed in the future to enable virtual participation of HCPs outside the ward.

In our study, a relative attended the VR-PDHA only in one case. In practice, however, it is not necessarily common for relatives to be in the clinic.

However, the presence of relatives during the home visits is often advantageous in order to discuss individual fall hazards and home-related training goals [16]. Moreover, it is possible to include carers in decision-making processes [3]. Furthermore it is important to involve relatives and patients in the process of providing aids and home modifications to meet all capabilities, needs and wishes and to generate acceptance [18, 28].

Once needs are identified, all interest holders, including architects or builders, could be involved early.

In the future, a large-scale study should investigate how the VR-PDHA affects the frequency with which PDHAs are performed in rehabilitation facilities and the amount of resources required (e.g. time, costs).

Further technical advancements are required to facilitate assessments and training within the virtual home environment. Additionally, for the future application of the prototype, the seamless and user-friendly scan and transfer of home scans from the patient's home to the clinic must be prioritised. The independent and competent performance of the home scan with a smartphone by relatives and caregivers at home appears to be necessary for implementation in a real-world setting. Otherwise, the PDHA would not enable resource savings in terms of travel time. Future research must first explore the extent to which relatives can perform a scan with a smartphone on their own. The next step is to design and test strategies to empower the relatives. Finally, the relatives must also have a LIDAR-enabled smartphone. This could initially be done by sending them such a device. The spread of Android smartphones with LIDAR technology on the market would facilitate accessibility and increase the chance of real-world implementation of the present prototype.

In order to enhance usability, it is necessary to integrate the innovation into an existing IT system via an interface. The development of multi-user scenarios in VR, as well as the consideration of the requirements of other user groups who are also interest holders in the PDHA process, offer potential for the technical extension of future prototypes.

Strengths and limitations

A number of methodological decisions were taken that may increase the reliability of the acceptance results and render them less susceptible to bias. The development phase was characterised by a high degree of user involvement from the main user group (i.e. therapists) and a subsequent iterative refinement by IT developers. The secondary users (i.e. patients) were included in the acceptance evaluation. These participants were defined beforehand and represented the intended user group of the innovative tool within the intervention. Therefore, our study might demonstrate a certain methodological strength compared to other studies investigating information and communication technology in the context of therapeutic home assessments as described in a recent literature review (Ninnis et al. 2019). Rather than relying on a convenient sample, the prototype was used within a real-world evaluation for a defined period of time. All patients eligible for inclusion (secondary users) were defined as the target group and invited to participate. This approach aimed to mitigate the risk of inviting subjects who fulfil certain criteria and are expected to agree to participate.

Consequently, the acceptance results of the study may be more transferable to the entire patient target group. Overall, fewer patients than anticipated were recruited. However, the follow-up interview was possible for most of the included participants, so that the patient's perspective on the intervention was well represented. Although the methodology was sufficient for a real world assessment of participants' acceptance, the absence of a control group might be a limitation.

Patients with severe aphasia and severe cognitive impairment were excluded from the intervention. However it is not impossible that these patients may benefit from the intervention and this should be investigated in the future. One inclusion criterion was "anticipated persistent functional limitation(s) associated with increased risk of falls in the home environment and/or need for environmental adaptations". Nevertheless, it cannot be ruled out that less severely impaired persons could also benefit from more participation-oriented therapy planning and education on fall prevention, i.e. they could benefit from our intervention. In this study, patients and relatives were not involved in the development, as we focused on the ward-based therapeutical use of ReTHo and they were therefore not identified as the main user group, but rather as interested parties assisting the assessment and providing the home data to be assessed. In the future development of the intervention design, relevant interested parties should be involved to perform the scan. At some point, it will be necessary to identify possible points of contact between the processes in the clinic and the above-mentioned outpatient interested parties when developing processes for carrying out the scan. The further generalisation of LIDAR-capable smartphone models could prove beneficial in this regard.

In our study, some therapists who were involved in the development of the intervention were also interview partners for the evaluation of the acceptance. In a further study, a strict separation of the contributors for development and evaluation will facilitate the objectivity of the evaluation.

Conclusions

This study demonstrates the development of a VR PDHA, which includes the use of the prototype, as a feasibility study in the clinical application context of the user groups. The prototype exceeds the capabilities of existing virtual home assessment applications. It provides benefits of a physical home visit without the need for extensive human or time resources, thereby supporting counselling on aids and modifications for both therapists and patients.

Technological advancement is required to support multi-user scenarios that enable simultaneous participation by therapists, patients and additional participants outside the clinic. Features modifying the VR environment may further support therapeutic decision-making. Seamless integration into clinical IT infrastructure and improved workflows for transferring home scan data from patients to clinical systems are critical for routine implementation.

Further clinical research is needed to compare VR-PDHA with traditional home visits as regards efficiency, resource use and effectiveness in supporting discharge planning. The potential for immersive environments to facilitate not only environmental assessment but also functional training within the virtual space should be investigated.

Understanding the role of immersive visualisation in enhancing communication and shared decision-making is another area for further investigation.

Abbreviations

COPM	Canadian Occupational Performance Measure
HCP	Healthcare professionals
OT	Occupational therapist
PT	Physical therapist
RT	Rehabilitation technician
VR	Virtual reality

Supplementary Information

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Supplementary Material 1.

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Authors' contributions

UKH prepaired all parts of the manuscript, SS edited all parts and gave advice and support.

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Data availability

Data is provided within the manuscript or supplementary information files.

Declarations

Ethics approval and consent to participate

The study was planned, conducted and evaluated in accordance with the Good Clinical Practice Guidelines and the ethical principles of the Declaration of Helsinki [43]. A study registration took place in a publicly accessible study register (DRKS) under the number DRKS00025836 before inclusion of the first study participant, and a vote of the ethics committee of Martin Luther University Halle-Wittenberg was obtained before the study started (processing number (2021-130 from August 8th 2021). All of the participants were given written and verbal information about the study and signed a consent form to participate in the study.

Consent for publication

All participants, including the people in the photo, have given their informed written consent to the publication of their anonymised data.

Competing interests

The authors declare no competing interests.

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Publisher's Note

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