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User-centered requests for an assistive robotic system in direct nursing care - a mixed method study

Murielle Madi[1,2*†], Maximilian Siebert[3†], Sina Langensiepen[1], Svenja Nielsen[2], Daniel Stark[3], Maurice Elissen[1], Elvira Schwarz[1], Zaira Fernandez Minguillon[1], Ulrich Broj[4], Mona Schweitzer[2], Gabriele Meyer[2] and Astrid Stephan[1*]

[†]These authors contributed equally: Murielle Madi and Maximilian Siebert.

*Correspondence:
Murielle Madi
murielle.madi@uk-halle.de
Astrid Stephan
asstephan@ukaachen.de

Full list of author information is available at the end of the article

Abstract

This study investigates the integration of user-centered design (UCD) principles into the development of an assistive robotic prototype for direct nursing care. Using a sequential mixed-methods approach, we conducted focus groups and interviews with nurses, care recipients, and their relatives to elicit user requirements. Participants expressed clear preferences related to safety, intuitive interaction, and contextual adaptability of the system. Findings show strong consensus on the need for voice control, ergonomic design, and reliability, while also highlighting barriers such as limited space and concerns about technical complexity. Some user needs proved difficult to translate directly into technical requirements, indicating the necessity for good interdisciplinary collaboration. The study underscores the importance of iterative development, tailored training, and ongoing evaluation to support effective implementation of such robotic systems. Future research should investigate more efficient methods to collect user requests and engage a brighter participants' population to refine robotic development processes.

Keywords Assistive robotics, Nursing care, User-centered design, Requirements engineering, Human-robot interaction, Interdisciplinary collaboration

1 Introduction

Patient centred care (PCC) addresses the holistic needs of individuals by providing physical support while promoting independence, social participation and overall well-being [44]. It aims to ensure quality of life by considering a person's abilities, preferences and ensuring safety, dignity and respect [36]. A strong relationship between care recipients and professional caregivers, particularly nurses, is essential and must extend beyond task-oriented care [34]. However, PCC is highly dependent on sufficient temporal and staffing resources, without which neither individualized nor safe care can be delivered [36].

1.1 Challenges in nursing care for bedridden care recipients

Caring for bedridden individuals presents multiple challenges. This group of care recipients cannot support themselves and require full or a high level assistance during nursing care procedures, such as frequent lifting, repositioning and holding during nursing tasks like dressing changes and hygiene interventions [49]. These requirements belong to nursing activities referred to as "direct nursing care", and are defined as hands-on and face-to-face care activities performed by nurses that involve direct interaction with care recipients [52]. This includes physical assistance, emotional support, monitoring of health status, and communication [52]. Physical assistance care activities contribute to high rates of musculoskeletal disorders and absenteeism among the nursing workforce [6].

Moreover, most physical assistance care activities require the presence of a second nurse, limiting personnel availability and impacting the ability to provide consistent PCC [42]. Such demands occur in hospitals, residential care facilities, and outpatient settings. Robotic assistance has the potential to relieve this burden by supporting nurses in physically demanding tasks.

1.2 Current development of robotics in nursing

Robotic systems in healthcare are increasingly used to support both social and physical care tasks. Social robots engage in direct interaction with humans, while service robots assist in practical care delivery within clinical environments [22]. Given the physical strain placed on nursing professionals, there is growing interest in robots that support lifting and repositioning. Several robotic systems illustrate different approaches to this problem, for example:

- Riman, RIBA, and Robear: Humanoid robots developed to lift and assist care recipients with mobility [6],
- RoNa (Robotic Nursing Assistant): A system designed to reduce physical strain on nurses and risk of injury, while improving patient comfort and safety during transfers [6],
- ROBERT (Robotic Rehabilitation Assistant): A robotic arm-based solution used for physical rehabilitation exercises [15],
- Wearable exoskeletons, such as ReWalk [19], SUITX [43] and devices from eksoBIONICS [7], are also being applied to reduce physical strain on healthcare workers during lifting and transferring tasks.

Despite growing market activity, most collaborative robots are designed to interact with care recipients, while only very few are developed specifically to assist nurses in direct nursing care [1]. Furthermore, most exoskeletons, though promising, remain in prototype stages, face several barriers and are rarely implemented in clinical healthcare routines [46]. While significant technical challenges contribute to this, there is also a notable lack of end-user involvement in the various phases of robotic development – especially when it comes to developing robots that collaborate directly with nurses and that are integrated into the workflow [1].

The PfleKoRo project, of which a crucial development phase is reported here, addresses this gap through a multidisciplinary team approach that engages input from stakeholders into all phases of development. While developing a robotic system, it is

crucial to establish a common understanding of the development tasks and to enable effective interdisciplinary communication [32]. Stakeholders must clearly articulate their expectations, avoiding premature consideration of potential solutions.

A significant challenge lies in the fact that the different perspectives and insights are inherently limited by the existing range of available tools and technologies. To ensure that the robot addresses genuine user requirements, PfleKoRo employs a user-centered design process rigorously aligned with ISO 9241 – 210:2019. Because the robot operates within established human workflows, we follow the standard's principles throughout the phases of needs elicitation, prototyping, and validation. Involving representative end-users at each stage enables early identification of critical pain points, empirical validation of design hypotheses, and reduction of costly redesign efforts. This methodology not only enhances usability and user satisfaction but also accelerates development, mitigates project risk, and ultimately yields a solution that delivers substantive value to its users.

The PfleKoRo project is situated within the broader context of nursing care, where maintaining patient dignity, promoting autonomy, and ensuring relational care are central. Frameworks such as McCormack and McCance's Person-Centred Nursing Framework emphasize the importance of individualized, context-sensitive interventions [25], which aligns with our user-centered approach to robotic development. Additionally, Jean Watson's Theory of Human Caring [48] and Rozzano Locsin's Technological Competency as Caring in Nursing [20, 21] support the relevance of integrating technology in ways that preserve compassionate, meaningful nurse–person interactions. While Watson emphasizes the primacy of human caring in nurse-person relationships, Locsin specifically addresses the coexistence of caring and technology, highlighting how technological competency can itself be an expression of caring in nursing practice.

As healthcare becomes increasingly technologized, it is essential that assistive systems support rather than replace core nursing values, such as therapeutic presence and person-centered interaction. By aligning robotic development with these principles, technology has the potential to enhance rather than diminish the human aspects of care [11].

1.3 Requirement analysis

To ensure the success of an assistive robotic system, a structured and early-stage requirements analysis is essential. This includes identifying user needs and expectations and translating them into system requirements through formalized engineering processes.

Requirements engineering, as defined by the Institute of Electrical and Electronics Engineers (IEEE), involves both the study of user needs and the systematic refinement of system requirements. [12].

According to Pohl [33] the requirements engineering process consists of four iterative steps:

1) Elicitation: Gathering requirements from stakeholders through interviews, questionnaires, and observation.
2) Negotiation: Negotiating and resolving conflicts among stakeholders;
3) Specification & Documentation: Documenting the requirements in a structured format;
4) Validation & Verification: Reviewing the documented requirements for completeness, consistency, and feasibility.

The outcome is a clearly defined and documented set of requirements forming the foundation of successive developmental efforts, including system design, implementation, testing, and validation. Requirements engineering is a continuous, collateral process which integrates in all phases of system development, when iterative, less ponderous process models are used [33]. To categorize and prioritize user requirements, the Kano model can be applied [8]. It classifies product features into five categories:

- Threshold requirements: expected but do increase user satisfaction.
- Performance requirements: expected and satisfaction-enhancing.
- Excitement requirements: unexpected but increase user satisfaction.
- Indifferent requirements: neutral impact on user satisfaction.
- Reverse requirements: negative impact on user satisfaction.

Since users tend to express only familiar or expected needs, techniques such as focus groups are more suited for identifying requirements [8].

The formulation of clear and precise requirements is crucial for the success of any project. Well-defined requirements serve as a foundation for design, development, and testing processes, ensuring that all stakeholders have a shared understanding of the product's objectives and functionalities. Ambiguous or poorly articulated requirements can lead to misunderstandings, scope creep, and ultimately result in products that do not meet user needs or expectations [24].

Utilizing a standardized requirement-specification framework, such as that proposed by Pohl [33], is customary:

- When? under what condition?
- THE SYSTEM.
- Shall/Should/Will/May.
- process verb.
- object.

1.4 The study aim and research questions

The challenge associated with the development of a robotic system is to design a system that adequately supports the healthcare needs as well as integrates seamlessly into clinical care. Therefore, the aim of this study is to report and evaluate user requests for a robotic prototype intended to assist in the care of bedridden care recipients and to translate those requests into system requirements suitable for development and implementation in nursing practice.

To guide the requirements analysis, the following research questions were addressed:

1. (a) What are the participants' requests related to lifting and holding a care recipients' lower extremity (for wound care or changing a compression bandage)?
2. (b) What general requests do users have concerning the prototype?
3. Which system requirements can be derived from these requests?

2 Methods

2.1 The PfleKoRo project and the prototype of an assistive robotic system

The reported study is part of the PfleKoRo project. The PfleKoRo project was initiated to reduce both physical and time-related loads on nurses by developing a cooperative

robotic system. A robotic prototype was developed using user-centered design (UCD) principles and requirements engineering. The prototype works cooperatively with nurses and supports physically demanding holding and repositioning tasks. Key stakeholders included nurses (direct users), engineers (developers), care recipients (direct beneficiaries), and family members (observers). The mention of users in this manuscript refers to nurses, care recipients and family members.

Prior to the project start, co-creation sessions identified routine nursing interventions that require assistance from a second caregiver. All identified tasks were specific to bedridden care, leading to the selection of this group as the primary focus.

In the conceptualization of the project, a robotic arm-based design was chosen. The prototype is based on a KUKA LBR Med robotic arm [16] and is integrated into a motorized caregiving cart (Fig. 1). It includes a camera system for patient identification, adaptive end-effectors to accommodate various body forms, and safety features derived from an interdisciplinary risk analysis.

To ensure that the prototype integrates appropriately into the care situation at all times, and to ensure its acceptance from the viewpoint of users, the project was divided in three phases:

1. Needs assessment: Identification and prioritization of nursing care activities requiring support, such as turning or lifting a patient's extremity [17].
2. Requirements analysis: Focused on lifting and holding a care recipient's lower extremity, selected for its feasibility within the project timeline;
3. Prototype evaluation: Evaluation by users to ensure usability and integration into care routines [23].

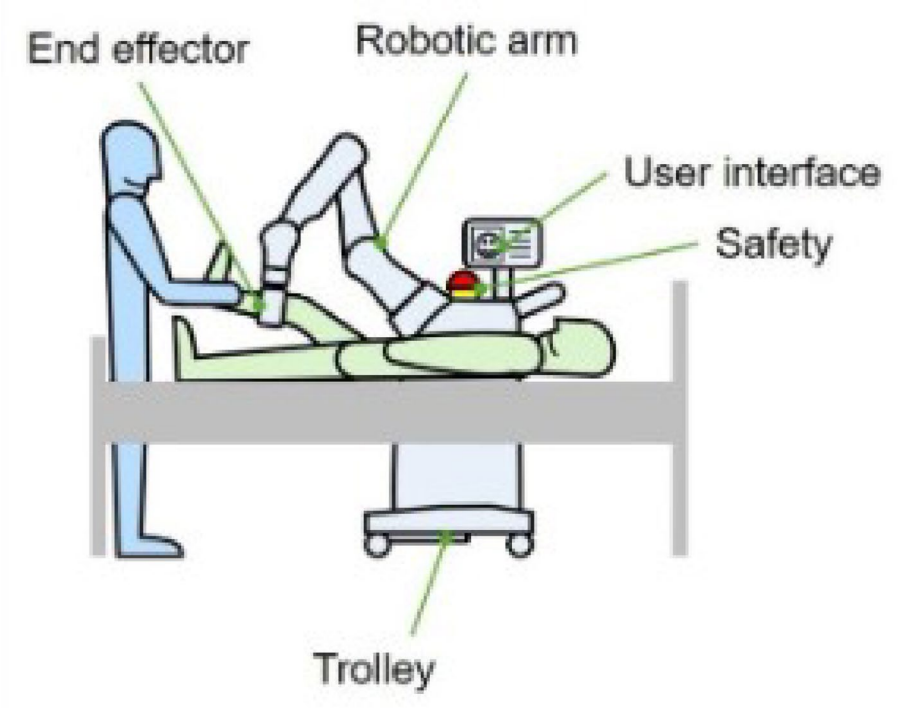

Fig. 1 Assistive robotic system PfleKoRo built upon a seven-axis lightweight robotic arm

Ethical aspects were implemented as well throughout the development process [31]. This manuscript focuses on Phase 2: the requirements analysis and the translation of user requests into system requirements. The care activities explored relate to standardized nursing interventions as defined by the Nursing Interventions Classification (NIC) taxonomy, such as "Positioning" (NIC: 0840) and "Mobility Assistance" (NIC: 0200) [47].

2.2 Design

In this study, the four steps of the requirements engineering (RE) process described by Pohl were systematically followed [33]. To elicit user requests, an explorative, sequential mixed-methods design was employed [2]. This facilitated both, open-ended data collection and the quantification and evaluation of user needs in later stages.

Following the principles of UCD [10] we integrated diverse stakeholder perspectives by conducting focus groups with nurses and individual interviews with care recipients and relatives. This approach supported the development of a context-sensitive understanding of user requirements for robotic assistance in nursing care.

The Kano model was used to design the focus groups and applied as an interpretative framework to support the classification of qualitative findings. While not used as a formal evaluation tool, it guided the identification of threshold, performance, and reverse requirements. Given the early stage of robot development, a standardized survey instrument was not considered appropriate for initial elicitation. Instead, focus groups were selected for their suitability in identifying baseline (threshold) and performance-related requirements, which users are often more capable of articulating during early conceptualization.

The Kano model [8] also informed the design of the focus group protocol. For example, threshold requirements were explored through questions addressing the functional purpose of lifting and holding a leg as well as the aids currently used to perform this task. To identify reverse requirements, participants were asked under what circumstances they would reject or avoid using the system (Table 1).

After qualitative data collection, we performed a qualitative content analysis [14]. The resulting user requests were subsequently refined and specified in collaboration with engineers. A follow-up survey with the original focus group participants was then conducted to validate the specified requirements.

2.3 Ethical considerations

The study was approved by the ethics committee of the Medical Faculty of the RWTH Aachen University (EK 427–20). Each participant signed an informed consent before participating in the study.

2.4 Recruiting process and inclusion criteria

A convenience sample of nurses, care recipients and relatives were recruited from one nursing home and one university hospital in Germany, which were involved in the PfleKoRo project. A manager in the nursing home recruited nurses who showed interest to participate in the study. At the university hospital, ward managers were informed about

Table 1 Example questions from the focus groups' interview guide

Topic	Questions
Attitude to the product of investigation	What was the first idea that came to your mind when you heard that a team wanted to develop an assistive robotic system for the care of the severely dependent?
Previous handling	For what purposes do you lift and hold the leg of a patient? What aids have you used so far for this activity?
User requests	Assuming the robot is already fully developed and available to assist in care. You are called to attend to a bedridden patient and wish to use the robot. How should the robot move (or be moved) towards the patient, and why should it do so in this way?
	You and the robot have now arrived at the patient's bed. Where may the trolley be positioned at the bed, and how much space may it occupy at the bedside without causing obstruction?
	Imagine you now want to position the leg for changing the bandage. How would you prefer to give commands to the robot arm?
	The robotic system has now received its command and is ready to start the task (an example). How should the point of contact be designed, with which the robotic arm touches the patients? What possible limitations are there due to skin conditions?
	What is important to you regarding the topic of hygiene?
	Suppose there was an emergency switch that you could use to stop the robot. Where would it be best located?
	What circumstances might potentially lead you to not use the system?

the study by the nurses who were part of the project team. The nurses who were part of the project team then recruited interested nurses within the teams. All the care recipients and relatives were recruited through the nurse manager of an intensive care unit at the university hospital and had a stable health condition during the time of the interview.

Nurses were included if they had:

a) completed a professional nursing education (at least three years of vocational training in Germany or a comparable international nursing education), no specialized roles were necessary.
b) professional experience (at least one year), and.
c) sufficient German language skills to participate in a focus group.

Care recipients were included if they:

a) were in need of care as bedridden care recipients at the time of the interview or in the 12 months prior to the interview, and.
b) had sufficient cognitive and German language skills to participate in an interview.

Relatives were included if they:

a) were related to a care recipient at the time of the interview or within the last 12 months preceding the interview, and.
b) had sufficient cognitive and German language skills to participate in an interview.

2.5 Data collection

Elicitation of user requests

Between May 2021 and July 2021, eight semi-structured interviews (duration 13–26 minutes), four with care recipients and four with relatives, and four focus groups (duration between 60 and 90 minutes) with nurses were conducted. Focus groups are known to have the potential to generate rich information, experiences and insights through the

interaction of participants with each other [13, 37]. Due to the SARS-CoV-2 pandemic, the focus group sessions could not be conducted in presence and were therefore conducted online using Microsoft® Teams. Interviews with relatives and patients, however, were carried out in person in adherence to the hygiene guidelines required at the time of the interviews and considering the health status of the participants. Interviews were conducted by a physician who was part of the project team (HW). Three healthcare and nursing researchers (SL, SN, MM) conducted the focus groups. In each focus group two researchers conducted the session; one was the primary moderator and the other one the co-moderator. An engineer from the research team acted as an additional silent observer during the focus group sessions. At the beginning of each focus group session, a brief introduction of the participants and the moderators took place.

To gather both general and scenario-specific user requests for the prototype, a question guide was developed in collaboration with the healthcare and nursing researchers and the engineers. The guide underwent an internal pilot testing with nurses and was revised accordingly. The guide is available as an online resource (OR 1) due to its length, but the main questions are displayed in Table 1. After an introduction round, the participants were asked about their attitude regarding the prototype and how they routinely lift and hold a leg. Then, in the next part, a brief video developed by the project team was played and showed a nurse from the project team changing a bandage on a care recipient's lower extremity. The video was used to provide a visual representation of the robotic assistive prototype being developed. The participants were then asked about their requests for the various components of the prototype (Table 1). A digital whiteboard that was visible for all participants was used during focus group sessions to collect the participants´ thoughts and to support the discussion. The focus group sessions were recorded by using Microsoft® Teams. The study procedures including the instrument used such as the interview/focus group guides were developed by us exclusively for this project to be able to extradite as many requests as possible from our participants.

The same format that was used for the focus groups was also used during the interviews with care recipients and relatives; however, some themes were not asked about such as how the robot should be moved to the patient's bedside and the prototype's hygiene. The interviews were recorded through a digital recording device. All the recordings were transcribed verbatim and deleted afterwards. Each participant in the focus groups and interviews received a small compensation for their participation.

2.6 Qualitative content analysis

Two researchers analyzed the complete data set together. Disagreements resulted in a discussion with a third researcher. All categories were checked for plausibility by a nurse who was part of the research team. The qualitative content analysis was carried out using the MAXQDA software. Main categories for the users' requests were initially derived from the question guide; subcategories were generated inductively.

Negotiation and Specification of system requirements

The collected user requests were discussed by an interdisciplinary team comprising an engineer, a healthcare researcher, and a nurse. All requests within each category were reviewed, discussed, summarized, abstracted, and subsequently transformed into

requirements. Throughout this process, and in accordance with the requirement analysis framework, care was taken to ensure these requirements accurately reflected stakeholder needs (correctness), were precisely formulated to eliminate potential misunderstandings (unambiguity), and were realistically achievable (practicability).

All system requirements were specified using the standardized requirement-specification framework described in 1.3.

Validation of system requirements

To reveal that the generated system requirements are still essential and of interest to nurses, an evaluation was conducted using an online survey (Microsoft® Forms) as a subsequent step after the formulation of the requirements. The online survey was developed by the healthcare researchers in the project and based on the results of the focus groups. It underwent a pilot testing and was reviewed for duration of completion and comprehensibility by two nurses. The questionnaire is available as an online resource (OR 2). Participants of the focus groups received an invitation to participate in the online survey a couple of weeks after the focus groups and were asked to anonymously weigh the technical requirements. A five-point Likert scale was used, ranging from 1 (strongly disagree) to 5 (strongly agree). The data were analyzed descriptively (using Microsoft Forms and Excel) and the frequency was reported. This weighing of technical requirements is linked to the Kano model in a sense that it assists in prioritizing improvements on development that could positively affect users' satisfaction.

2.7 Participants

From an initial pool of 40 nurses interested in participating in the study, 16 ultimately took part, distributed across four focus groups, each comprising three to five participants. The remaining nurses could not participate, primarily due to scheduling conflicts. Additionally, interviews were conducted with four care recipients and four relatives, resulting in a total number of 39 study participants, whereas 30 were females. The gender distribution was the result of random selection among interested participants. Eleven nurses worked in a university hospital (dermatology, neurology, operative intensive care, haemato-oncology, weaning units) while five nurses were employed in a nursing home setting (Table 2).

Table 2 Characteristics of the interviews, focus groups and survey participants

		Focus groups (nurses)	Survey (nurses)	Interviews (patients)	Interviews (relatives)
Number of participants	**Total number**	16	15	4	4
	Females	12	11	3	4
	Males	4	4	1	0
Work setting	**Intensive Care**	6	6	/	/
	Standard care hospital ward	4	5	/	/
	Nursing home	6	4	/	/
Mean age	**In years (range)**	38 (22–53)	Not assessed	Not assessed	Not assessed
Mean working experience	**In years (range)**	14 (2–32)	/	/	/

3 Results

3.1 Qualitative content analysis: identified requests

The analysis of the focus groups as well as the interviews yielded eight primary categories of user requests, subdivided into three scenario-specific requests and five scenario-independent requests (Table 3).

Scenario-specific requests:

1. **Touching Points**: Nurses emphasized the importance of identifying appropriate anatomical areas for contact when lifting a care recipients' leg. Participants recommended large surface areas over precise points to avoid injury, stressing slow, deliberate movements that accommodate each care recipient's range of motion.

Participants were unable to specifically identify specific touching points during leg lifting.

"in a way that doesn't hurt me" (care recipient (CR)1, Interview (I)2).

Often, reference was made to a distal point of the knee.

"under the hollow of the knee and below the heel" - (nurse (N)9, focus group (FG)3).

Nurses, relatives and care recipients also emphasized that the care recipient's leg should not be gripped or touched at specific points, but over a large surface area.

"it is always important to use only the support surface and not to grasp, because the risk of injury is simply too great" -(N4, FG2).

The participants reported that movements should adhere to physiological norms, accommodating individual range of motion.

"you can't hold every patient in the same place" - (N5, FG2).

They expressed that ideally, these movements should be executed with a deliberate slowness and should be modified in case of pain.

"(movement) rather slowly, see how the patient accepts it" - (N3, FG1).

Participants conveyed that abrupt movements should be avoided in fear of accidents.

"what if the leg falls down or slips, or a movement occurs that is harmful" - (Relative (R)1, I1).

2. **End Effector (Gripper)**: Participants expressed diverse opinions on the design of the end effector (connecting piece linking the prototype to the care recipient's leg). Regardless of the design, the end effector must avoid applying punctual pressure and should be made from hypoallergenic materials.

Some nurses saw the possibility of using thin, adaptable and, ideally, transparent slings.

"two slings that go down and can be moved variably by the nurse" - (N14, FG4).

However, other nurses preferred the concept of interchangeable bowl forms in varied sizes.

Table 3 The eight primary categories of user requests

User Requests	
Scenario-specific (holding and lifting a leg)	Scenario-independent (general requests)
1. Touching points	4. Trolley features
2. End effector (Gripper)	5. Reasons for non-use
3. Trolley locations	6. User interface
	7. Energy supply
	8. Safety issues

"support surfaces that can be changed in size" - (N5, FG2).

"bowl form that you can adapt individually to each patient" - (N3, FG1).

Regardless of these preferences, there was agreement that, it is imperative that care be taken during application to avoid applying pressure to the leg.

"there must be no punctual pressure only on too narrow a surface" - (N5, FG2).

For those advocating the use of shells, specific attributes were underscored, such as (re)heatable, soft, flexible, malleable, and elastic.

"it should definitely be soft" - (N7, FG2).

"normal skin temperature" - (N1, FG1).

Furthermore, the material composition of the shell should exclude metals, nickel, silver, or latex to ensure compatibility and comfort for care recipients.

"it should not hurt me, it should not be some metal sheet" - (CR1, I2).

"plastic and easy to clean" - (R2, I3).

3. **Trolley Locations**: Nurses expressed their preferred locations for positioning the prototype on the care recipient's bedside. Care recipients were generally indifferent to the placement, while relatives preferred that the prototype be placed away from the patient's head.

A prevailing consensus within nurses emerged, suggesting that the optimal placement of the device should be on the side opposite to the leg requiring care. Elaborating on this perspective, one nurse articulated,

"*definitely on the other side. I mean, if I'm standing next to the leg that has to be treated, then of course the device (prototype) has to stand on the other side"*- (N7, FG2).

Another nurses' preference by nurses was the placement of the prototype at the foot of the bed.

"it should be placed at the end of the bed" - (N5, FG2).

Furthermore, two nurses called for a prototype that integrates into the bedside.

"a bedside with a robotic arm which is already integrated into the bedside" - (N14, FG4).

Care recipients were mainly indifferent about the location of the prototype during use.

"I do not care where it stands, as long as it does not ruin my eyeglasses" - (CR2, I5).

Conversely, relatives firmly rejected the idea of situating the prototype above or near the patient's head.

"if it stands close to the head, this could cause a strange feeling"- (R1, I1).

favoring instead its placement at the foot of the bed or on the opposite side of the nurse.

"I would rather it be located at the foot end or at the end of the lower body" - (R1, I1).

Scenario-independent (general) requests.

1. **Trolley Features**: Participating nurses were asked about the mobility, shape and size of the prototype. Relatives and care recipients were not asked questions in this regard.

Nurses emphasized the need for the prototype to be small and compact, since larger dimensions might pose spatial challenges in care recipients' rooms:

"if it's larger than an X-ray machine, then it doesn't fit at all" - (N12, FG3).

Additionally, they requested the possibility for the trolley to be circular in shape:

"if it is round, I can lean over it" - (N 12, FG 3).

The nurses further expressed a preference for convenient transportation of the prototype, one nurse expressed the following.

"if I cannot use the elevator, which is always a bit of a time issue, I can quickly tuck it under my arm and carry it up the stairs" - (N7, FG2).

To allow effortless movement in all directions, it was suggested that the trolley be equipped with caster wheels or electronic assistance.

"I think there should be electronic assistance on the wheels" - (N3, FG1).

According to the nurses, the trolley should be fixed with an electronic brake. One nurse expressed:

"it should have electronic brakes, where you press a button, and it doesn't move anymore, and then press Start again, or something like that. And you can actually activate it during the care procedure, move it around, and then lock it again" - (N14, FG4).

Some nurses pointed that they would prefer not to use mechanical brakes, as these are usually difficult to reach and often do not work suitably. One nurse pointed that.

"at any given time the pedal brakes on the tires stop working properly" - (N6, FG2).

In addition, one nurse expressed a desire to trace the location of the prototype in the institution so that it could be found quickly for use.

"it should have a GPS" - (N5, FG2).

2. **User Interface**: A variety of operating methods were discussed, with a strong preference for voice control.

Some participants desired to physically interact with the prototype's arm:

"... so that it reacts to pressure from the side [...] that the thing notices that pressure is coming from the left and it follows you" - (N9, FG3).

Others mentioned displays on the trolley,

"touch pad" - (R4, I6).

"something like a joystick" - (N12, FG3).

or voice control.

"voice command" - (N7, FG2).

However, voice control was most frequently mentioned.

"speaking to the system is fastest" - (CR3, I6).

offering hands-free operations.

"above all, when you have both hands free to do what you need to do. And you don't have to put anything down in order to operate the machine" - (N3, FG1).

Relatives noted that voice control could convey a more human-like aspect to the device:

"... a more human aspect than just pressing buttons on other devices" - (R1, I1).

All groups of participants emphasized that the system should be activated using brief commands.

"short and concise commands" - (N5, FG2).

Additionally, there was a request for confirmation before an action.

"repeat a command again, just to be on the safe side and make sure it was understood correctly" - (N7, FG2).

Another suggestion was to incorporate multiple languages within the system.

"maybe that you can store different languages for use. So, four or five languages that are really common" - (N7, FG2).

as well as addressing the device by a name.

"it would be nice if the robot had a name" - (N14, FG4).

Participants preferred that the microphone be integrated into the trolley.

"there should be a microphone on the robot" - (N2, FG1).

to avoid added work.

"if the microphone is not part of the robot, you have to disinfect it again, that's just an additional step" - (N11, FG3).

Challenges associated with voice control were highlighted,

"if it's similar to a navigation system, where the answer is I didn't understand you 5 times, then it would not function" - (R2,I3).

especially considering that German is not the native language of many nurses working in Germany.

"I think more than half of the people working on our ward are from different countries and voice control might be a bit of a problem" - (N8, FG2).

It was also feared that the device might respond to casual conversations.

"it would be problematic if someone simply speaks in the room and the robot is sensitive enough to capture what is being said" - (N5, FG2).

In addition, one nurse had the idea to store patient data in the prototype.

"it would be very practical if you could say you had a certain storage. So the first time, for example, I enter the height and the working height at which I want it to work and then it saves the information for later use" - (N3, FG1).

3. **Energy Supply**: While not directly asked about it, nurses still mentioned issues of energy supply.

Several participating nurses raised concerns about the practicality of a wired system, mentioning issues related to accessible sockets:

"Because if you have to pull the bed away every time to get to the socket in the wall, then that would be a problem for us" - (N1, FG1).

Moreover, the presence of an extra cable was deemed an additional safety risk.

"you must then jump over the cable all the time to finish your work" - (N6, FG2).

Most of the nurses would prefer a long-lasting rechargeable battery-powered assistance system.

"battery life is very important. When it only last 10 minutes, then I won't use it" - (N11, FG3).

Ideally, the system would be packed with a second rechargeable battery for replacement.

"for example the machine should have a battery that you can easily replace with one that is already available within the machine"- (N5, FG2).

The envisioned battery should be lightweight and small.

"I think it should be my arm length and not very heavy so that each person can hold it" - (N12, FG3).

Additionally, there was a request that the battery should always maintain a reserve power to ensure the controlled lowering of a patient's leg even at time of very low power.

"If the battery is empty, then I could still use the reserve to let the leg down" - (N5, FG2)".

4. **Safety**: This category was divided into two aspects: hygienic requirements and ensuring safe operation of the prototype.

Regarding hygienic considerations, participants emphasized the need for the prototype to be easily disinfected.

"the important thing is that you can clean it really thoroughly and well" - (N2, FG1).

without consequences such as material discoloration.

"you need a device that can withstand the chemical requirements with which it is cleaned without changing in color for example" - (N3, FG2).

This entails having smooth surfaces devoid of grooves or crevices.

"it should have a smooth surface where dirt cannot accumulate"- (N9, FG3).

Some participants requested a plastic sleeve over the robotic arm.

"it is important that the machine is wipeable and if you have an infectious patient, you have to put the cover on" - (N1, FG1).

However, this suggestion was rejected by others to minimize waste or due to barriers to finding the covers.

"such a cover…no idea, then you don't know where the covers are and would lose time searching for them" - (N6, FG2).

To ensure safe operations, an easily accessible emergency button was proposed.

"an emergency stop, so that if something goes wrong, you can cancel it immediately"- (R1, I1).

There was a debate about whether the system should directly stop when the emergency button is pressed.

"it should have two emergency buttons, one that just stops it and another one to return it to its initial position and you would use the button that is most convenient to the situation at hand" - (N5, FG2).

Although the prototype is only operable by nurses, we asked relatives and care recipients about the preferred operator of the system. Responses varied significantly. One patient and one relative preferred patient self-operation, with the capability to press the off button in case of an emergency:

"…the patient can operate it, they are the ones to notice what is comfortable or uncomfortable for them. The nurse can't always really judge that" - (R4, I6).

"emergency stop that the patient can operate" - (CR3, I6).

Other relatives and care recipients rejected the idea of allowing individuals without professional training to operate the system.

"the authorized person should operate it and not the patient" - (R3, I4).

1. **Reasons for non-use of the prototype**: When asked for reasons why the prototype might not be used, participants voiced concerns that can be categorized into two groups.

The first group comprises the personal and individual factors and the second group the technical, spatial and organizational factors. Care recipients were against using the system in cases of terminal illness, dementia, anxiety, or confusion.

"ethically speaking, the machine should not be used with terminally ill patients" - (N6, FG2).

Utilizing the prototype for patients with cannula systems was also questionable.

"when the patient has cannulas then very sensitive care is required" - (N3, FG1).

Additionally, a complex user interface could lead to non-use:

"If it is very complicated to operate, that would be beyond me"- (N3, FG1).

From an organizational standpoint, various factors were highlighted. The number of available prototypes was an issue.

"it is also a question of where would you park it and how many machines do you have" - (N14, FG4),

the speed at which the prototype performs a task.

"of course you'd prefer to get a colleague to help, if fetching and installing and whatever (the robot arm) takes longer than if you were just to say, let's just turn the patient around quickly" - (N16, FG4),

and the duration of cleaning.

"returning it to its place and cleaning it in between patients, that it very time consuming" - (N11, FG3).

Furthermore, the size of the prototype and the space available in the patient's room affect the use decision.

"the space in the room and the question if the machine fits in the room are of greater importance for us" (N5, FG2).

3.2 Specification of system requirements

The requirements engineer (RE) proposed a formulation according to the subject predicate object (SPO) model [50], which transformed the user request into a system requirement. The nurse and the healthcare scientist then approved this formulation or made modifications. Additionally, all participants assessed the meaningfulness of the statements (Table 4).

The derived 46 technical requirements. The term "intuitively operable" refers to a system that users can easily understand and use without extensive instruction [30].

3.3 Nurses' validation of system requirements

All but one of the nurses, who participated in the focus groups, took part in the online survey (Table 2). The evaluation process revealed a strong consensus on many requirements. 70% or more of the nurses provided ratings of four points (agree = A) or five points (strongly agree = SA) for 36 out of the total 46 requirements. Key aspects, such as the emergency release mechanism, system stability, and safety features, received high levels of agreement.

The stability of the assistive system prototype (100% SA), ensuring prevention of all types of injuries (100% SA) and the design of the system to be liquid- tight (100% SA) were completely agreed upon. The nurses also agreed on the importance of aspects, such as the swift release of the prototype in case of emergencies (93% SA), the presence of an easily accessible emergency stop button (93.3% SA) and the easiness to clean the prototype (93% SA). Moreover, other factors were agreed upon such as the ability to release the leg at any time (87% SA), the prototype's capability to be securely fixed and released at the intended location of use (87% SA), and that the end effector should feature a spacious surface (87% SA) that can be adapted to accommodate variations in leg size (87% SA). In addition, if equipped with voice control, the system should respond to concise and unambiguous commands (87% SA).

Table 4 The derived 46 technical requirements. The term "intuitively operable" refers to a system that users can easily understand and use without extensive instruction [28]

Mobility of the assistive system (AS)
1. The AS must be easily movable to the desired location.
2. The AS must be transportable to the desired location without protruding parts.
3. The AS must be easily repositionable at the deployment site.
4. In case of emergency, the nursing staff must be able to separate the AS from the care recipients as quickly as possible.
5. The AS (trolley) must be easily fixable and unlocked at the desired site.
6. Disruption of workflow due to the dimensions of the AS must be avoided.
Operation of the AS
7. The AS must be quickly operational.
8. Any impact on workflows due to the operation of the AS must be minimized.
9. The AS must store and provide necessary data of care recipients for the execution of caregiving tasks.
If voice control is implemented into the AS, then.
10. it must support various languages.
11. it must be activated using a distinct name.
12. it must understand short, distinct commands.
13. a confirmation of commands must occur before execution.
14. it must have a built-in microphone.
15. it must have an alternative control concept.
If the alternative control concept consists of a display, then.
16. it must be intuitively operable.
17. the display must be accessible at all times.
If the alternative control concept consists of a mobile display, then.
18. it must be stowable in the nurse's clothing.
19. it must withstand falls.
20. it must be possible to charge it on the AS.
Movements of the robotic arm
21. The robotic arm of the AS must perform physiologically correct movements on the care recipient.
22. Abrupt movements of the robotic arm must be avoided.
23. The robotic arm of the AS must adapt its movements to the individual mobility of the care recipients.
24. The AS must avoid moving over the head of the care recipient.
The point of contact (end effector) with care recipients.
25. must have body temperature.
26. must distribute weight uniformly and over a large surface area.
27. must be hypoallergenic.
28. must prevent skin injuries.
29. must be adjustable to the specific needs before starting the activity (such as size or contact point).
30. must be adjustable to the specific needs during the activity (such as size or contact point).
If the robotic arm only moves when a switch is held down continuously, then.
31. this switch should be foot-operated.
32. this switch should be hand-operated.
If the assistance system is equipped with an emergency stop, then.
33. it must be accessible at all times.
34. this must return the robotic arm to the starting position of the care activity when actuated.
35. activating it must bring the robotic arm to an immediate stop.
Additional requirements for the safety system
36. If the AS detects sudden or defensive movements from the patient, it must come to a stop.
37. The nursing staff must be able to detach the care recipient's leg from the system at any time.
Hygiene
38. The AS must be easy to clean.
39. The AS must be liquid-resistant.
40. The AS must have a replaceable protective cover.
Energy supply
41. The AS must operate without a power cable.
42. If the AS is equipped with a battery, limitations to daily caregiving tasks due to the battery must be avoided.
Additional requirements for the AS

Table 4 (continued)

Mobility of the assistive system (AS)
43. Limitations to caregiving tasks caused by the AS must be avoided.
44. The risk of injury due to the form of the AS must be minimized.
45. The AS must be stable at all times and in every position.
46. The AS must be locatable within the facility.

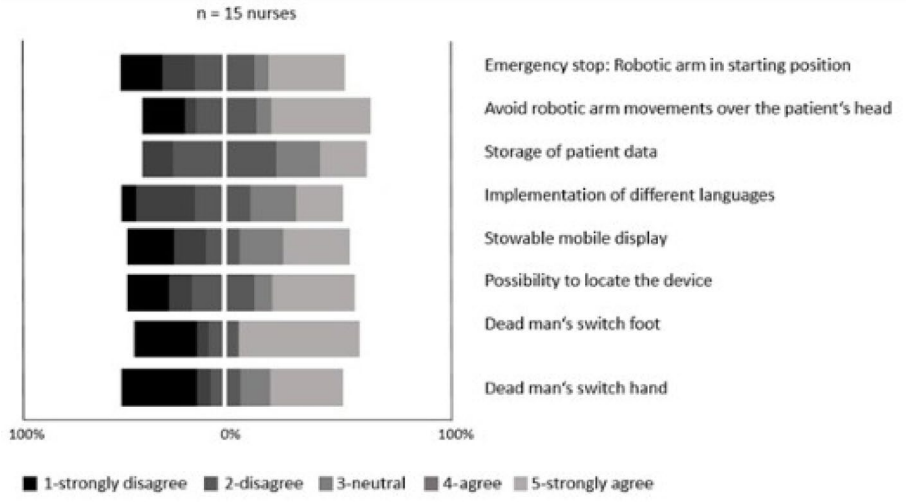

Fig. 2 Inconsistently evaluated requirements

Contrary to the mentioned high agreement, we found a larger range of approval, disapproval and neutral ratings in 17% (8 out of 46) of the requirements. No conclusive preference was apparent concerning inquiries relating to whether the robotic arm should revert to its initial position upon activation of the emergency stop, or if the arm could be maneuvered over the patient's head. Controversy emerged regarding the possibility to locate the device, the integration of supplementary patient data storage, and the introduction of multi-language voice control. The question of whether the assistive system should be equipped with a foot or hand safety switch (if legally required) also remained unresolved (Fig. 2).

4 Discussion

In our study, scenario-specific and general users requests in relation to a robotic prototype in the field of direct nursing care were collected and analyzed. They were subsequently translated into a set of system requirements. The results demonstrate that user requirements are deeply tied to the perceived safety, usability, and appropriateness of the technology in everyday care practice. This analysis provides a comprehensive overview of the user requests, which will inform the technical design and implementation of the prototype. By addressing both scenario-specific and general requests, the prototype can be tailored to meet the practical needs of its users, ensuring safety, efficiency, and ease of use.

4.1 UCD and inter-professional work

This study put a lot of emphasis on UCD, ensuring that user needs directly inform the development of the robotic prototype. Prior research underlines the importance

of including users in the development of care robotics, given that these technologies interact with the users [32]. Since nursing care involves dynamic interactions between nurse and care recipient, the integration of a robotic system introduces a triadic relationship—requiring mutual understanding among all parties involved [32]. This is supported by research showing that co-creation processes significantly enhance usability and acceptance [29]. Early user involvement, a deep understanding of user perspectives, and attention to unspoken needs are likewise critical elements for successful design, as highlighted in both our results and existing literature [41].

However, despite the frequent labeling of robotic design as "multidisciplinary," relevant stakeholders—particularly from nursing—are often absent from development processes. This highlights a persistent gap in the literature regarding effective nursing participation in robotic design [40]. Our project offers a concrete counterexample by facilitating interprofessional collaboration and integrating user feedback throughout the development process.

Importantly, the robotic system is intended not to replace nurses, but to support tem by reducing physical strain and freeing time for relational, cognitively demanding care tasks [32, 39].

Delegating physical tasks to robots in nursing homes can free up nurses to engage more meaningfully with residents, as shown in recent findings [42]. Achieving such real-world benefits requires aligning system functions with users' core goals; a process best supported through iterative and participatory development approaches [41].

4.2 Usability

Participants in our study emphasized that the prototype's ease of use encourages daily adoption. This reflects a core usability principle: systems should minimize effort and integrate smoothly into existing workflows [41]. Participants particularly stressed intuitive operability and compatibility with work environments.

Similar findings have been reported in other studies. For instance, robots perceived as heavy or lacking adequate support infrastructure were deemed impractical by users [35]. Consistent with our results, environmental constraints and insufficient technical support were shown to reduce motivation to adopt such systems. Some nurses may also resist robotic tools out of preference for familiar routines [51]. To overcome such resistance, ease of learning, perceived usefulness, and alignment with user goals are critical factors [41].

Concerns about losing the human element of care were echoed in both our study and previous research: When robots take over physical tasks, nurses may fear an increased workload or a loss of emotional connection with care recipients [45]. The need for robots to be flexible, reliable, and easy to clean were also mentioned in other studies, and limited adaptability was identified as a key barrier to implementation [29]. Addressing these issues requires systems that support diverse user needs—something best achieved through iterative, user-centered design processes, as our study actively pursued [41].

4.3 The specific characteristics of the prototype

User feedback in our study emphasized physical interaction, ease of operation, and contextual suitability. A preference emerged for a soft, safe, and non-intrusive end-effector, consistent with research showing that rubber materials and warming elements foster

a more human-like interface during care tasks [5]. Voice-operated control was highly favored for hygiene and convenience, especially during hands-busy procedures or in sterile environments, as hands-free systems are known to reduce contamination risks [51].

However, concerns were raised about system responsiveness and the importance of clear confirmation signals in noisy or stressful situations. Effective voice interfaces require reliable feedback, error tolerance, and contextual awareness—elements that support user trust and ease of use [41]. Our participants' suggestions for multimodal confirmation (e.g., visual or auditory cues) reflect these principles.

Prototype size and maneuverability also emerged as critical, particularly in cramped care environments. Spatial limitations can hinder integration, disrupt caregiver workflows, and reduce safety [35]. Battery performance was another concern, with participants emphasizing the need for long-lasting, low-maintenance power systems; otherwise, technical complications would lead to abandonment in favor of human support [35].

Overall, these findings illustrate essential interaction design principles such as contextual fit, system visibility, ease of use, and low cognitive load [41].

4.4 Safety

Our study supports findings from previous robotics projects regarding safety in care environments. Participants emphasized the need for an emergency stop button, echoing earlier studies who highlight the button's role in preventing harm during unintended contact [5, 45]. Although some robotic systems operate autonomously, our findings and other studies indicate that the presence of a healthcare professional nearby is essential for reassuring care recipients [26].

Our results also align with reviews stressing that nurses should retain full control of robotic systems to ensure safe and appropriate use [45]. This principle guided the PflegeKoRo prototype's development: it is operable only by qualified nursing professionals.

Participants further raised concerns about tripping hazards, particularly from the prototype's cables in care recipients' rooms. Similar risks were observed in another study, where slow-moving robots and environmental obstacles created potential safety issues for both users and care recipients [35]. These findings reinforce the critical role of context-aware safety design in robotic systems and support the integration of reliable control mechanisms to foster trust and usability.

4.5 Cultural considerations and applicability beyond institutional settings

Although cultural factors were not explicitly addressed in our study, the literature emphasizes the importance of personalized and culturally sensitive design approaches, especially in private homes where family roles and values may shape care practices [9, 18].

Robotic systems in such contexts must accommodate diverse cultural expectations and care norms, requiring flexible interfaces and behavior models. Moreover, previous research shows that care recipient acceptance of robotic assistance depends on clear functional intent—for instance, medical tasks (e.g., cleaning or repositioning) are more accepted than affective ones [5].

While our study focused on prototype development in institutional care settings, its findings raise important questions about applicability to home-based care, where care environments are less standardized and professional support is not always available. Studies have shown that robots introduced in home care must be especially easy to operate, compact, and adaptable to varying spatial layouts and user routines [3, 27]. Additionally, the absence of on-site technical support in home environments underscores the need for high reliability and intuitive interaction design.

Regardless of the setting, robots must maintain a care-centered focus, ensuring that the human user remains the primary concern in interaction and design [32].

4.6 Training, Staffing, and fair access in robotic integration

Our participants emphasized the importance of sufficient training for effective robot use; particularly in light of limited staffing levels. This aligns with findings from another study where staff shortages made it difficult to plan consistent training sessions, resulting in uneven preparedness and limited uptake [35]. Successful adoption of interactive systems depends heavily on well-supported onboarding, tailored to users' contexts and workflows [41].

Both our results and the literature suggest that giving professional caregivers the ability to adapt robotic systems to individual care settings could enhance usability and acceptance [29]. However, these assumptions require validation through real-world clinical testing. Introducing robotic systems without robust, context-sensitive evaluation risks disrupting care routines or diminishing user trust. Moreover, access has to be fair and timely. Reliable and punctual operation is essential for ensuring that all care recipients are served equally, while equitable access to robotic care must be maintained regardless of financial constraints [28, 45]. These considerations underline the need for inclusive design and equitable implementation strategies.

4.7 Transformation of user requests into system requirements

User requirements that do not differ from already existing supporting tools in everyday use - like user safety, or hygiene - could be specified and received high agreement rates in the validation study. These requirements could be classified as threshold requirements according to the Kano model as they are absolutely necessary but do not lead to a higher level of user satisfaction [38]. Additionally, requirements such as those related to the user interface and system transport capabilities were generated. These requirements are aligned with existing products and can be classified as performance requirements according to the Kano model as they lead directly to a higher user satisfaction. They also generated high agreement rates in the validation study, as expected [38].

Requirements regarding the innovative parts of the system – like the gripper or the positioning system – were indifferent and harder to specify. While users were able to describe their current way of physically assisting a care recipient, they struggled to imagine a robot performing this task. This aligns with Feldhusen's assertion that users in the early stages of requirements analysis describe the status quo and their current problems but do not propose solutions (nor are they expected to) [8]. Furthermore, it underscores that requirement analysis is an iterative process that is continually advanced throughout the system development lifecycle.

The method of having a RE engineer derive requirements in direct collaboration with a healthcare scientist and a nurse has proven exceptionally effective, as evidenced by the high approval rate in the validation study. This approach allowed for the immediate clarification of care-specific terminology and the direct addressing of questions related to workflows and other relevant conditions.

Generally, the user requests proved to be highly valuable and showed the importance of user integration early into a development progress.

5 Conclusion

This study identified essential user requirements for the development of an assistive robotic prototype in direct nursing care. Participants emphasized usability, safety, hygiene, adaptability to spatial constraints, and intuitive interfaces such as voice control. The involvement of nurses, care recipients, and relatives revealed both, general and context-specific requests, underscoring the importance of user-centered design in healthcare robotics. Incorporating user feedback throughout the development process proved critical for system acceptance and practical relevance.

5.1 Study limitations

While interdisciplinary collaboration and user involvement were central to this study, several limitations should be noted.

Some user requests could not be translated into technical requirements due to legal or technical constraints. Although we included nurses, care recipients, and relatives, participation was limited by time and availability, especially in the survey phase. The survey tool, developed for practicality, was not statistically validated, limiting the generalizability and reliability of the results.

Although focus groups offer valuable insights into current practices, they are limited in fostering innovation. Nonetheless, they provide a strong foundation for designing user-centered systems. Using focus groups rather than individual or group interviews allowed for exchange of ideas but may have introduced group dynamics that influenced responses, such as dominant voices shaping the discussion [4]. We have hardly observed such influences in the focus groups and if so, efforts were made to moderate this. Nevertheless, group dynamics may have affected the depth or diversity of feedback.

Several sessions were held via Microsoft® Teams, which, while practical, may have reduced the richness of interaction due to limited non-verbal cues and occasional technical issues.

Finally, he context-specific nature of the study, conducted within institutional acute and long-term care settings in Germany, further limits generalizability. However, in line with the concept of case-to-case transfer [4], we believe the findings may be transferable to similar care environments where comparable technological integration and professional roles exist.

5.2 Directions for future research

While this study demonstrates the value of interdisciplinary collaboration in bridging technical feasibility with user expectations, future research should aim to gather user perspectives more efficiently and build more directly on existing findings. The identified system requirements are not yet comprehensive; further iterative studies using

prototypes in controlled settings are necessary. The requirements generated in this study may also serve as a reference for future healthcare robotics projects. Future work should explore long-term implementation in clinical routines, involve a wider range of users and settings (including home care), and ensure ongoing adaptation through iterative testing.

Supplementary Information

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Supplementary Material 1

Supplementary Material 2

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Author contributions
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Data availability
Data not included in the manuscript can be made available on reasonable request.

Declarations

Ethical approval
The study was approved by the ethics committee of the Medical Faculty of the RWTH Aachen University (EK 427–20).

Consent to participate
Each participant signed an informed consent before participating in the study.

Consent to publish
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Competing interests
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Author details
[1]Department of Nursing Science, Uniklinik RWTH Aachen, Aachen, Germany
[2]Institute of Health and Nursing Science, Medical Faculty of Martin Luther University Halle-Wittenberg, University Medicine Halle, Halle, Germany
[3]Institute of Applied Medical Engineering, RWTH Aachen University, Aachen, Germany
[4]Department for Operative Intensive Medicine and Intermediate Care, Uniklinik RWTH Aachen, Aachen, Germany

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