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Robot-assisted mobilisation in the intensive care unit: does it offer relief to mobilising specialists? A qualitative longitudinal study at a German university hospital

A. C. Mehler-Klamt[1] · J. Huber[1] · N. Koestler[1] · A. Warmbein[2] · I. Rathgeber[2] · U. Fischer[2] · I. Eberl[1]

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Abstract
Background Immobility among intensive care patients can result in significant impairments. Reasons for this issue include a lack of specialised staff and equipment, as well as safety concerns associated with transferring patients to a therapy device. Nevertheless, early mobilisation is recognised as beneficial for improving patient outcomes. This study explores the perspectives of healthcare professionals on the use of a robotic system for patient mobilisation and identifies related stress and relief factors.
Method This qualitative longitudinal study was conducted at a German university hospital, where 29 interviews were conducted with nurses at three different data collection points. The data were analysed using qualitative content analysis in accordance with Mayring.
Findings The utilisation of the VEMOTION® robotic system generally did not lead to any physical discomfort. However, the adoption of this technology presented certain challenges. Non-routine users initially experienced psychological strain, primarily due to the extensive preparation required and the need to integrate the system into established routines. Additionally, structural factors, such as nurse-to-patient ratios and the layout of the care facilities, were identified as significant determinants affecting both the practicality of mobilisation and associated stress levels.
Conclusions Robotic systems like VEMOTION® can alleviate the physical workload of nurses. Successful integration and psychological adaptation depend on familiarity and routine use of the technology. Addressing structural and staffing factors is crucial for optimising robotic assistance in patient care. Further research should delve into these dynamics and explore the broader implications of technology adoption in healthcare.
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1 Introduction

The healthcare sector faces a significant shortage of skilled workers, exacerbated by demographic changes, particularly impacting intensive care units [1]. This shortage leads to increased physical and psychological strain on ICU staff, negatively affecting patient care quality [2]. Prolonged immobility in intensive-care patients, often due to staff scarcity, heightens the risk of acquired muscle weakness or delirium [3–5]. According to Simon [2], the professional groups of nurses felt mentally, but also physically, highly stressed by knowing of the insufficient care of the patients and the generally very

✉ A. C. Mehler-Klamt, amrei.klamt@ku.de | [1]Professorship of Nursing Science, Faculty of Social Work, Catholic University of Eichstätt-Ingolstadt, Osternstr. 26, 85072 Eichstätt, Germany. [2]Clinical Nursing Research and Quality Management Unit, University Hospital LMU Munich, Marchioninistr. 15, 81377 Munich, Germany.

high workload. This contributes to increased sick leave and attrition rates among nurses [6]. Furthermore, conventional patient mobilisation, if not performed ergonomically, can cause substantial musculoskeletal strain on mobilising staff [7]. The German S3 guideline "Positioning therapy and mobilisation of critically ill patients in intensive care units" recommends that mobilisation should be carried out by the treatment team [8] in order to minimise safety risks. This is difficult to fulfil due to staff shortages and leads to increased stress or impaired care.

In response to these challenges, innovative digital and robotic systems like VEMOTION® are being developed to support mobilising professionals and improve patient outcomes [9]. This qualitative longitudinal study explores mobilising specialists' perceptions of using such robotic systems and the associated stress and relief factors, offering potential solutions to the pressing issues in intensive care settings.

1.1 Early mobilisation

The S3 guideline "Positioning therapy and mobilisation of critically ill patients in intensive care units" defines early mobilisation for the German-speaking area [8]. It generally describes mobilisation as follows: "Mobilisation includes measures for patients that initiate and support passive or active movement exercises, aiming to promote and maintain their ability to move" [8]. Early mobilisation is defined as "commencement of mobilisation within 72 h after admission to the intensive care unit" [8]. Treatment is recommended to involve performing mobilisation daily and for a sufficient period of time [8]. That definition is the guiding principle for this publication.

Mobilisation can be practised in three levels. It can be passive, active with assistance, or active [3, 10–13]. All three forms of mobilisation are possible without or with (robotic) aids.

As established in a preliminary study [26], there is currently no standardised protocol for early mobilisation in intensive care units at the LMU Hospital. The lack of a formalised protocol underlines the innovative nature of the introduction of the VEMOTION® robotic system and the exploratory nature of this study. Nevertheless, all participants were proficient in conventional mobilisation techniques and received comprehensive training in the VEMOTION® system, which covered both theoretical and practical aspects. The initial support from the system providers ensured smooth integration into the ICU routine.

1.1.1 Mobilisation with the VEMOTION® robotic system

VEMOTION® is an adaptive robotic assistance system designed to mobilise intensive-care patients directly in their hospital beds, eliminating the need for transfer to a therapy device [14]. As can be seen in Fig. 1, patients are secured in

Fig. 1 Robot-assisted mobilisation with the VEMOTION® [19]

an adapted bed with seat, chest and pelvic straps, and their feet anchored to the robotic system's bottom plate. Thigh cuffs be connect the patient to the robot, allowing the bed to simulate step-like gait movement and gradually achieve verticalisation to 70° [15–17]. This process reduces the physical strain on mobilising specialists, as noted by Warmbein et al. [18], and eliminates the safety risks associated with patient transfer. VEMOTION® supports both passive and active assisted mobilisation and is designed for operation by a single specialist, according to ReActive Robotics [19].

1.1.2 Conventional mobilisation

This article defines conventional mobilisation as mobilisation of critically ill patients without electrically or robotically operated aids. Based on a qualitative survey by Nydahl et al. both nurses and physiotherapists are responsible for performing conventional mobilisation [20]. The responsibilities of the respective tasks that arise during mobilisation could not be clearly assigned within the survey. In order to establish the best possible comparability to the movements of the VEMOTION®, the interviews in this study refer to conventional mobilisation to sitting, walking, or standing. Since these kinds of mobilisation cannot be performed only during the first 72 h of admission to the inventive care unit, the report on results generally speaks of *mobilisation*.

1.2 Stress factors in connection with mobilisation of intensive-care patients

Working with critically ill patients is subject to many stress factors that may also impact the health of clinical specialist staff. "High levels of workplace stress, if left untreated, can have harmful impacts on many aspects of their lives, manifesting into depression, anxiety, insomnia, burnout, poor self-esteem, and other mental-related health problems" [11]. According to Rothe et al. [21], it is therefore very important to create a working environment that promotes mental health, well-being and work-life balance. Nurses in particular comprise an occupational group demonstrably subject to a great deal of stress [22–24]. This not only affects their psychological well-being, but also some somatic illnesses such as back pain [22]. Hämmig´s quantitative cross-sectional study [25] has shown that musculoskeletal disorders are primarily a consequence of physical workload or wrong posture at work, and only secondarily a consequence of (general) stress. Sleep disorders are often caused by stress at work. They are exacerbated by stress in one's private life [25]. Structural factors, such as insufficient collaboration in the inter-professional team or a lack of resources, represent some further stress factors in terms of enabling mobilisation for mobilising specialist staff [21, 24, 26]. Patient-related factors, such as critical patient conditions or frequent occurrence of vascular access lines, also appear difficult for mobilising specialist staff, thereby affecting the feasibility of mobilisation [26]. It is evident that the psychological and physical illnesses described significantly affect healthcare costs and the quality of patient care [22, 27]. Reasons for this include, among other things, personnel bottlenecks making it impossible to maintain high quality of care and endangering patient safety [21].

2 Goal and research questions

This qualitative longitudinal study [28] was conducted to explore and understand the experiences and perceptions of mobilising specialist staff in using the robotic VEMOTION® system that can take over part of the mobilisation of intensive-care patients. The study aimed to capture the nuanced complexities of physical and psychological impacts, including the stress and relief factors asscociated with the adoption and integration of the robotic system in patient mobilisation routines. The following research questions served as the guiding principles:

1. How do mobilising specialist staff narrate their experience with the use of a robotic system for early mobilisation of intensive-care patients?
2. What are the perceived physical and psychological impacts, notably stress and relief factors, articulated by mobilising specialist staff in relation to the use of the VEMOTION® robotic system for patient mobilisation in intensive care settings?

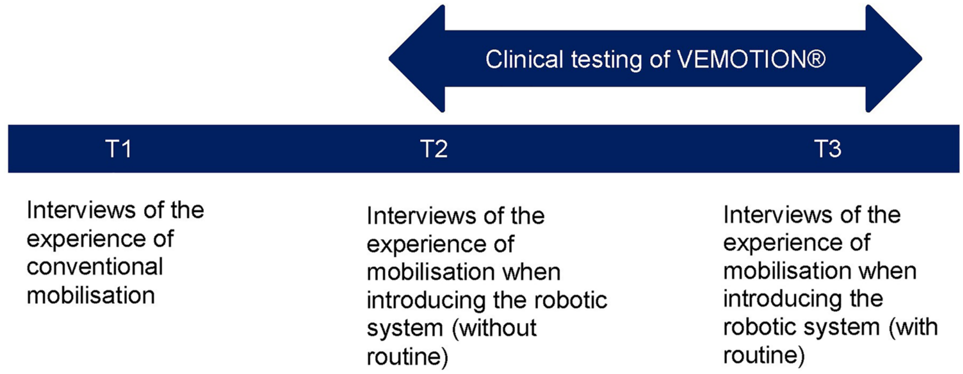

Fig. 2 Representation of the study design (own presentation)

3 Methods

3.1 Study design

A qualitative longitudinal study [28] was chosen because it allows for the exploration of the evolution of experiences with the robotic system over time and a nuanced perspective on the development of perceptions and interactions with the technology against a backdrop of exposure and relief. In order to comprehensively record this development, three data generation points were carried out in which episodic interviews [29] were conducted (see Fig. 2):

- *T1:* Data generation point T1 serves as the baseline phase, capturing the experiences of mobilising professionals with conventional mobilisation methods. The objective at this stage is to garner a comprehensive understanding of the established practices, challenges, and stressors inherent in conventional mobilisation approaches, prior to the integration of the robotic system. This foundational data generation point sets the stage for a nuanced comparison with subsequent phases, offering a rich context for the study's qualitative analysis.
- *T2:* Data generation point T2 concentrates on the early stages of integrating the VEMOTION® system, documenting the initial experiences, challenges, and learning trajectories of the mobilising professionals. This phase offers a deep dive into the preliminary psychological and physical impacts associated with transitioning to the robotic system, capturing the staff's immediate responses to this novel technology. T2 serves as a pivotal moment in the study, revealing the nuanced dynamics of adaptation and the initial adjustments required to assimilate the VEMOTION® system into regular mobilisation routines.
- *T3:* T3 shows a more advanced phase in the integration of the VEMOTION® system, a stage where mobilising professionals have had opportunity to familiarise themselves with the technology and refine their proficiency in its application. The main focus of T3 is to explore the development of perception and stress levels, investigating how these aspects change as users gain experience and the system is integrated into routine mobilisation procedures. This stage is crucial for understanding the longitudinal impacts and the potential for the robotic system to foster a more efficient and less stressful mobilisation environment.

The study description is based on the checklist *Standards for Reporting Qualitative Research* (SRQR) [30].

3.2 Setting

The study was conducted with mobilising nurses from two anaesthesiologic adult intensive care units at the LMU hospital in Munich. These wards focus on subsequent treatment of urological, gynaecological, general, and trauma surgery surgeries as well as care following organ transplants.

3.3 Sample

Targeted sampling was chosen for the survey [31]. The following inclusion criteria were defined: Nurses and physiotherapists with at least three years of professional experience in an intensive care unit as well as nurses with specialist further

Table 1 Sample of the qualitative survey (own presentation)

Interview participants n = 29	T1 n = 13	T2 n = 13	T3 n = 3	Total n = 29
Gender [n (%)]				
Male	n = 4 (30.8%)	n = 5 (38.5%)	n = 3 (100%)	n = 12 (41.4%)
Female	n = 9 (69.2%)	n = 8 (61.5%)		n = 17 (58.6%)
Work experience [years] Not specified [n (%)]	M: 5.2 (SD: 3.6) 1 (7.7%)	M: 9.5 (SD: 62.1)	M: 7 (SD: 3)	M: 7.4 (SD: 6.5) 1 (3.4%)
Interview length [min]	M: 19.12 (SD: 7.10)	M: 17.60 (SD: 4.13)	M: 21.72 (SD: 10.11)	M: 18.72 (SD: 6.15)

training in the area of anaesthesia and intensive care (in accordance with the specifications of the Deutsche Krankenhausgesellschaft; DKG) were included. All participants had to be employed at the Hospital.

Excluded from participation are individuals who are members of the project team, nurses with less than three years of experience in an intensive care unit, or those without with specialist further training in the area of anaesthesia and intensive care (in accordance with the specifications of the Deutsche Krankenhausgesellschaft; DKG). Physiotherapists with less than three years of experience in intensive care units are also excluded. Additionally, individuals not employed by LMU Hospital or not operationally assigned to the study wards are excluded.

Participants were recruited between August 2021 and April 2022, contacted via email, phone, or in a personal enquiry. At the end of the recruitment phase, the interview sample comprised 29 nurses. Despite efforts, physiotherapists could not be recruited due to external constraints.

The sample of the qualitative survey is shown in Table 1.

3.4 Data generation and analysis

The data collection was carried out through episodic interviews [29]. The development of the interview guidelines for this study was meticulously executed using the SPSS method (collect, check, sort and subsume) in accordance with Helfferich [32]. This structured approach ensures that the interview questions are both comprehensive and focused on the research objectives.

Initially, a brainstorming session was conducted to gather a wide array of potential questions and subject areas. This explorative phase is crucial as it allows for the collection of a diverse set of questions that can cover various aspects of the topic under study, including both theoretical considerations and practical observations drawn from the literature. Once the collection phase was completed, a rigourous review process ensued, where each questions was reviewed for it`s relevance and potential to elicit meaningful data. This step is pivotal as it ensures that each question serves a purpose, aligns with the study`s aims, and has the capacity to contribute valuable insights. Questions that were deemed redundant, irrelevant, or too similar to others were removed to streamline the interview guide and maintain focus. Following this, the remaining questions were then sorted into distinct questions. Leading questions were identified to serve as open-ended prompts that encourage broad discussion, maintenance questions were designed to keep the conversation going and delve deeper into specific topics, and specific follow-up questions were crafted to explore particular details or experiences mentioned by participants. This sorting process is instrumental in organizing the interview structure, ensuring that it flows logically and covers the necessary breadth and depth. The final step of subsumption involved classifying the refined questions into a structured guideline [32]. This step transforms the assorted questions into a coherent instrument that facilitates the interview process, ensuring that all pertinent topics are addressed systematically. The SPSS process resulted in the identification of four guiding subjects, which are central to understanding the mobilisation process and its implications. These four guiding subject areas were related to conventional mobilisation at T1 and to robot-assisted mobilisation with the VEMOTION® at T2 and T3.

They are listed in Table 2. As recommended by Mayring, a mock interview was conducted with a nurse [33]. The interview turned out to be suitable for the planned survey here and could be included in the sample. The guided interviews were audio-recorded and then transcribed in accordance with the rules of Kuckartz et al. [34]. The researchers were present for all robot-assisted mobilisations, identifying the routine users and the non-routine ones by questions. This was based on the subjective assessment of the persons. Only three carers considered themselves as experienced. Therefore, only three interviews could be conducted at survey time T3. New content kept appearing in these interviews and data saturation could not be achieved. It was not possible to recruit more participants with routine and to achieve

Table 2 Guiding subjects with explenation and sample question (own presentation)

Guiding subject	Explenation	Sample question
Mobilisation design/ integration into everyday working life	This subject area examines how mobilisation, both conventional and robot-assisted, is conceived and incorporated into the daily routines of healthcare settings, highlighting the practicalities and logistics involved in the process	Can you please describe a typical mobilisation situation (with the VEMOTION®)?
Participating professional groups/ persons	This focuses on the roles and experiences of various professionals involved in the mobilisation process, offering insights into multidisciplinary collaboration and individual contributions	Who is involved in mobilisation (with the VEMOTION®)?
Experience/feelings during mobilisation	This explores the subjective experiences of those involved in mobilisation, capturing emotional responses, challenges, and satisfactions encountered during the process	Are there certain situations or factors in which you perceive mobilisation (with the VEMOTION®) as relieving?
Physical effects of mobilisation	This addresses the tangible outcomes of mobilisation, considering the physical impact on healthcare professionals	Are there certain situations or factors in which you perceive mobilisation (with the VEMOTION®) as physically stressful?

data saturation within the specified survey period. Data saturation was approached with meticulous attention to the depth and richness of information provided by the participants. For T1 and T2, saturation was considered achived when the interviews began to yield redundant content, indicating that within the nursing cohort, further interviews were not eliciting new themes or altering the emergent patterns. This observation was consistent with the principle that data saturation occurs when additional data no longer contribute to further insights regarding the research question. The absence of physiotherapists in the participant group represents a limitation. Consequently, data saturation refers context-specifically only to the data obtained from the nurses.

The interview data were analysed by AMK and JH, using the summarising qualitative content analysis in accordance with Mayring [35]. Initially, both researchers independently conducted a detailed analysis of the data. This independent analysis facilitated the formation of initial category structures. Deductive categories were formed first based on the leading questions [34]. Inductive category formation followed by acquiring further categories from the material. The categories were further combined for redundant content in another reduction step. Subsequently, AMK and JH engaged in a collaborative review process, often referred to as the 'four-eyes principle'. During this phase, they meticulously compared and discussed their independently formed categories, ensuring a consistent and cohesive categorisation of data. Discrepancies, primarily semantic rather than conceptual, were carefully examined and resolved through mutual agreement, underscoring the collaborative nature of the research process. This iterative dialogue contributed to the refinement of the category system, resulting in a set of categories that encapsulated the richness of the data. These categories were then systematically reviewed and consolidated, removing redundancies and enhancing clarity. Furthermore, AMK and JH consistently engaged in consultation and validation processes throughout their collaboration. These steps were integral to ensuring the accuracy and reliability of their findings, further solidifying the methodological rigour of their research approach.

Transcription and data analysis took place using the MAXQDA 2022 programme (release 22.3.0), ensuring a rigorous and structured analytical approach. The collaborative effort between AMK and JH in this iterative process of analysis and category refinement underscores the methodological robustness and interpretative alignment within our study.

3.5 Quality criteria

The study selected the quality criteria of appropriateness, process documentation, argumentative interpretation validation, regularity, proximity to the subject, communicative validation and triangulation [33] to ensure the quality of the research. Proximity to the subject matter was primarily guaranteed through the alignment of the research method and question with the object under investigation. Comprehensive process documentation of the results and the research procedures was maintained, ensuring a well-documented textual performance. This documentation was complemented by the knowledge gain achieved during the study, contributin to the article`s originality. Regularity was upheld by ensuring consistency and repeatability in the analysis process. This consistency extended acress the entire dataset, enabling reproducibility by the researchers team. To maintain argumentative interpretation validation, interpretations were logically derived from the data, preserving a clear and coherent connection between the evidence and the conclusions. The communicative validation took place in regular meetings with the research team. Triangulation was successfully implemented by conducting multiple data analyses, facilitating the identification of corresponding categories. This methodological approach enhanced the credibility and reliability of the study's outcomes.

3.6 Ethics and data protection

Before the study was performed, the responsible ethics committee, the data protection officer, and the staff council of LMU Klinikum gave a positive assessment. Participants consented to participate in written form in the sense of informed consent [36]. All methods were performed in accordance with the relevant guidelines and regulations as set out in the Declaration of Helsinki. The data were stored and evaluated in pseudonymised form in accordance with data protection regulations [37]. They were stored on the servers of the university implementing this study, protected against unauthorised access. Decryption only took place for data destruction in case of withdrawal from the study. Once possible within the scope of the data evaluation, the relevant data were anonymised. The data collected during the study will be destroyed following completion of the research project. All active researchers have a nursing background with a focus on intensive care. However, they had no professional relationship with the participants themselves, which rules out any distortion of the results through personal relationships.

4 Findings

The qualitative content analysis in accordance with Mayring [35] permitted derivation of a total of six categories. They are listed in Table 3.

4.1 Content-related findings of the three survey times

4.1.1 Processes and routine

The design of mobilisation can be divided into preparatory, implementation, and follow-up measures. According to the participants, feasibility will be checked before starting any mobilisation. This depends primarily on the patient's state of health as well as on the vascular catheters and other lines to and from the patient: *"First of all, it depends on the patient for me […] What kind of condition are they in and is it justifiable from the circulatory situation?"* (PK 9, T1, para. 6). If the patient is deemed fit for mobilisation, preparatory measures will commence. The patient is first informed about the planned mobilisation. For a smooth process, the environment often has to be adapted accordingly in addition to preparing the

Table 3 Categories and their definition of the interviews (own presentation)

Categories	Category type	Category definition
Processes and routines		This describes the procedures and routines for conventional and robot-assisted mobilisation design
Organisation in the interprofessional team	Deductive	This includes involvement and collaboration of different professional groups in (robot-assisted or conventional) mobilisation
Integration into the workflows	Deductive	This includes process-related and personnel-related factors influencing robot-assisted and conventional mobilisation, respectively
Enabling and inhibiting factors	Inductive	This describes influence factors that promote or inhibit mobilisation
Physical effects	Deductive	This describes the assessments of physical relief or stress
Psychological effects	Deductive	This describes the assessments of psychological relief or stress

patient themselves: "*Of course I inform the patient, see if what I am planning is possible at all and then prepare them and their environment*" (PK 12, T1, para. 6).

Furthermore, additional aids are sometimes used for conventional mobilisation. Only the VEMOTION® was needed for robot-assisted mobilisation. Some safety aspects must be considered for both forms of mobilisation. Present vascular catheters, ventilation tubes, and close patient monitoring are particularly important here: *"Once the robot is in the room, I set up all the cables, measuring instruments and monitors […]. That is always important [so that] the safety for mobilisation is guaranteed"* (PK5, T2, para. 2).

Depending on the patient's condition, a second person will also be called in for support: *"I wouldn't do it alone. […] When I look at the infusions, I don't have the ventilation in view. And these are vital in the ICU. The CVC must not come out, and neither must the ventilation tube. Therefore, it takes at least two people" (*PK3, T2, para. 35).

In contrast to VEMOTION® mobilisation, the procedures of conventional mobilisation are usually already routine in accordance with the mobilising specialists. There is still a lack of continuity in the case of robot-assisted mobilisation: *"I have already memorised the routine. I went through it entirely for one week and then I already had a routine. Now it's been a month since I did it. Of course, I have lost my routine now."* (PK3, T3, para. 10). The processes of VEMOTION® become more familiar after repeated use according to the participants. Deliberate adherence to sequences consequently leads to a more routine application, which ultimately also results in time savings: *"The routine does help some. It took me 20 min to prepare the first time, and only 10 min the last time"* (PK 3, T3, para. 14). It is also easier to develop and vary one's own routine after a while: *"If you know what you are doing, you can do some things beforehand. That's just easier"* (PK2, T3, para. 4).

4.1.2 Organisation in the inter-professional team

Conventional mobilisation of intensive-care patients takes place across all occupational groups according to the participants. The nurses and physiotherapists are primarily responsible for this. Robot-assisted mobilisation, in contrast, is performed only by nurses because physiotherapists could not be included in the study. Both forms of mobilisation were preferably performed by two persons. This is considered particularly advantageous for robot-assisted mobilisation. Preparation of the robot-assisted mobilisation in particular takes a lot of time according to the users, especially as compared to conventional mobilisation: "*Yes, […] it is faster when you are working in pairs*" (PK 10, T2, para. 36). This is also confirmed by some experienced participants (T3): "*With a supportive nurse, it's definitely quicker and more effective because you don't have to go to the other side of the bed [or] run back and forth*" (PK 2, T3, para. 44). Safety aspects play a major role here again as well: "*[…] setting up […] takes two people, […] also [to] secure the tubes and […] it is [also] better for the patient's well-being if there is someone on either side of the bed"* (PK 12, T2, para. 30). On the other hand, some other participants said that they prefer to perform the preparation alone and only call in another person at need, in particular when the routine of setting up and taking down the system (T3) has become established. This is relevant in terms of time, in particular for the subsequent mobilisation unit. It is considered of advantage that a person can temporarily leave the room while performing robot-assisted mobilisation, which is not the case with conventional mobilisation. However, a nurse must keep an eye on the patient to be mobilised at all times, even during robot-assisted mobilisation: *"[…] once the robot starts […] you have to stay* there" (PK 10, T2, para. 12). Furthermore, it is helpful if at least one person is familiar with the patient in order to be able to assess what mobilisation level is feasible. Therefore, some participants also state that involvement of a physiotherapist would be useful during robot-assisted mobilisation. In addition, physiotherapy can better assess a physiological gait pattern. This is necessary in particular when the robotic system performs the gait movement. Some participants indicate that the involvement of two nurses is sufficient, as it is a *"strictly passive thing"* (PK 2, T3, para. 44).

Coordination processes within the inter-professional team were considered particularly relevant for both conventional and robot-assisted mobilisation. In this context, organisational and temporal arrangements as well as process coordination during the mobilisation measures were mentioned: "*You have to coordinate on when to mobilise. And on how long it will take and how long the colleagues have time for mobilisation"* (PK5, T1, para. 44). The participants stated that the nurses in charge of this usually take the leading role, while the nurses or physiotherapists brought in to help (only T1) take a supporting role. While the nursing focus is primarily on monitoring vital parameters and controlling and coordinating any present catheters in a joint conventional mobilisation of ICU patients, physiotherapy focuses primarily on *"respiratory therapy […], exercises of balance and trunk control"* (PK 8, T1, paras. 41–46). In the case of robot-assisted mobilisation, it is particularly important to agree on the time when the mobilisation is to be performed since the nurse responsible for the patient in the VEMOTION® must always sign off before a mobilisation: "*[…] you always have to tell your colleagues that you are now mobilising with [VEMOTION®] because then you are not really available for anything else*" (PK 2, T3, para. 50).

4.1.3 Integration into the workflows

According to the nursing professionals interviewed, conventional mobilisation is performed at least once or twice, and in some cases up to three times a day. As a rule, mobilisation takes place once in the morning and once in the afternoon. The available personnel resources and time as well as the individual condition of the patients to be mobilised or the patients to be covered by the same nurse are decisive for the frequency of daily mobilisations: "*Very different. It always depends on the combination of patients we take care of […] or […] how complex mobilisation is*" (PK 7, T1, para. 23). The patient's condition is another factor in robot-assisted mobilisation that can make integration into workflows difficult. If the patient to be monitored at the same time is in a different room from the patient to be mobilised, integration into the work processes will be reduced since the nurse will be tied to the VEMOTION® bed for the robot-assisted mobilisation and the other patient cannot be adequately monitored.

With sufficient staff, both from the physiotherapy and nursing sides, conventional mobilisation can be used more frequently: "*In the morning shift, you just notice […] the presence of physiotherapy and in the late shift you notice that you have more time [for mobilisation]*" (PK9, T1, para. 25). In the morning, nursing staff mainly performs personal hygiene measures, while things such as sitting on the edge of the bed or transferring to a mobilisation chair will take place in the afternoon. It is also reported that mobilisation in the sense of a transfer to another therapy device in conventional mobilisation is first performed by staff on the morning shift. A return transfer would then be performed by an employee of the late shift at a later time, depending on patient condition. This type of distribution is not reported in combination with VEMOTION®. Most participants state that they prefer to perform robot-assisted mobilisation in the afternoon. The reasons are the high time expenditure and the lack of routine (T2). This makes it difficult to integrate the task into the already time-consuming morning shift: *"I think that […] with VEMOTION® does not work in the morning. It just takes too long for that*" (PK 10, T2, para. 22). Routine (T3) seems to make mobilisation more feasible in the morning shift: "*Both in the morning shift and in the late shift. As mentioned, it always has to fit into the course of the day. It really does take half an hour after all"* (PK2, T3, para. 18). Some participants state that conventional mobilisation is less time-consuming than robot-assisted mobilisation: "[…]*such brief mobilisation to the edge of the bed is clearly more time-saving for us than using VEMOTION®"* (PK5, T2, para. 16). It was considered positive that other activities can be done in the patient's room during mobilisation with VEMOTION®: *"You can do some things, such as drawing up infusion solution"* (PK8, T2, para. 7).

4.1.4 Enabling and inhibiting factors

Sufficient staff is conducive to the mobilisation of intensive-care patients, both conventionally and robot-assisted. According to the participants, sufficient staff would also mean more time for mobilisation. The participants stated that conventional mobilisation is often supported by physiotherapy staff. According to one participant, the permanent integration of a physiotherapist in the team of the intensive-care ward would be particularly advantageous for the time aspect in conventional mobilisation: *"If we had a <u>permanent</u> physiotherapist on our ward […]. That would of course be really good […] because then you are not always so limited in time"* (PK 11, T1, para.16). Involvement of physiotherapy in robot-assisted mobilisation is equally beneficial: *"I think physiotherapy could be really well involved in this. Just basically in the subject of mobilisation, they know much better what a physiological movement sequence should look like […]"* (PK 9, T2, para. 34). Mobilisation alone generally is hardly possible. Some participants state that the support of another nurse is necessary for both forms of mobilisation: *"I think we need a second nurse in normal everyday work. That would be <u>unchanged</u> as compared to conventional mobilisation. Using the VEMOTION® all by yourself, that won't work"* (PK 1, T2, para. 10).

In addition to a sufficiently staffed team of nurses and physiotherapists, coordination, good cooperation in the interprofessional team, and the motivation and commitment of the staff play a decisive role: *"[…] if you know when to mobilise, you can plan it well, then it's not really a problem.* Vice versa*, if there were <u>no</u> organisation, it would be rather an obstacle to the workflow"* (PK 8, T2, para. 37). In addition, scientific findings on the benefits of robot-assisted mobilisation could increase the motivation of the mobilising specialist staff: *"I think if we had more facts, for example: The mobilisation robot shortens the length of stay […] by this and that many percent […], then there would be more insight and also more understanding why one should do that"* (PK 11, T2, para. 46).

Mobilisation with VEMOTION® is particularly recommended for early mobilisation: *"I don't think it's so bad for the beginning, because they have so many tubes to deal with at the beginning, you can't walk with them. And they are still so weakened*

[…]. The bed is better for it then. You simply don't have to disconnect as much then. You can leave all of that on. The chest tubes in particular, it's incredible effort to attach them somewhere if they come along" (PK 1, T2, para. 12). Some of the participants rather recommend VEMOTION® for a different patient group: *"It's a sensible device that is not always efficient for the patient group that it is intended for. […] For that patient group it may or may not be sensible. I think that there are other patients who would profit more from having this bed system"* (PK2, T3, para. 26).

In addition, the cooperation and motivation of the patients themselves are a conducive factor for mobilisation. This was addressed in the context of both conventional and robot-assisted mobilisation: *"Patients who are not compliant. If the patient doesn't understand what is going on or just doesn't feel like it, then we can slog away and we won't get them anywhere"* (PK 13, T1, para. 25).

In general, the specified processes in the survey phase of the study also seem to be an obstacle to use of the robotic system since the participants had to plan use of the VEMOTION® at the beginning of the shift in each case. This made it difficult to react to spontaneous changes in the organisation of work, such as those occurring in the intensive care unit due to deteriorating patient conditions.

4.1.5 Physical effects

The majority of the nurses interviewed reported mainly back complaints in connection with conventional mobilisation. Pain in the knee, elbow, hand, hip, or pelvis is described as well: "*Back pain, hip pain, knee pain […] That means in the places […] that I use to […] carry the weight. Back is number one, of course"* (PK9, T1, para. 19). According to the participants, complaints occur in both professional and private contexts. Mobilisations of patients with obesity, contractures, or special clinical pictures, such as critical-illness polyneuropathy [CIP], are named as the main causes. According to the participants, mobilisation of severely overweight patients is, therefore, performed more hesitantly: "*If the [patient] is very heavy […], you will think thrice about whether to mobilise or not*" (PK 4, T1, para. 24).

Physical stress factors are also reported for use of the VEMOTION® robotic system. These happen mostly when setting up the unit and preparing the patients. The main reason for this, however, is the complex system for application of the patient securing devices and operation of the VEMOTION®: "*[…] you need a second [person] to lift or position the legs [so that] you can slide [the seat adapter] down well. […] I found it physically exhausting at first"* (PK, T2, para. 54). It is also often necessary to switch to the other side of the hospital bed to avoid catching or disconnection of catheters, infusion lines, or ventilation tubes: *"The only thing that is stressful is when you have to circle the bed 10 times to prepare the patient"* (PK2, T3, para. 68). According to the participants, another person's support is, therefore, preferred, in particular during the preparation of robot-assisted mobilisation. The effort required during mobilisation as such was perceived as less stressful. Some also reported less physical discomfort, such as back or joint pain: "*But apart from that, at least it doesn't strain my back at all"* (PK5, T2, para. 61). Compared to conventional mobilisation and the inclusion of other aids or techniques, the use of VEMOTION® was described as advantageous and more energy-saving: *"[…] if we compare it to other techniques, then it is much more strenuous to passively pull someone over the edge of the bed or to get them out to a chair* via *a standing position of course than […] to put on two straps and harness them into the robot"* (PK 13, T2, para. 77). It is also reported that patients who are intubated are easier to mobilise robot-assisted than conventionally: *"It wasn't any great physical effort now and that was certainly a patient, I certainly wouldn't have mobilised them otherwise"* (PK 10, T2, para. 74). The safety aspect is particularly decisive here. According to the participants, the ventilation tubes can be kept in view better during mobilisation with VEMOTION® than during positioning or transfer in conventional mobilisation: *"[…] that's what I like about VEMOTION®. It's easy to pre-sort everything so that it is actually safe"* (PK 1, T2, para. 56).

4.1.6 Psychological effects

Low staff capacities, lack of time, as well as patient-related influences were perceived as particularly burdensome in both conventional and robot-assisted mobilisation. The high effort in terms of time, in particular in the case of robot-assisted mobilisation, was often considered to be very stressful: "*I have to say that I found mobilisation very stressful, very exhausting in the first few days. This expenditure of time alone […]"* (PK9, T2, para. 48). With acquired routine, on the other hand, the feeling of stress appears to decrease: *"Now in the early days it is […] still more demanding mentally. For the conventional method, we just know what we have to do. But I think that is also going to happen over time"* (PK 1, T2, para. 56).

In particular for conventional mobilisation, patients with specific symptoms, such as CIP or obese patients, are a challenge not only for the physical but also the psychological perceived stress. The general condition and the ventilation situation of the patients also play a decisive role: *"[…] the challenges for mobilisation for me are: How large is the patient,* *how awake is the patient, how heavy is the patient […], is the patient ventilated or not, [how] many drains are there […]?"* (PK 1, T1, para.19).

Special vascular catheters were found to be particularly stressful in conventional mobilisation as well as in robot-assisted mobilisation alike. The focus for them also is on the safety aspect, which must be considered with both forms of mobilisation. Insufficient patient cooperation was also perceived as a hindrance in both conventional and robot-assisted mobilisation: *"It is very difficult and stressful when the patient […] actively works against you […]. It is mentally and physically exhausting alike […]"* (PK 4, T2, para. 38).

Taking care of another patient at the same time is hardly possible in combination with the responsibility of a VEMOTION® patient: *"[…] I don't think working with two patients is feasible, to be honest. I think if the other patient is too [demanding], the mobilisation will also turn very stressful"* (PK9, T2, para. 48). This is the case in particular with a patient in a different hospital room so that they cannot be continuously monitored. This causes high psychological stress arises: *"[If] you keep having the other [patient] in the back of your mind, […] [and you] don't hear any alarms when the [bed] is far away, you might have a bad feeling, you might want to check on them again, check on them again. And of course, you can get them on the monitor, but […] if they are restless or delirious maybe, that doesn't help either*" (PK9, T2, para. 50). Users of the robotic system (T2 and T3) also found it difficult when patients were treated with the device who they believed would have benefited more from conventional therapy (e.g., patients who could already sit independently on the edge of their beds): "*I can't really say it's a relief now either, because […] I wouldn't have performed [robot-assisted] mobilisation on them now […].*" (PK 13, T2, par. 65–67).

Involving the patient and their relatives, on the other hand, could lead to relief as well. Regarding robot-assisted mobilisation, greater routine was mentioned the most. It would be desirable for long-term relief: *"I think routine, of course. It would help if you really did it on a regular basis. Another thing might be restructuring the working day or the shift in such a way that one makes space for this kind of mobilisation"* (PK9, T2, para. 52). According to the participants, a better staffing ratio and 1:1 care of the VEMOTION® patient to be mobilised would also be beneficial to introduce mobilisation with VEMOTION® on a regular basis and to ensure long-term relief. An additional mobilisation specialist would be equally beneficial*: "Something that would take the pressure off me would be a support person who just helps organise the whole thing, [who] runs with the robot and virtually takes care of the preparation. They could support monitoring in time […] and everything else. You're just that much aster when you work in pairs"* (PK2, T3, para. 32–34).

5 Discussion

The testing of the VEMOTION® system in healthcare has resulted in a differentiated view of mobilisation processes, both conventional and robot-assisted. Coordination within the inter-professional team seems to be vital for both conventional and robot-assisted mobilisation since it is the only way to ensure care of patients in need of care at the same time. A nurse-to-patient-relation of 1:2 is common in German intensive care units [38]. If the patients to be covered at the same time is placed in a different room from the patient to be mobilised robot-assisted due to structural conditions, continuous care of the patients can only be ensured by colleagues taking over this task. This seems to result in increased psychological stress in particular in connection with patients who require a lot of care. In the case of VEMOTION® mobilisation, mobilising professionals are also not allowed to leave the bed for reasons of safety, even while the robotic system is taking care of mobilisation. Although tasks such as preparing medicines, which have to be done in the patient's room anyway, could be done in parallel, adaptation of the work organisation seems to be possible only with the routine handling of the robotic system. The long duration of robot-assisted mobilisation (in particular due to preparation time) is also often listed as a stress factor. It was repeatedly mentioned that the late shift was better for mobilising patients due to the fact that the focus is even more on labour-intensive nursing activities, such as body care, including prophylactic interventions, in the morning shift than in the late shift. The late shift apparently being the mobilisation shift could also be shown by earlier studies [26]. This does not seem to depend on whether the VEMOTION® is used or whether conventional mobilisation takes place.

The German Interdisciplinary Association for Intensive Care and Emergency Medicine (DIVI) also makes clear that physiotherapy should be integrated into the care team of the intensive care unit for the entire day to ensure early and regular mobilisation treatment to prevent related long-term impairments in patients [38]. In light of the fact that physiotherapy and nursing should be responsible for the mobilisation of patients in a inter-professional team, the fact that nurses were solely responsible for robot-assisted mobilisation in this study is an additional stress factor for the nurses [20, 26]. According to the participants, physiotherapists are much better able to assess whether the robotically generated gait movement is physiological. This is also confirmed by the literature [8, 38]. It can be assumed that coordination and collaboration in inter-professional healthcare teams involving both nursing staff and physiotherapists will lead to more effective and less stressful mobilisation sessions, regardless of whether conventional or robot-assisted measures are involved.

It was mostly reported both for robot-assisted and conventional mobilisation that it should be done by two persons each. The reason for this was in the complex preparation of the patient with the application of safety-relevant straps first and foremost in robot-assisted mobilisation. The fact that a second person is involved in the robot-assisted mobilisation usually has the background of saving walking distances during preparation (around the bed). For conventional mobilisation, however, the second person seems to be important in particular for the implementation and thus represents a safety aspect that seems to be of increased relevance in particular due to the transfer to a therapy device [39, 40]. This transfer is not necessary for robot-assisted mobilisation with the VEMOTION® [14, 18]. This appears to positively affect the perception of physical stress, where little to no physical discomfort was generally reported in relation to mobilisation. In contrast, it was frequently mentioned with conventional mobilisation that back complaints occur in connection with mobilisation. This brings a high risk of long-term impairments that may also affect musculoskeletal disorders (MSD) [41] and that seems to reduce with robot-assisted mobilisation.

As also described in the literature, acceptance of a robotic system is one of the biggest requirements for a successful trial of a robotic system [42]. It can be a barrier or a promoting factor. Routine in handling robot-assisted mobilisation is closely linked to this. It can only develop through a certain frequency of use. Participants reported that they felt more confident in using the device the more often they used it and the more continuous this use was. Sharing of scientific insights on improved patient outcomes by using robotic systems also creates an incentive for integrating it into patient-related work processes. The tendency towards increased confidence and reduced stress in routine use observed in the survey time T3 emphasises the potential benefits of integrating such technologies into routine healthcare. The integration of the VEMOTION® system into the daily workflows of intensive care units can, according to the tendency in T3, lead to improved organisational efficiency, which can result in medical staff being able to spend more time on direct patient care. Additionally, while the integration of innovative technologies like the VEMOTION® system presents a promising avenue for enhancing patient care and reducing physical strain on staff, it's crucial to recognize that technology is only one aspect of creating a supportive and sustainable work environment. Alongside technological advancements, it's imperative to explore and invest in broader strategies aimed at improving working conditions [24]. These measures, in conjunction with technological solutions, can collectively contribute to a more holistic approach to enhancing the well-being of healthcare professionals and the quality of patient care.

5.1 Limitations

There was an increased turnover in the nursing team due to the Covid-19 pandemic. For example, nurses from other areas, such as anaesthesia in the operating theatre, who were working on a restricted basis during the pandemic, were deployed in a supportive capacity in the project intensive care units. In addition, waves of illness kept occurring among the nursing team. Therefore, consistency of the staff trained in the robotic system VEMOTION® within the nursing team could not be achieved. This resulted in a lack of consistent routine in robot-assisted mobilisation, which affected the survey time T3, which is why only three interviews and thus no data saturation could be achieved here. This limits the robustness of this data generation point.

Despite the recognised value of inter-professional collaboration in the mobilisation of patients, the involvement of physiotherapists in the VEMOTION® mobilisation process was not possible. This was not due to a lack of interest or recognition of the potential benefits of the system, but was a direct result of strategic decisions at the departmental level, based on acute staff shortages and an already heavy workload. This limitation is particularly noteworthy as it contrasts with the interdisciplinary approach typically advocated for in patient mobilisation, where both nursing and physiotherapy professionals are considered essential [20, 26]. To ensure the robustness and transparency of the research process, the interview guide was carefully designed, the data was systematically collected and analysed and ethical and data protection safeguards were put in place. These methodological safeguards contribute significantly to strengthening the credibility of the study results.

The need to assess the impact of methodological rigour on the reliability and potential applicability of the study's conclusions was recognised. Although the study was conducted in a specific context, the findings obtained are considered very valuable as they provide a solid basis for future research in this area. It is expected that the findings, based on a thorough and conscientious research approach, will make a meaningful contribution to professional practice and stimulate further scientific enquiry that will allow deeper exploration and clarification of the patterns and issues identified.

5.2 Recommendations for further research and practice

Based on the results, further studies with a focus on impact of robotics on patient outcomes is recommended to incentivise users. Intervention and outcome studies to examine the effects of robotics on patient outcome are recommended.

Furthermore, the study should be performed again for a longer period of time, outside of the pandemic. This would minimise the influence of high fluctuation that affected routine of the mobilising specialists. It is also recommended that the physical stress and relief factors of robot-assisted mobilisation be examined using an additional quantitative examination. It is recommended that physiotherapy staff also be instructed in order to be able to guarantee the inter-professional task of mobilisation in robotic-assisted mobilisation as well when introducing a robot-assisted system. Beyond this, it is recommended to further develop the robotic VEMOTION® system to clearly reduce the preparation time in order to achieve psychological relief for the mobilising specialists as well. In general, the focus should also be on good working conditions for healthcare workers in order to minimise mental stress in this area. These should include key factors such as the intensity of work, the organisation of working hours, social relationships and an appropriate working environment.

6 Conclusion

The exploration of the time and personnel resources emerged as a pivotal element in both robot-assisted and conventional mobilisation. The preparation time required for patient mobilisation seems to be a great psychological stress factor. For experienced users, however, this stress seemed to no longer apply at the same scope since the processes were already internalised and therefore less time-consuming to perform. The robotic system was noted for its capacity to relieve physical strain, contrasting with the musculoskeletal complaints often associated with conventional mobilisation methods. Interestingly, the alleviation of physical strain was constitend across users regardless of their routine with the system, underscoring the inherent ergonomic advanteges of the robotic system.

The study also highlighted the nuanced role of routine and continuity in the use of the robotic system, particularly in relation to psychological stress. The decision to utilise the system was influenced not only by the user's familiarity with the technology but also by broader factors such as the severity of the patient's condition, nurse-to-patient ratios, and logistical aspects like the proximity of other patients requiring care.

In summary, while the robotic system offers notable physical advantages, its psychological impact is multifaceted, shaped by a blend of user experience, operational routines, and the broader care environment. These findings contribute valuable perspectives to the discourse on the integration of robotic systems in patient care, underscoring the need for a holistic approach that considers both technological and human factors.

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Data availability The datasets utilized for this study are not publicly available due to IRB agreements; however, they are available from the corresponding author on reasonable request.

Code availability Not applicable.

Declarations

Ethics approval and consent to participate Before the study was performed, the responsible ethics committee of the LMU university hospital (21-0355), the data protection officer of the LMU university hospital, and the hospital's staff council approved the study. Patients and mobilising specialist staff consented to participate in written form in the sense of informed consent [36]. Patients consented to participate before a planned intensive care stay after surgery. We confirm that all methods were performed in accordance with the relevant guidelines and regulations as set out in the Declaration of Helsinki.

Consent for publication Patients and mobilising specialist staff consented for publication in written form in the sense of informed consent [36].

Competing interests The authors declare that they have no competing interests. We emphasise that the company ReActive Robotics had no influence on the design, conduct, analysis or interpretation of the results of the study. Our research team remained scientifically independent throughout the study, and we received no financial compensation that could compromise the objectivity of our findings. We are committed to transparency and scientific integrity and ensure that all potential conflicts of interest are fully and transparently disclosed.

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