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Can Mobilising Specialists be Relieved by a Robotic System for the Early Mobilisation of Intensive-Care Patients? A Quantitative Longitudinal Study at Two Data Collection Points at a German University Hospital

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Abstract

Immobility in intensive-care patients can lead to significant health risks and costs for the health system. Reasons for this include the shortage of specialist staff in nursing and physiotherapy who typically handle mobilisation activities for intensive-care patients. The use of robotic systems aims to facilitate early mobilisation and thereby counteract prolonged immobility. Whether this can also alleviate the workload for staff has not yet been sufficiently investigated. To examine the psychological stress and behaviour of mobilising specialist during conventional and robot-assisted mobilisations of intensive-care patients and to draw conclusions regarding the impact on and relief for the mobilising staff due to the robotic system, a quantitative longitudinal study was conducted with two data collection points (T1, T2). Aspects of body posture, the perceived stress of mobilising staff, as well as the time and personnel required for mobilisation were collected through non-participatory standardised observations. Descriptive statistics were used for data analysis of the observations of 35 conventional mobilisations (T1) and 55 robot-assisted mobilisations (T2). Additionally, a follow-up was conducted for nine robot-assisted mobilisations to assess the routine use of the robotic system. The duration of robot-assisted mobilisation had significantly longer process compared to conventional mobilisation. A significant correlation was found between the subjectively assessed feasibility of mobilisation and psychological stress (PSaR) experienced by the specialist staff during robot-assisted mobilisation. The more confident users felt in robot-assisted mobilisation, the less psychologically stressfull they found it. Overall, robot-assisted mobilisation was more ergonomic and less stressful for the musculoskeletal system of the users.
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Keywords Robotics · Critical care nursing · Intensive care unit · Early mobilisation · Robot-assisted · Quantitative longitudinal study

Abbreviations

ECMO	Extracorporeal membrane oxygenation
FWB	Further training in intensive care and anaesthesia
ICU	Intensive care unit
MSD	Musculoskeletal disorders

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NIV	Non-invasive ventilation
PD	Nursing service
PHYS	Physiotherapy
PSaR	Subjective assessment of psychological stress
WMSD	Work-related musculoskeletal disorders
WHO	World Health Organisation

1 Background

Patients treated in an intensive care unit (ICU) can experience prolonged immobility [1]. However, initiating early patient mobilisation within 72 h of admission to the ICU, as stipulated by the German S3 guideline "Positioning therapy and mobilisation of critically ill patients in intensive care units" [2], can help mitigate potential long-term damage, such as the development of ICU-acquired weakness [3]. This approach may also reduce costs for the healthcare system [4]. The primary reasons for delayed or omitted early mobilisation include a shortage of resources among specialist staff and inadequate equipment [5, 6]. Additionally, caring for patients in the ICU entails significant physical and psychological stress for specialist staff. These stress factors not only affect job satisfaction but also private well-being [7]. Moreover, high levels of stress can affect self-esteem and contribute to burnout [8].

To address challenges like this, robotic systems can be utilised, some of which can even assist or take over mobilisation activities to counteract patients' prolonged immobility and alleviate the workload of the mobilising specialist staff [9]. One such robotic system is the adaptive robotic assistance system VEMOTION® developed by ReActive Robotics.

The system comprises a specialised intensive care bed equipped with a docking point for the robotic system, which can be controlled via an associated monitor to generate gait movements (see Fig. 1). This setup allows the hospital bed, with the robotic system attached, to function as a therapy device without transferring the patient. For therapy, the patient is securely fastened to the bed using specialised securing units, including a seat adapter and fastening straps. The robotic system is then docked, and in-bed gait training can be initiated, with the bed adjustable to 70 degrees. The monitor allows for configuring various settings, enabling passive or assisted mobilisation. A video demonstrating the system's functionality can be viewed here: https://www.youtube.com/watch?v=PdYcFUgMj-Q [10].

The robotic system VEMOTION® can be classified under rehabilitation or therapy robotics, which have been developed in connection with rehabilitative approaches for various neurorehabilitative challenges. However, in German-speaking countries, there is only a limited body of knowledge on these systems [11]. Additionally, there are other types of care robotics which can be categorised into two further types based on their fields of application or functionality [11]. One of the three categories is socio-assistive systems (including emotional robotics). These systems focus on the socio-communicative aspects of care and include humanoid robots and robotic animals. The third category is service robotics (for caregivers and individuals in need of assistance). These robots support simpler service tasks and focus on logistics in care practices. The systems can relieve caregivers (e.g. nurses but also informal caregivers like related persons) in various areas depending on their category. For example, a system that covers socio-communicative aspects and can interact with residents of a nursing home is more likely to be involved in relationship work and primarily provide psychological relief to caregivers. A system classified under service robotics, which can perform tasks such as fetching and carrying, can primarily reduce physical strain by shortening walking distances for caregivers [12]. How systems classified under therapy or rehabilitation robotics can provide relief is not yet sufficiently researched [11, 13]. Therefore, this quantitative longitudinal study focuses on the stress perception of specialist staff during robot-assisted mobilisation of patients requiring intensive care. To this end, both conventionally performed mobilisations and robot-assisted mobilisations of patients requiring intensive care are included in this study. Mobilising specialist staff refers to nursing and physiotherapy professionals, as these are the primary groups involved in patient mobilisation [14, 15].

To ensure comparability with the movements facilitated VEMOTION®, conventional mobilisations of patients to sitting, walking, or standing positions were observed during data collection. The objective of observing only early mobilisations was not fully achieved due to staff turnover resulting from the pandemic and reduced familiarity with the robotic system. Therefore, the results report only refers to "mobilisation" as a whole.

Fig. 1 The VEMOTION.® robotic system (ReActive Robotics, 2021)

Table 1 Variables of the observation sheet with variations (own presentation)

Construct	Variables	Variations
Basic data	Survey point	T1, T2, Follow-up
	Time	6:00 AM–2:00 PM 2:00 PM–10:00 PM
Socio-demographic data of the users	Gender	Female, male, other
	Professional qualification	PD with/without FWB, physiotherapy
	Age and experience in ICU	In years
Socio-demographic data of the patients	Gender	Female, male, other
	Weight	In kilograms
	Size	In centimetres
	Medication	Catecholamines, analgesia, catecholamines and analgesia, no medication
	Form of ventilation	Invasive, non-invasive, no ventilation
	Ventilation access	Tube, tracheostomy, NIV mask, high-flow therapy, no ventilation access
	Inlet and outlet drains/catheters	Number and location
Work organisation	Preparation, execution, follow-up time	In minutes
	Mobilisation aids	Anti-slip mat, slide mat, bed gallows, slide board, bed sheet, mobilisation chair, bed bicycle, forearm walker, commode chair, VEMOTION®
	Persons involved	Number of mobilising specialist staff
	Application of kinaesthesia	Yes/no
Posture of the mobilising specialist staff	Back flexion lumbar spine	Bent, straight
	Upper body forward tilt in the cervical spine/thoracic spine	< 20°, 20°–60°, > 60°
	Knee	Bent, straight
	Foot position	Parallel stance, step stance, fencer stance
	Foot position in relation to the patient bed	Parallel (0°), oblique (< 90°), lateral (> 90°)
	Shoulder posture	Shoulder elevation, neutral position
	Evasive movements upper body	Lateral, rotation, lateral rotation
Subjective assessments of the users	Psychological stress (PSaR)	Numerical scale 0–10
	Feasibility	Numerical scale 1–7

The study description is based on the checklist for observational studies "STrengthening the Reporting of OBservational studies in Epidemiology" (STROBE) [16].

2 Objectives

The study aims to test the VEMOTION® robotic system during mobilisation in an intensive care unit (ICU) setting.

The following research questions served as the guiding principles:

1. What differences can be observed in terms of the psychological strain or relief experienced by mobilising specialist staff during conventional mobilisation compared to mobilisation with the VEMOTION® robotic system?
2. What are the effects on patient-, user-, and process-related aspects of testing the robotic system VEMOTION® for mobilising patients in the intensive care unit?

3 Methods

3.1 Study Design

This is a prospective observational study conducted at a single center, with data collected at two time points. The study

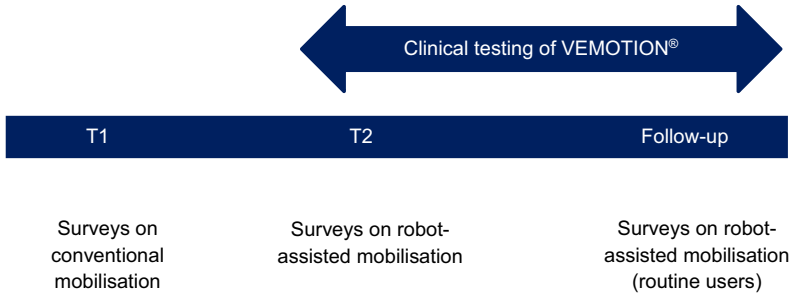

Fig. 2 Study design of the longitudinal study (own presentation)

Table 2 Absolute and relative frequencies of the observations in T1 (conventional mobilisation) and T2 (robot-assisted mobilisation) (own presentation)

Survey point	Number of observations absolute/relative frequency
T1 (conventional mobilisation)	n = 35/32.1%
T2 (robot-assisted mobilisation)	n = 55/50.5%
Follow-up (robot-assisted mobilisation—with routine)	n = 9/8.2%
T1 excluded	n = 5/4.6%
T2 excluded	n = 5/4.6%
Total	n = 109/100%

was conducted from August 2021 to April 2022 in two anaesthesiologically managed intensive care units of a German university hospital that treats approximately 500,000 patients per year in two locations [17]. The range of the anaesthesiological intensive care units includes follow-up treatment after urological, gynaecological, general, and trauma surgery, as well as following organ transplants (Table 1).

A total of 109 standardised non-participant observations of mobilisations were carried out [18], distributed across the two data collection points, T1 and T2, and a follow-up (see Fig. 2). Ten of these observations were excluded during the study (see Table 2). Ninety of the observations included in the data analysis were records from the T1 and T2 data collection points, and nine mobilisations were observed within the follow-up group. The observations were analysed using descriptive statistics.

The selection of a quantitative approach for this study allows for objective measurement and statistical analysis of the physical and psychological strain experienced by staff during mobilisation. This method provides clear, quantifiable data that can be used to assess the effectiveness and impact of the VEMOTION® robotic system compared to conventional mobilisation techniques. The use of descriptive statistics enables the identification of specific areas where the robotic system can alleviate strain, offering concrete evidence to support its implementation.

Involving stakeholders from the field, particularly nurses, was crucial as they are the primary users of the mobilisation system. Their practical insights and experiences are invaluable in evaluating the system's effectiveness and usability. By involving mobilising specialists in the study, the analysis reflects real-world conditions and challenges, making the findings more relevant and applicable. Their contributions provide both a practical perspective, highlighting the operational feasibility and efficiency of the robotic system in actual clinical settings, and a user experience perspective, assessing how user-friendly and supportive the system is in reducing physical and psychological strain. Focusing on the physical and psychological strain of staff is particularly relevant given the current personnel shortage in Germany [5]. Mobilising specialists in better physical and mental states are more capable of providing high-quality care, which directly benefits patient outcomes. By addressing the strain on staff, the study aims not only to improve their well-being but also to enhance the overall quality of patient care. This dual focus on staff and patient outcomes underscores the importance and relevance of our study.

4 Sample/study Participants

4.1 Mobilising Specialist Staff

Nurses and physiotherapists with a minimum of three years of professional experience in an intensive care unit, along with nurses with specialist further training in anaesthesia and intensive care (in accordance with the specifications of the Deutsche Krankenhausgesellschaft; DKG), were planned to be included. Additionally, all participants had to be employed at the University Hospital LMU Munich, Germany, working in the project wards, and had to consent to the observation.

Fig. 3 Observation situation during the training of a new observer to the implementation of standardised observation

4.2 Group Composition (T1, T2 and Follow-Up Group)

At both T1 and T2, study participants were selected based on their shifts and mobilisation activities and asked to consent to participate. After consenting, the mobilising professionals were then observed during conventional or robot-assisted mobilisations. Participants who were already familiar with the use of the robotic system and had previously consented to participate in the study during the T2 observation were observed again during a follow-up.

4.3 Patients

The study included only adult patients aged eighteen years and above who were scheduled for an intensive care stay after surgery, as this was the most suitable time for planning and obtaining informed consent. A homogeneous composition with regard to the surgical intervention was considered, and further inclusion criteria included an expected duration of ventilation of at least 48 h, a height between 1.50 m and 1.95 m, and a weight between 45 and 135 kg.

5 Data Collection and Evaluation

Data collection was carried out using standardised, non-participant observations during different mobilisation methods by mobilising specialist staff in the intensive care setting. This enabled the observation of participants in their working environment (field observation) [19]. Observers were visible and present at all times for the mobilising specialist staff and explicitly acted as researchers during data collection [20] (see Fig. 3).

All observers were thoroughly trained. The training included detailed instructions and practice sessions to ensure that every observer understood the practical challenges and study objectives. Only those who were either physiotherapists or nurses with professional experience in intensive care units were allowed to observe.

In the process of operationalising the phenomena "perception of psychological and physical stress", the standardised observation sheet was initially created. Preparation was based on a previously conducted systematic literature research and evaluation of the preliminary studies performed within the framework of the MobiStaR project [9, 13, 15]. The relevant variables and their variations were identified before designing the observation sheet. This initial step involved determining which specific factors needed to be observed and measured during the mobilisation process. Variables were selected based on prior literature, expert consultations, and the study's objectives.

Once the relevant variables were identified, the observation sheet was designed to include these variables along with explanatory illustrations for quick and uncomplicated use and uniform documentation [19]. The primary focus of the observation was always on the person who took the leading role in mobilisation. This role was determined before mobilisation was performed and documented in the observation sheet.

The observation sheet was designed directly by the researchers. It was then reviewed and adapted to the questions in collaboration with other researchers from the field of intensive care and physiotherapy. During the pretest phase, the observation sheet was subjected to practical testing to ensure the variables were effectively operationalised. Operationalising involved translating the identified variables into measurable indicators and ensuring they could be consistently and accurately recorded by different observers. Two researchers applied the survey instrument in parallel, using the same sample drawn from the population of interest. They then reflected on the perspectivity, selectivity, and constructedness of the observation process. The same results were obtained, confirming the reliability of the procedure. Inter-rater reliability was checked and accepted without further testing.

Furthermore, the designed observation sheet was tested by five persons from the fields of nursing science and nursing practice as well as physiotherapy, within the scope of an expert validation and consent for the first form of content validity, or apparent validity [21]. In addition, the observations in the pretest could be practicably documented on the survey form, and the two initial researchers rated the contents of the observation sheet as comprehensible and appropriate. Due to the standardisation of the observation sheet, the quality criterion of objectivity of implementation was considered to be fulfilled, and further adaptation of the observation sheet was not necessary [21]. No further psychometric tests for validity and reliability were conducted within the scope of this study.

6 Description of the Observation Sheet

The standardised data collection form comprises basic data, anonymised data of the test persons, process-related data on mobilisation duration and work organisation as well as variables on body postures of the mobilising specialist staff, their subjective assessment of psychological stress and relief, and feasibility of robot-assisted mobilisation. Table 1 lists the constructs, the respective variables, and their characteristics.

The time of the survey defined the start of the observation and was assigned to the nursing shift (morning shift: 6:00 AM—2:00 PM and afternoon shift: 2:00 PM—10:00 PM).

The professional qualification of the mobilising specialist staff (users) was differentiated into "nursing service (PD) with and without specialist further training in anaesthesia and intensive care (FWB)" and "physiotherapy (PHYS)".

Patient-related variables included height in centimetres and body weight in kilograms, from which the "Body Mass Index" variable was calculated. In a further step, a categorical variable was formed, based on the WHO classification [22]:

- Underweight (BMI < 18.5 kg/m.^{2})
- Normal weight (BMI 18.5–24.9 kg/m.^{2})
- Overweight (BMI 25.0–29.9 kg/m.^{2})
- Obesity (summarising classes 1–3) (BMI > 30 kg/m.^{2})

In addition to recording the type of ventilation and access as well as medication, drains and catheters were documented, completing the picture of the patient´s situation within the framework of the research question.

One focus of the study was to capture differences based on user- and process-related criteria. Process times for the duration of mobilisation (preparation, execution, and follow-up), the use of mobilisation aids, and the involvement of additional persons, as well as the body posture of the mobilising specialist staff during mobilisation, were documented for this.

The subjective assessment of psychological stress (PSaR) was recorded using a 10-point numerical scale with the variations of 0 = "no stress", 10 = "very severe stress".

Additionally, the subjective assessment of the mobilising specialist staff for the feasibility of the robot-assisted mobilisation was surveyed using a 7-point numerical scale (1 = "not feasible at all", 7 = "highly feasible").

Data analysis was performed with the IBM statistical software SPSS® version 29. Microsoft Excel® for MAC version 16.72 was used for the graphical preparation.

6.1 Statistical Methods

The information collected in writing from the observation sheet was transferred into an analysable, digital format, coded and converted for data analysis. For this purpose, a raw data set was created in tabular form in Microsoft Excel for MAC®, the variables and their numerical coding were defined in a code plan. Missing or implausible values were cleaned up and then imported into the statistics programme SPSS® [23]. On enhance data quality, two independent researchers entered the data, verifying each other's entries. The measurement level of the variables is predominantly nominal-scaled. Socio-demographic and process variables have a metric level of measurement, while numerical scale surveys have an ordinal level of measurement.

Subsequently, the data set was described based on absolute and relative frequencies, as well as position measures such as the arithmetic mean, median, minimum, and maximum, range, and standard deviation [24]. The data were checked for normal distribution as a prerequisite whether parametric or non-parametric procedures need to be applied. For this purpose, the data were graphically examined using a histogram and boxplots, and finally confirmed using the Kolmogorov Smirnov test [25]. Due to the absence of a normal distribution in the data, the Mann–Whitney U test, a non-parametric alternative to the T-test for two independent samples, was employed to analyse possible differences between conventional and robot-assisted mobilisation [26]. For correlations between conventional and robot-assisted mobilisation, the Kendall-Tau-b correlation coefficient was used. Ordinally scaled data, which may not necessarily have an equivalent distance between categories but can be arranged in a natural order, can be assessed for correlations using Kendall's rank correlation coefficient [26]. A 95% confidence interval with a p-value < 0.05 was chosen for the data analysis [25].

7 Results

7.1 Basic Data

Table 2 displays the survey points' duration and the corresponding mobilisation methods, along with the absolute and relative frequencies of the observations. It also highlights the cases excluded due to missing inclusion criteria. Five observations were excluded at each of the survey points T1 and T2 due to the inclusion criteria "specialist training in anaesthesia and intensive care" or "nurse with at least three years of experience in intensive care", as the users did not meet these criteria. During the COVID-19 pandemic, anaesthetic technical assistants, who typically work only in the operating theatre, were deployed to intensive care units to assist due to staff shortages. As elective surgeries were cancelled, these professionals were reassigned to intensive care units and the ten observations were conducted with these individuals.

At the time of conducting the observations, it was unclear how to handle this unplanned professional group within the study. Therefore, these cases were included initially but were

Table 3 Age, gender, professional qualification, and intensive care experience of the users in T1 (conventional mobilisation) and T2 (robot-assisted mobilisation) (own presentation)

			Age in years	ICU experience in years
T1	Female PD with FWB n = 9 PD without FWB n = 13	Mean value	31.23	7.09
		Median	31.50	6.00
		Std. deviation	4.73	4.13
		Minimum	24	3
		Maximum	45	20
	Male PD with FWB n = 7 PD without FWB n = 6	Mean value	33.00	7.38
		Median	31.00	6.00
		Std. deviation	9.47	2.87
		Minimum	20	3
		Maximum	58	12
T2	Female PD with FWB n = 28 PD without FWB n = 6	Mean value	33.21	7.24
		Median	31.50	6.00
		Std. deviation	7.00	5.38
		Minimum	24	3
		Maximum	54	25
	Male PD with FWB n = 9 PD without FWB n = 12	Mean value	35.19	11.14
		Median	33.00	8.00
		Std. deviation	7.94	8.94
		Minimum	25	3
		Maximum	55	33

Table 4 Type of ventilation and ventilation access of the patients in T1 (conventional mobilisation) and T2 (robot-assisted mobilisation) (own presentation)

Date of survey	Form of ventilation	Ventilation access			Total
		Tube	Tracheostomy	NIV mask	
T1 n = 14	Invasive	n = 2/15.4%	n = 11/84.6%	n = 0/0.0%	13
	Non-invasive	n = 0/0.0%	n = 0/0.0%	n = 1/100%	1
T2 n = 33	Invasive	n = 24/75.0%	n = 8/25.0%	n = 0/0.0%	32
	Non-invasive	n = 0/0.0%	n = 0/0.0%	n = 21/100%	1

subsequently excluded based on our predefined inclusion and exclusion criteria once we had the opportunity to review and analyse the collected data in detail.

In total, the observed mobilisations were exclusively carried out by nurses (62.2% female, 37.8% male). Physiotherapists did not participate in the observed mobilisations.

The observations occurred more frequently during the afternoon shift (70.0%) than in the morning shift at both survey points regarding the time of mobilisation.

7.2 Socio-Demographic Data of the Users

At both survey points, there were more female nursing professionals (T1: 22/62.9% vs. T2: 34/62.2%) than male, and more female nurses with specialist training (n = 37) than male nurses (n = 16) at both survey points. The relative proportion overall of nurses with specialist training (PD with FWB) was 58.9%, and the average age was 33.1 years (± 24.9/13.1; SD = 6.89). The nurses without further training were younger on average (mean = 32.00 ± 13.0/12.0; SD = 5.50) and had a shorter intensive care experience (mean = 6.21 ± 13.79/3.21; SD = 3.56) than those with further training.

Table 3 reflects the socio-demographic data of the users, including specialist training, age, and intensive care experience, differentiated by the time of survey and gender.

7.3 Socio-Demographic Data of the Patients

Patients were, on average, 56.3 years old (± 11.7/20.3) and 50.0% female (n = 45).

The mean BMI in survey T2 was with 23.0 kg/m^2 slightly higher than in survey T1 (22.7 kg/m^2). Normal-weight patients represented the largest group overall (52.2%) and

were differentiated by observation time points T1 (n = 20: 57.1%) and T2 (n = 27: 49.1%). There were more underweight subjects during robot-assisted mobilisation at survey time T2 (n = 13: 23.6%) than during conventional mobilisation (n = 4: 11.4%). At the survey time point T2, ten (18.2%) overweight patients were mobilised with the assistance of the VEMOTION®, compared to eight (22.9%) patients with a BMI between 25.0—29.9 kg/m^2 during conventional mobilisation.

With regard to medication, only the documentation of medication for analgesia, catecholamines, and simultaneous administration of both groups of medication was observed. 33 patients (60.0%) were analgosedated at T2, while only four patients (11.4%) were analgosedated during conventional mobilisation. Half of the patients (n = 28: 50.9%) mobilised with the VEMOTION® received circulatory support with catecholamines. This was necessary for only thirteen patients at the survey point T1 (37.1%). During conventional mobilisation, however, more than half of the patients (n = 18: 51.4%) did not receive any analgosedation or catecholamine. At the time of robot-assisted mobilisations, only thirteen patients (23.6%) were neither analgosedated nor did they need any catecholamine.

Eleven (84.6%) of the thirteen invasively ventilated patients in T1 had a tracheostomy and only two (15.4%) had a tube. During robot-assisted mobilisation (T2), significantly more of the 32 invasively ventilated patients (n = 24: 75.0%) were fitted with a tube than with a tracheostomy.

Table 4 shows the absolute and relative distribution of the variables ventilation mode and ventilation access differentiated by T1 and T2.

There were a total of 28 mentions of ingoing and outgoing tubes in T1 and 71 in T2. Table 5 shows the absolute frequencies sorted by drains, ingoing catheters, and extracorporeal therapy devices.

Table 5 Inlet and outlet drains, catheters, and extracorporeal therapy devices in T1 (conventional mobilisation) and T2 (robot-assisted mobilisation) (own presentation)

Inlet and outlet drains and catheters	Number/type	Survey point T1	Survey point T2
Chest drains	1	2	8
	2	2	8
	> 2	2	32
Pulmonary catheter	Yes	1	14
Extracorporeal devices	ECMO	1	0
	Haemodialysis	5	0
Other drains	1	3	13
	2	4	6
	> 2	8	0

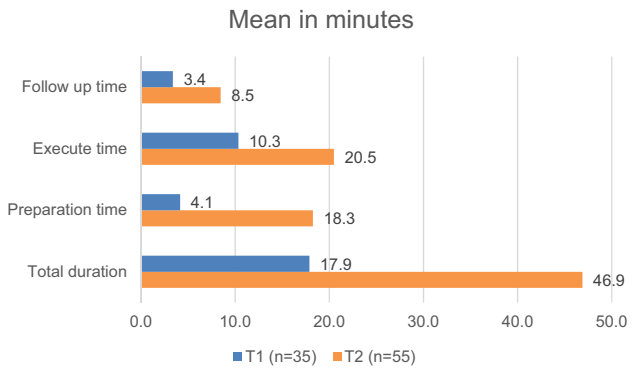

Fig. 4 Average time of preparation, execution, follow-up and total duration in minutes in T1 (conventional mobilisation) and T2 (robot-assisted mobilisation) (own presentation)

7.4 Work Organisation

The process-related data on the organisation of work were documented based on the time required in the process steps of preparation, execution, follow-up and the calculated total duration of mobilisation, the number of specialist staff mobilising, and the aids used as well as the application of kinaesthesia.

Significant differences were evident in the time required between conventional and robot-assisted mobilisation in all sub-steps of mobilisation. Figure 4 shows the median time required in minutes, differentiated by preparation, execution, follow-up, and total duration of mobilisation.

The Mann–Whitney *U* test was used to demonstrate significant and high effect sizes (in accordance with Cohen) [26] between the times required for conventional and robot-assisted mobilisation. The greatest difference between T1 (n = 35) and T2 (n = 55) was seen in the preparation time (see Table 6).

A bed sheet was used as a support during conventional mobilisation (n = 7) and a slide board was used in two cases while the users did not use any other aids besides the VEMOTION® during robot-assisted mobilisation. These aids were used to transfer patients in bed or to transfer them to another therapy device, such as a mobilisation or therapy chair. In three observations, patients were assisted in walking by a forearm walker.

In terms of staffing, two nurses were involved in most mobilisation cases at all survey points (T1 n = 20: 57.1%; T2 n = 42: 76.4%). In twelve cases (34.3%) a nurse mobilised the patients conventionally without the VEMOTION® (T1) without further staff support. By comparison, seven robot-assisted mobilisations (12.7%) were performed by a nurse without further staff support at survey point T2. Three or

Table 6 Results of the Mann–Whitney *U* test for process times (own presentation)

	Preparation time	Execution time	Follow-up time
Mann–Whitney *U* test	24.500	128.500	140.000
Z	− 7.778	− 7.002	− 6.841
Asymp. sig. (2-sided)	< 0.001	< 0.001	< 0.001
Effect severity r	0.82	0.74	0.72

Table 7 Back flexion in the thoracic and lumbar spine, absolute and relative frequencies in T1 (conventional mobilisation) and T2 (robot-assisted mobilisation) (own presentation)

Variable	Variation	Absolute/relative frequencies	
		Survey point T1 n = 35	Survey point T2 n = 55
Flexion Thoracic spine area	< 20 degrees	n = 12/34.3%	n = 21/38.2%
	20–60 degrees	n = 19/54.3%	n = 32/58.2%
	> 60 degrees	n = 4/11.4%	n = 2/3.6%
Flexion Lumbar spine area	Straight	n = 19/54.3%	n = 30/54.5%
	Bent	n = 14/40.0%	n = 25/45.5%
	Missing values	n = 2/5.7%	n = 0/0.0%

more persons were rather the exception during conventional (n = 3: 8.6%) and robot-assisted mobilisation alike (n = 6: 10.9%).

The use of kinaesthetic techniques during mobilisation was examined as well. There were no major differences between the mobilisation methods. Use of kinaesthesia was observed in six (17.6%) nurses during conventional mobilisation. Eight (15.4%) nurses used kinaesthetic techniques for mobilisation with the VEMOTION®.

7.5 Posture of the Mobilising Specialist Staff

The most frequent variation of each posture of the mobilising person was documented when observing the postures of the mobilising nurse.

Table 7 shows the flexion in the lumbar spine and thoracic spines of the users during survey points T1 and T2. Only a marginal difference in flexion in the lumbar spine was found between conventional (n = 14: 40.0%) and robot-assisted mobilisation (n = 25: 45.5%). Upper body inclination in the thoracic spine to 20–60 degrees was also nearly unchanged in T1 (n = 19) with 54.3% and in T2 (n = 32) with 58.2%. The lowest tilt of the upper body of < 20 degrees was observed in 38.2% of robot-assisted mobilisations (n = 21) which was similary frequent to that during conventional mobilisation (n = 12: 34.3%).

In the observation sheet, evasive movements of the upper body were defined as lateral flexion of the upper body, rotation at the waist, their combined movement, or no evasive movement. During fourteen conventional mobilisations (40.0%) and eighteen mobilisations with the VEMOTION® (33.3%), a combined evasive movement to the side and rotating at the waist was observed. Whereas in ten of the robot-assisted mobilisations (18.5%) an evasive movement was observed rotating exclusively at the waist, this movement was evident in six of the conventionally performed mobilisations (17.1%). No evasive movements were performed in twenty robot-assisted mobilisations (37.0%) and in nine conventional mobilisations (25.7%).

The observation of the leg posture was recorded based on the flexion or extension of the knees, the position of the feet in relation to each other, and the angle at which the mobilising specialist was standing in relation to the bed. The nurses stood at an angle of more than 90 degrees to the bed only once during both conventional and robot-assisted mobilisation (T1: 2.9%; T2: 1.9%). A position parallel to the bed was documented most frequently in 45 robot-assisted mobilisations (83.3%). This parallel position to the bed was also chosen most frequently by the nurses during conventional mobilisation (n = 26) with 74.3%.

In both forms of mobilisation, the knees of the mobilising persons were rather extended than bent, but in T1 (n = 26) to a higher proportion (78.8%) than during mobilisation with the VEMOTION® (n = 36: 65.5%). The fencer stance was recorded only once at T1 (2.9%), and during six robot-assisted mobilisations in T2 (11.1%). Most frequently, a parallel stance could be observed among the nurses during mobilisations (T1 n = 26: 74.3%; T2 n = 41: 75.9%).

The most noticeable difference in the observation of the postures was recorded in the position of the shoulders. Shoulder elevation was observed significantly less frequently in the users during robot-assisted mobilisation (T2). Figure 5 below shows that users pulled their shoulders upwards in two-third of cases during conventional mobilisation (n = 24), while users' shoulders remained in a neutral position in nearly 70% of robot-assisted mobilisations (n = 37).

7.6 Users' Subjective Assessments of Psychological Stress

The subjective assessment of psychological stress (PSaR) by the mobilising specialist staff during mobilisation was conducted using a 10-point numerical scale (0 = no stress, 10 = very severe stress). On average, the users reported psychological stress of 3.24 (± 5.76/3.24; SD = 2.27) at both survey points. At survey point T1, the mean was slightly lower (n = 35: 3.09 ± 3.91/3.09, SD = 1.884) than at survey point T2 (n

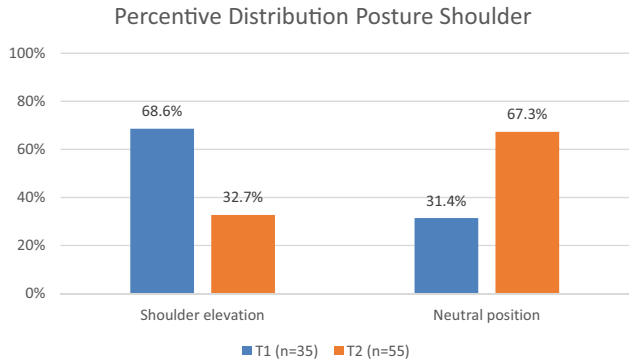

Fig. 5 Percentage distribution of the variable "shoulder elevation/neutral position" in T1 (conventional mobilisation) and T2 (robot-assisted mobilisation) (own presentation)

Table 8 Results of the Mann–Whitney *U* test for subjective assessment of psychological stress and relief in T1 (conventional mobilisation) and T2 (robot-assisted mobilisation) (own presentation)

	T1 PD with FWB (n = 16) PD without FWB (n = 19)	T2 PD with FWB (n = 37) PD without FWB (n = 18)
Mann–Whitney *U* test	143.000	291.000
Z	− 0.303	− 0.760
Asymp. Sig. (2-sided)	0.762	0.502

= 55: 3.35 ± 5.65/3.35; SD = 2.503). Using the Mann–Whitney *U* test, no significant differences at the 0.05 significance level were found between the two survey points T1 and T2 (U = 948.000; z =—0.121, p = 0.904).

Figure 6 displays the distribution of the subjectively assessed psychological stress (0 = no stress, 10 = very strong stress) differentiated based on the professional qualification of the nurses with and without additional training at survey points T1 and T2.

When differentiating based on the professional qualification of the nurses, the position measures in T2 showed marginal differences in robot-assisted mobilisation between the groups of nurses with and without specialist training. The Mann–Whitney *U* test shows no statistical significance here (see Table 8).

The correlation between years of intensive care experience and the age of the nurses and their subjective assessment of psychological stress and relief (PSaR) was tested using the Kendall-Tau-b correlation coefficient. There were no significant results in T1 during conventional mobilisation. However, at the point of the survey T2, a weak negative correlation was found between the nurses' time of experience in an intensive care unit and their perception of psychological stress. The observed nurses with a longer period of

Table 9 Correlation coefficient Kendall Tau b of PSaR with age and ICU-experience of users in years in T1 (conventional mobilisation) and T2 (robot-assisted mobilisation) (own presentation)

Survey point	Age in years of user	ICU experience of user
T1	− 0.141	− 0.204
T2	− 0.040	− 0.270**

**The correlation is significant at the 0.01 level (two-sided)

experience in intensive care showed subjectively lower psychological stress during robot-assisted mobilisation. Table 9 displays the results of the correlation coefficient Kendall Tau b of the variable "Subjective assessment of psychological distress and relief" (PSaR) with age and years of intensive care experience for the mobilising nursing staff (users) at both survey points.

Furthermore, the subjective assessment of the feasibility of the mobilisation was additionally requested using a 7-point numerical scale (0 = not feasible at all, 7 = very feasible) at the point of the survey T2 to detect any changes in the psychological stress during robot-assisted mobilisation with the VEMOTION®.

When considering all users without differentiation in professional qualification, it was found that individuals who predominantly rated the feasibility of mobilisation with the VEMOTION® as high assessed themselves as less psychologically stressed than individuals who felt less able to perform mobilisation with the VEMOTION® (PSaR/feasibility: Kendall Tau b =—0.435, p = < 0.01, n = 54).

Regarding assessment of the feasibility of robotic mobilisation with the VEMOTION® in survey T2 between the groups of nurses with and without specialist training (PD with FWB: n = 36; PD without FWB: n = 18), however, the Mann–Whitney *U* test showed no significant differences (U = 313.500, z =—0.197, p = 0.844).

8 Results of the Follow-Up

The opportunity was taken to conduct nine observations of routine users of the robotic system as part of a follow-up. A total of nine robot-assisted mobilisations of routine users could be observed. Despite the small number of cases, the results will nevertheless be reported for selected variables in the following descriptive and in comparison with the observations of survey point T2.

Patients in the follow-up group had an average age of 56.2 years (± 11.8/6.2; SD = 5.45), predominantly female (n = 77.8%), and an average BMI of 22.9 (± 3.1/1.9; SD = 1.45).

Three out of nine (33.3%) nurses had specialist training (PD with FWB), with an overall average age was 32.6 years

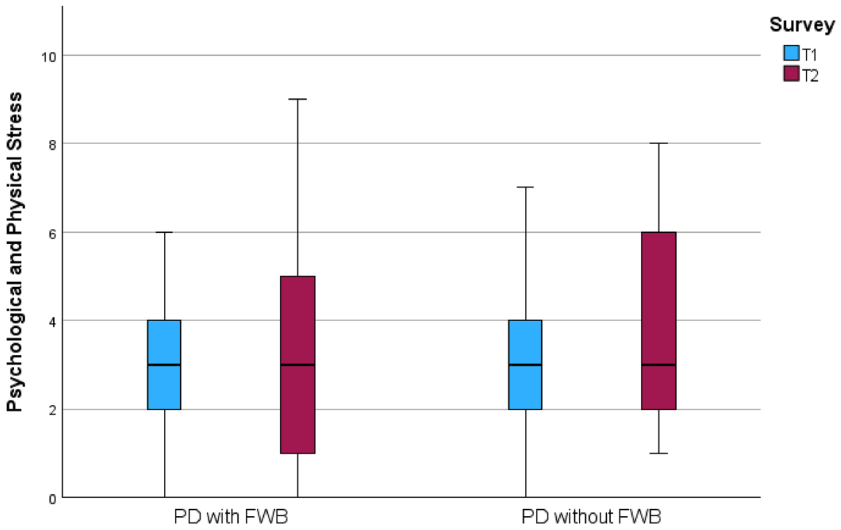

Fig. 6 Distribution of subjective psychological stress and relief sorted by occupational qualification in T1 (conventional mobilisation) and T2 (robot-assisted mobilisation) (own presentation)

(± 3.4/5.6; SD = 2.60). Notably, nurses with further training were slightly younger on average (n = 6: 32.3 ± 3.7/5.3; SD = 4.73) than nurses without further training in ICU (n = 3: mean = 32.7 ± 1.3/1.7; SD = 1.37) but had longer intensive care experience (mean = 10.0 ± 2.0/4.0; SD = 3.46) compared to those without further training (mean = 4.3 ± 1.7/1.3; SD = 1.37).

Regarding medication, seven patients were analgosedated (77.7%), two of whom required catecholamines and two patients (22.2%) required no medication. All four invasively ventilated patients were on a tube. Four patients received no ventilatory therapy and one patient was ventilated non-invasively with an NIV mask.

There were a total of 22 mentions of inflow and outflow drains or catheters. In all cases of the follow-up, hemodialysis and two or more chest drains were documented.

There were nearly no differences between the follow-up group and the observations in the T2 group regarding the average time for preparation, implementation, follow-up and total duration (total duration: T2: 46.9 min vs. follow-up group: 46.3 min).

Regarding the number of mobilising specialists, in 77.8% (n = 7) only one person without further support performed the mobilisation with the VEMOTION®. This was the case for non-routine users in only seven mobilisations (12.7%) at the time of the survey T2. Kinaesthetic techniques were also not used in the follow-up group (n = 6, 75.0%).

An upright back position was observed more frequently in the postures during the follow-up compared to the survey time point T2. Table 10 shows the flexion in the lumbar and thoracic spine of the users during the survey times T2 and follow-up.

Regarding the position of the shoulders, a neutral shoulder position was observed most frequently among the experienced users in the follow-up, as at the time of the T2 survey.

Table 10 Back flexion in the thoracic and lumbar spine, absolute and relative frequencies in T2 (robot-assisted mobilisation) and follow-up (own presentation)

Variable	Variation	Absolute/relative frequencies	
		Survey point T2 n = 55	Follow-up n = 9
Flexion Thoracic spine area	< 20 degrees	n = 21/38.2%	n = 5/55,6%
	20–60 degrees	n = 32/58.2%	n = 3/33.3%
	> 60 degrees	n = 2/3.6%	n = 1/11.1%
Flexion Lumbar spine area	Straight	n = 30/54.5%	n = 7/77.8%
	Bent	n = 25/45.5%	n = 2/22.2%

This was even the case for eight out of nine experienced users in the follow-up (88.9%).

In the subjective assessment of the routine and nurses on their psychological stress during mobilisation with the VEMOTION®, only marginal deviations in the scatter measures were noticeable compared to group T2 (T2 n = 55: mean = 3.35 ± 5.65/3.35; SD = 2.50; follow-up group n = 9: mean = 3.22 ± 0.6.78/3.22; SD = 3.07). Regarding the subjective assessment of feasibility in connection with psychological stress, there was a higher correlation measure among the routine users in the follow-up (Kendall Tau b = − 0.743, p = < 0.01) than among the non-routine users in group T2 (Kendall Tau b = − 0.435, p = < 0.01).

9 Discussion

This artic provides an overview of the possible physical and psychological burdens and reliefs for the mobilising specialist staff in conventional and robot-assisted early mobilisation.

There was a significant correlation between the psychological stress perceived by the mobilising personnel and the

feasibility of robot-assisted early mobilisation. Psychological stress perception was lower when early mobilisation was assessed as feasible (PSaR/feasibility: Kendall Tau b =—0.435, p = < 0.01, n = 54). This seems to remain unchanged even when routine use of the robotic system has already begun (Follow-up group: Kendall Tau b =—0.743, p = < 0.01). This can be explained based on the secondary evaluation of a stress stimulus in the sense of the transactional stress model in accordance to Lazarus [27]. The model describes that whether a specific stimulus leads to a stress response or not depends on the individual's evaluation using three processes (primary, secondary, and tertiary evaluation). Secondary assessment involves evaluating one's own coping skills and opportunities, where self-efficacy, i.e., confidence in one's abilities, plays a relevant role [28]. Applied to the use of robot-assisted early mobilisation, this means that individuals who feel confident in using the robotic system or perceive its application as feasible rate themselves as less psychologically stressed.

The implementation of conventional early mobilisation seems to be hindered by factors such as tube or ventilator access or excessive analgosedation, among other things [29]. These barriers did not apply to robot-assisted early mobilisation investigated in this study. Significantly more patients in the robot-assisted early mobilisation group were ventilated invasively with a tube (75.0%) in this study than in conventional early mobilisation (15.4%). In addition, significantly more robot-mobilised patients were analgosedated (T2: 60.0%; T1: 11.4%). Furthermore, significantly more patients with drains and special accesses, such as a pulmonary catheter, chest drains, or extracorporeal therapy devices (ECMO, hemofiltration) were mobilised with the robotic system than with the conventional method (T1: n = 28; T2: n = 71). In the follow-up group, all patients had at least one drainage and one haemodialysis. This shows that the robotic system can also be used for seriously ill patients without posing additional challenges for the nursing staff.

We included data on nursing shifts based on findings from a preliminary studie, which indicated that mobilisations were conducted during both early and late shifts. The morning hours were often described as particularly stressful [15], leading us to include this variable in our dataset to analyse if this stress impacted early mobilisation concerning shifts. Our results show that most mobilisations, both conventional and robot-assisted, took place during the afternoon shift, suggesting that in our study, the preference was for the late shift where users had more time for mobilisations.

An average of two specialists were involved in each mobilisation in both conventional and robot-assisted early mobilisation. This need for personnel, which, in the context of a possibly existing personnel shortage, has already been examined as a barrier to the implementation of conventional early mobilisation, should also be critically assessed for robot-assisted early mobilisation [29]. However, the results in the follow-up group show that in 77.8% of cases only one nurse was involved in robot-assisted mobilisation. In comparison, only 12.7% of mobilisations in T2 were performed by only one nurse. This suggests that routine users can utilise the system more efficiently, which could lead to a reduction in staff workload in the long term.

The study situation, with only nurses performing the mobilisations, does not correspond to the results of studies that have investigated responsibilities in the performance of early mobilisation. Nydahl et al. [14] and Mehler-Klamt et al. [15] show that both nurses and physiotherapists share equally responsibility for the mobilisation of critically ill intensive-care patients. Despite the recognised value of interprofessional collaboration in intensive patient mobilisation, the involvement of physiotherapists in this study was not possible. This was not due to a lack of interest or recognition of the system's potential benefits, but rather a direct result of strategic decisions at the departmental level, prompted by acute staff shortages and an already heavy workload.

Compared with robot-assisted early mobilisation, the times for preparation, performance, and follow-up, as well as the total duration of conventional early mobilisation, were each significantly shorter than robot-assisted early mobilisation (total duration: T1: mean = 17.9 min; T2: mean = 46.9 min). The large amount of time required, in particular in relation to the preparation of robot-assisted early mobilisation (T1: mean = 4.1 min; T2: mean = 18.3 min), is attributed to securing the safety belts and docking the robot to the hospital bed. However, the fact that robot-assisted mobilisation took an average of twenty minutes can be considered positive for the patients since it adhered to the time specified by the S3 guideline [2].

The lack of statistical effects of qualifications or competence levels on the perception of stress by care staff is consistent with other research studies [30]. However, the professional experience of specialist staff appears to influence their psychological stress perception. For instance, this study revealed that nurses with more extensive intensive care experience rated themselves as less psychologically stressed when using robot-assisted mobilisation than nurses with less intensive care experience (intensive care experience/PSaR: Kendall Tau b = − 0.270, p = < 0.01). This indicates that less experienced nurses might require more support and training to adapt to the new system effectively. Providing additional training sessions, mentorship programmes, and stress management resources could help mitigate the psychological stress experienced by less experienced nurses. Ensuring that all staff members, regardless of their experience level, are adequately supported during the transition to using robotic systems is crucial for the successful implementation of such technologies and for maintaining a healthy and productive working environment. In the follow-up group, only three out

of nine nurses had specialised training (33.3%). On average, these nurses were slightly younger but more experienced in intensive care than their colleagues without further training. This indicates that experience in intensive care plays an important role in the successful use of the robotic system.

The literature often reports a lack of aids for patient mobilisation, which is perceived as a major obstacle by mobilising specialist staff [15, 31]. This study demonstrated that mobilisation with the VEMOTION® did not require the use of any additional aids. In contrast, different devices were used to transfer patients to mobilisation chairs in conventional mobilisation. This can be challenging not only due to a potential lack of available aids but also because transferring to a therapy device can pose a safety risk to all involved parties (specialist staff and patients) [32, 33]. The postures adopted during the transferring to the therapy device are often performed incorrectly, which can lead to back pain and, subsequently, to musculoskeletal disorders [32, 33].

There were few relevant differences between robot-assisted and conventional mobilisations in terms of posture of the mobilising specialist staff. During robot-assisted mobilisation, the upper body was bent less than 20 degrees in the thoracic spine region with similar frequency compared to conventional mobilisation (T1: 34.3%; T2: 38.2%). An upper body tilt can increase strain on the back muscles and is, therefore, a potential risk factor for back pain [34]. Rotation from the waist was also observed with a similar frequency in robot-assisted and conventional mobilisation (T1: 17.1%; T2: 18.5%). Notably, robot-assisted mobilisation exhibited fewer evasive movements overall compared to conventional mobilisation (T1: 25.7% vs. T2: 37.0%). This is remarkable because the robotic system is controlled, especially during preparation and follow-up, via a monitor that requires repeated turning for the next step of execution. Evasive movements such as rotation can exert additional strain on the lumbar region. This strain can lead to lower back pain and lumbar conditions such as herniated discs and other musculoskeletal disorders [35–37]. Therefore, it is positive that robot-assisted mobilisation is often performed without evasive movements.

In general, care staff are at an increased risk of work-related musculoskeletal disorders (WMSD), which can be caused by incorrect movement patterns, among other factors. In addition, mental pressure, such as stress, appears to have a positive effect on the development of musculoskeletal disorders (MSD) [38]. The shoulder area, neck, and lower back are particularly susceptible [38]. A risk for manifestation in the shoulder area, aside from the basic physical strain, is particularly associated with mobilisation methods involving patient transfers [32]. Therefore, incorrect movements, such as rotation or shoulder elevation, should be avoided at all costs in work processes. Shoulder elevation occurred less frequently during robotic mobilisation in this study than during conventional mobilisation (Shoulder protrusion in T1: 68.6% vs. shoulder protrusion in T2: 32.7%), which can be viewed positively in relation to the development of WMSD. In general, kinaesthesia can support the avoidance of incorrect movements and thus reduce the risk of MSDs [39]. Kinaesthesia was rarely used within this study, both in robotic and conventional mobilisation (T1: 17.6%; T2: 15.4%).

More ergonomic patient handling can be achieved in the step or fencer stance by shifting one's weight, thereby reducing back strain [33]. The fencer stance was more frequently observed at observation points T2 than at T1 (fencer stance T1: 2.9%; T2: 1%). However, it cannot be definitively concluded from the results of this study whether this is directly related to the robotic system. The foot position should generally be chosen to prevent rotation in the lumbar region, as mentioned above. Additionally, bending the knees during mobilisation helps alleviate strain on the back [33]. This was observed less frequently than knee extension in both conventional and robot-assisted mobilisation. The follow-up results show that experienced users of the robotic system adopted an upright posture more frequently and raised their shoulders less often. This could indicate better ergonomics and less physical strain. The subjective strain of the carers remained largely unchanged, but the correlation between perceived feasibility and mental strain was higher for routine users (T2: Kendall Tau b =—0.435, $p = < 0.01$ vs. follow-up: Kendall Tau b = -0.743, $p = < 0.01$). This supports the assumption that familiarisation with the system reduces subjective strain.

Overall, robot-assisted mobilisation was more ergonomic and less stressful for the musculoskeletal system.

10 Limitations

The original goal of exclusively observing early mobilisations starting within the first 72 h after admission to the intensive care unit [2] could not be consistently achieved due to the restrictions caused by the Covid-19 pandemic. Teams experienced increased turnover as nurses from other areas, who were working on a limited basis due to the pandemic, were deployed to the project ICUs in a supportive capacity. This resulted a lack of consistency in the introduction to the VEMOTION® robotic system and within the nursing team.

Furthermore, it was not possible to instruct physiotherapists in the robotic system and thus include them in the observations for staffing reasons. Thus, only nurses could be instructed and observed, which contradicts the fact that both nurses and physiotherapists are considered mobilising specialist staff [14, 15]. This limitation is particularly noteworthy as it contrasts with the interprofessional approach typically advocated in mobilisation of intensive-care patients, where

both nursing and physiotherapy professionals are deemed essential [14, 15].

Additionally, this is a monocentric study conducted in a university hospital. The perspective of several university hospitals as well as hospitals with different levels of care could not be considered.

Due to use of non-participant observation, it cannot be ruled out that the study participants adapted their behaviour to the research situation, potentially affecting the results. However, obtaining informed consent within the ethical framework necessitated this approach.

The observation sheet underwent checks for initial content validity and intercoder reliability based on a systematic literature search, pretest, and consensus by a panel of experts. Therefore, further research is required to conduct psychometric tests on the quality and reliability of the data collection instrument.

Comparability between conventional and robot-assisted mobilisation also cannot be fully illustrated, as the movements generated by the robotic system cannot comprehensively replicate conventional mobilisation. Therefore, mobilisation to sitting, walking, or standing were chosen because the robotic system can perform verticalisation with leg movement and these conventional mobilisations are closest to the movement of the robot.

In comparison to survey point T1, feasibility was only additionally queried for point T2 in the form of a 7-level scale in order to evaluate testing of the new device in terms of feasibility from the users' perspective.

11 Recommendations for Further Research and Practice

Based on the results regarding physical stress, it is recommended to continuous training in kinaesthesia for mobilising specialist staff. This training helps to manage muscle work, which is a relevant concern both in conventional and robot-assisted mobilisation. Furthermore, when introducing a robotic system, attention should be given to regular use to establish a routine in handling the system. Routine seems to reduce psychological stress and increase user acceptance of robotic systems. Apart from this, all mobilising occupational groups, including physiotherapists, should be familiar with the use of the robotic system for early mobilisation to promote multi-professional cooperation. This is because mobilising intensive-care patients can be viewed as a multi-professional task and thus requires the perspective of physiotherapy, which can assess movement patterns much better than the nursing staff.

In this study, a follow-up with nine observations of routine users of the robotic system was conducted. The follow-up results are promising and indicate that the robotic system can be a useful addition to conventional mobilisation in the long term. The increase in efficiency and the potential reduction in physical strain for users are important advantages that should be investigated further. For future studies, it would be useful to observe a larger sample of routine users.

A multicentric study would also provide a broader perspective on the burden and relief experienced. Furthermore, examining the experiences in a qualitative design should be reconsidered to make the experiences of VEMOTION® users more transparent and to better understand the reasons for non-acceptance or acceptance.

12 Conclusion

The fact that the VEMOTION® robotic system serves as both a hospital bed and a therapy device offers numerous advantages that positively impact the workload of the care staff. There is no need for patient transfer to a therapy device, which is associated with high safety risks, and eliminates the related movement sequences, often performed incorrectly and linked to back pain. Moreover, neither a ventilator tube nor patient analgesia appears to pose obstacles to robot-assisted mobilisation. Additionally, mobilisation with the VEMOTION® requires no use of additional aids, which are typically in short supply on the wards.

Robotic early mobilisation with the VEMOTION® seems to reduce physical strain since many physically demanding movements are eliminated, and the mobilising specialist staff only need to assist with mobilisation before and after. However, the lengthy preparation and follow-up times for robotic mobilisation can be seen as an additional effort that complicates integration into the daily routine. This may lead to reduced usage of the system and can impact user acceptance.

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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.

Declarations

Conflict of interests The authors declare that they have no competing interests.

Ethical 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. 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.

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