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Bridging the Awareness-Application Gap in Emerging Rehabilitation Technologies: A Cross-Sectional Survey of Rehabilitation Trainees

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ABSTRACT

Background: Emerging rehabilitation technologies are reshaping rehabilitation assessment, intervention, monitoring, and service delivery. However, the extent to which rehabilitation trainees are prepared to understand and use these technologies remains insufficiently characterized. This study aimed to evaluate rehabilitation trainees' awareness, practical use, exposure depth, self-perceived application competence, perceived barriers, and educational support needs related to emerging rehabilitation technologies.

Methods: A cross-sectional questionnaire survey was conducted among rehabilitation-related trainees and early-career respondents. The questionnaire assessed demographic characteristics, awareness and self-reported practical use of seven technology categories, technology learning interest, exposure to technology-related knowledge and practice, self-perceived application competence, contextual and competency-related barriers, and preferred educational supports. Descriptive statistics were used to summarize the data. Awareness-application gaps were calculated as percentage-point differences between awareness and self-reported practical use. Exact McNemar tests and Benjamini-Hochberg adjustment were used for exploratory paired comparisons where applicable. Internal consistency of multi-item scales was assessed using Cronbach's alpha.

Results: A total of 135 valid questionnaires were analyzed. Awareness was highest for wearable devices, rehabilitation robots, and intelligent rehabilitation assessment or training software, whereas self-reported practical use remained substantially lower across all technology categories. The largest awareness-application gaps were observed for brain-computer interface technology (31.86%), virtual reality (VR) rehabilitation (29.63%), intelligent rehabilitation assessment or training software (28.85%), and wearable devices (28.15%). Most participants expressed at least some interest in technology-related learning, but structured exposure and operational practice remained limited. Contextual barriers were perceived at a near-moderate level, with rapid technology iteration and insufficient training/practical application showing the highest mean scores. The most frequently reported competency-related barriers were lack of learning resources and inadequate proficiency in operating new equipment. Participants most strongly preferred basic training equipment courses and integration of technology equipment content into existing courses.

Conclusion: Rehabilitation trainees showed meaningful interest and partial awareness of emerging rehabilitation technologies, but awareness was not consistently translated into self-reported practical use, supervised exposure, or clinical learning. Curriculum reform should move beyond technology introduction and provide progressive, practice-oriented, clinically integrated training to support technology-ready rehabilitation competence.

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1. Introduction

Rehabilitation is increasingly recognized as a core component of health systems and universal health coverage. The global need for rehabilitation is driven by population ageing, the rising prevalence of chronic non-communicable diseases, improved survival after acute injury and severe illness, and the continuing burden of disability across the life course [1]. The World Health Organization defines rehabilitation as a set of interventions designed to optimize functioning and reduce disability in individuals with health conditions in interaction with their environment [2-3]. Within this broad framework, rehabilitation is not limited to restoring physical capacity after injury; it also supports communication, cognition, respiratory function, participation, independence, and quality of life. As rehabilitation needs expand, health systems face persistent shortages in service capacity, equipment, trained personnel, and access to timely, continuous, person-centered care [4-5].

Technology-oriented rehabilitation has emerged as one response to this growing demand. Rehabilitation robots can provide repetitive, task-specific, intensive, and quantifiable training; wearable devices can support motion capture, physiological monitoring, home-based follow-up, and objective outcome measurement; virtual reality (VR) systems can create motivating and task-oriented environments for motor and cognitive training; telerehabilitation can extend service delivery beyond hospitals and clinics; brain-computer interfaces and brain regulation approaches have expanded the possibility of neurotechnology-assisted training; and intelligent rehabilitation assessment or training software can support data-driven evaluation, feedback, and individualized planning [6-12]. These technologies differ in maturity, cost, required infrastructure, clinical indications, evidence strength, and regulatory pathway, but they share a common educational implication: rehabilitation practitioners increasingly need to understand not only therapeutic principles, but also device operation, data interpretation, safety management, patient communication, and most importantly, technology-clinical integration.

At the educational level, these developments challenge traditional rehabilitation curricula. Conventional training has often emphasized anatomy, pathology, therapeutic techniques, manual skills, communication, and clinical reasoning. These foundations remain essential, but they are no longer sufficient when rehabilitation services increasingly involve complex human-machine interaction and technology-generated data. A trainee may need to decide whether a patient is appropriate for robot-assisted gait training, how to adjust a wearable sensor protocol for a frail older adult, how to explain VR tasks to a patient with cognitive impairment, or how to interpret an automated assessment report without over-relying on the device. These scenarios require a blend of clinical judgment, technical literacy, risk awareness, and reflective decision-making. Therefore, education must prepare learners to become critical users of technology rather than passive observers of technological novelty.

Despite rapid technological development, clinical implementation remains uneven. Many technologies that are frequently discussed in research, industry, and policy have not been fully incorporated into routine rehabilitation education or daily clinical learning. A trainee may have heard of rehabilitation robots, VR rehabilitation, or brain-computer interfaces, yet may have few opportunities to observe real use, operate equipment, interpret output data, or understand how technology changes clinical decision-making. This gap is particularly important in rehabilitation education because future professionals develop professional identity, clinical reasoning, safety habits, and confidence through repeated exposure and practice. When emerging technologies remain only conceptual content, students may develop awareness without operational competence, or interest without readiness for clinical integration.

The gap between awareness and application also intersects with broader issues in digital health competency. Recent digital health education frameworks emphasize that learners need more than technical familiarity; they require competencies in communication, workflow integration, data literacy, safety, ethics, equity, and continuous learning [13,14]. In rehabilitation, these competencies may be even more complex because technology use is often embodied, task-based, and highly patient-specific. For example, the safe use of robotic exoskeletons requires understanding indications, contraindications, setup, patient tolerance, therapist supervision, emergency procedures, and progression principles. Similarly, using wearable data for rehabilitation planning requires knowledge of signal quality, clinically meaningful metrics, data limitations, and how data should influence goals and intervention strategies. Therefore, educational research should evaluate not only whether trainees know a technology, but also whether they have sufficient exposure and practice to use it meaningfully.

Existing studies have examined clinicians' attitudes toward rehabilitation technologies, perceptions of VR rehabilitation, telerehabilitation adoption, and digital health competencies among health professionals [8,9,13,14]. However, evidence focused on rehabilitation of trainees remains limited, especially regarding the combined assessment of awareness, self-reported practical use, exposure depth, perceived application competence, perceived barriers, and preferred educational supports across multiple technology categories. Understanding these dimensions can help educators identify where technology-oriented rehabilitation training should be strengthened and how curricula can progress from introductory knowledge to practice and clinical readiness.

Accordingly, this cross-sectional survey investigated rehabilitation trainees' awareness and practical use of seven categories of emerging rehabilitation technologies, quantified the awareness-application gap, evaluated learning interest and depth of exposure, assessed self-perceived technology application competence, and identified barriers and educational support needs. We aimed to provide an empirical basis for improving rehabilitation education and for designing technology-integrated training models that better prepare trainees for contemporary rehabilitation practice.

2. Materials and methods

2.1 Study design and reporting standard

This study used a cross-sectional questionnaire design to assess rehabilitation trainees' awareness, self-reported practical use, learning exposure, perceived competence, barriers, and educational needs related to emerging rehabilitation technologies. The study was designed as an exploratory educational survey and was reported with reference to the Strengthening of the Reporting of Observational Studies in Epidemiology (STROBE) principles for cross-sectional studies [15]. The aim was to describe current educational status and identify curriculum-relevant gaps; no intervention was conducted, and no clinical patient data were collected.

The core analytic logic of the study was to distinguish technology awareness from self-reported practical application. Awareness was defined as having heard of, learned about, or recognized a given technology category. Practical use was defined as a self-reported binary indicator of whether respondents had used, operated, or participated in the application of the technology in learning, internship, clinical observation, work, or related practice. The questionnaire did not ask respondents to distinguish on-site observation, assisted operation, supervised use, and independent use. Therefore, practical use in this study should be interpreted as self-reported practical exposure or participation rather than objectively verified operational competence. The awareness-application gap was calculated to quantify the difference between awareness and this self-reported practical-use indicator.

2.2 Study setting, participants, and recruitment

Participants were recruited from rehabilitation-related educational and training contexts. Eligible respondents were rehabilitation trainees or early-career individuals with rehabilitation-related backgrounds, including students and respondents from specialties such as physical therapy, occupational therapy, speech therapy, respiratory therapy, rehabilitation engineering, hyperbaric oxygen therapy, medical radiologic technology, and other rehabilitation-related directions. Respondents were invited to complete an anonymous questionnaire voluntarily. No incentives linked to academic assessment were provided.

The inclusion criteria were as follows: (1) being enrolled in or having experience with rehabilitation-related education, internship, or early professional practice; (2) being able to understand the questionnaire content; and (3) providing informed consent before participation. Questionnaires with incomplete key outcome information, obvious response patterns, or duplicate submissions were excluded. A total of 135 valid questionnaires were included in the final analysis. The final sample size was considered appropriate for an exploratory descriptive survey aimed at generating curriculum-improvement evidence rather than estimating population-level prevalence with high precision.

2.3 Questionnaire development and survey domains

The questionnaire was developed according to the study objectives, the categories of technology commonly discussed in contemporary rehabilitation, and the educational dimensions relevant to trainees' technology readiness. The instrument included four main domains. The first domain collected demographic and educational information, including gender, age, participant identity, and specialization.

The second domain assessed awareness and practical use of seven categories of emerging rehabilitation technologies: intelligent rehabilitation assessment or training software, rehabilitation robots, telerehabilitation, VR rehabilitation, wearable devices, brain-computer interface technology, and brain regulation technology. The selection of technology categories was intended to reflect the range of tools that trainees may encounter in modern rehabilitation education and clinical environments. The categories included technologies with relatively direct operational features, such as robots and wearable devices, as well as technologies that may require stronger conceptual or data-related understanding, such as intelligent assessment software and brain-computer interfaces. This design allowed the survey to explore whether trainees' awareness and application differed across technologies with different levels of accessibility, visibility, and technical complexity.

The third domain evaluated frequency and depth of exposure to technology-related learning and practice. Items covered learning interest, exposure to technology-related knowledge, attention to technological developments, self-reported understanding, experiential or operational exposure, operation of technology, clinical application of technology, and technical data analysis.

The fourth domain assessed self-perceived barriers and preferred educational supports. Contextual barriers included rapid technology iteration, insufficient training and practical application, insufficient equipment availability, and low patient acceptance of emerging technologies. Competency-related barriers and educational support preferences were assessed using multiple-response items.

2.4 Outcome measures

The primary descriptive outcomes were awareness rate, self-reported practical use rate, and awareness-application gap for each technology category. Awareness and practical use were coded as binary variables for each category. Because the survey did not further classify the level of practical participation, the practical use rate was not treated as a direct measure of independent operational competence. The gap was expressed as the difference in percentage points between awareness and self-reported practical use. Larger values indicated that a technology was recognized by more respondents than had practical exposure to it.

Exposure, understanding, and self-perceived competence items were rated on a five-point ordinal scale. Response options represented increasing frequency, depth, or perceived ability, ranging from very few or no, very little, generally, a lot, to quite a lot. For descriptive interpretation, scores of 1-2 were summarized as low-score responses and scores of 4-5 as high-score responses. Mean and standard deviation were calculated for each item to allow comparison across domains, while distributions were also reported to preserve the ordinal nature of the scale.

For barrier items, higher scores indicated a higher perceived level of barrier. Multiple-response items were used to identify specific competency-related barriers and preferred educational support formats. These items were summarized as frequencies and percentages of respondents selecting each option. Internal consistency was assessed for the exposure/competence item set and for the contextual barrier item set. Corrected item-total correlations and Cronbach's alpha if item deleted were calculated to evaluate whether individual items contributed consistently to the corresponding composite construct.

2.5 Data collection and quality control

Data were collected using a self-administered questionnaire. Before answering, participants were informed of the study purpose, the voluntary nature of participation, and the anonymous handling of responses. To reduce misunderstanding, technology categories and response options were presented in clear and accessible language. The questionnaire did not collect identifying information that would directly reveal participants' identity.

Quality control was conducted during data cleaning. Responses were checked for completeness of key variables, logical consistency, and duplicate submissions. For multiple-response questions, each selected option was treated as an independent binary indicator. Missing values were not imputed because the analysis was descriptive and the final valid dataset contained complete information for the principal analyses.

2.6 Statistical analysis

Categorical variables were summarized as frequencies and percentages. Continuous or ordinally scored items were summarized as mean ± standard deviation, and mean values were considered when interpreting central tendency. Awareness-application gaps were calculated as absolute percentage-point differences. Because awareness and self-reported practical use were paired responses within the same participants, exact McNemar tests were used for exploratory paired comparisons when the contingency table structure allowed meaningful testing. To reduce the risk of false-positive findings caused by multiple comparisons, Benjamini-Hochberg adjustment was applied to the exact McNemar p values. Cronbach's alpha was used to assess internal consistency for multi-item scales. Corrected item-total correlations were interpreted as evidence of whether an item aligned with the overall construct. All analyses were conducted using standard statistical procedures for descriptive cross-sectional survey data. A two-sided p-value < 0.05 was considered statistically significant for exploratory analysis, while emphasis was placed on effect size, distribution patterns, and educational interpretation rather than on hypothesis testing alone.

2.7 Ethical considerations

The study involved an anonymous educational questionnaire and did not include clinical interventions or collection of patient information. Participation was voluntary, and informed consent was obtained electronically before questionnaire completion.

3. Results

3.1 Participant characteristics

A total of 135 valid questionnaires were included in the analysis. Among the respondents, 45 participants (33.33%) were male, and 90 (66.67%) were female. Most participants were undergraduate students majoring in rehabilitation-related disciplines, and 75.56% of them were aged 20 years or younger. Second-year undergraduates accounted for 42.96% of the sample, followed by first-year undergraduates (34.81%), third-year undergraduates (17.78%), and other respondents, including early-career practitioners or participants with different educational backgrounds (4.44%). The participants represented multiple rehabilitation-related professional directions, including physical therapy, occupational therapy, speech therapy, respiratory therapy, rehabilitation engineering, hyperbaric oxygen therapy, medical radiologic technology, and other specialties. Speech therapy accounted for the largest proportion of respondents (18.52%), followed by physical therapy (17.78%) and medical radiologic technology (14.81%). Detailed demographic and educational characteristics are presented in Table 1.

3.2 Awareness, self-reported practical use, and awareness-application gap of emerging rehabilitation technologies

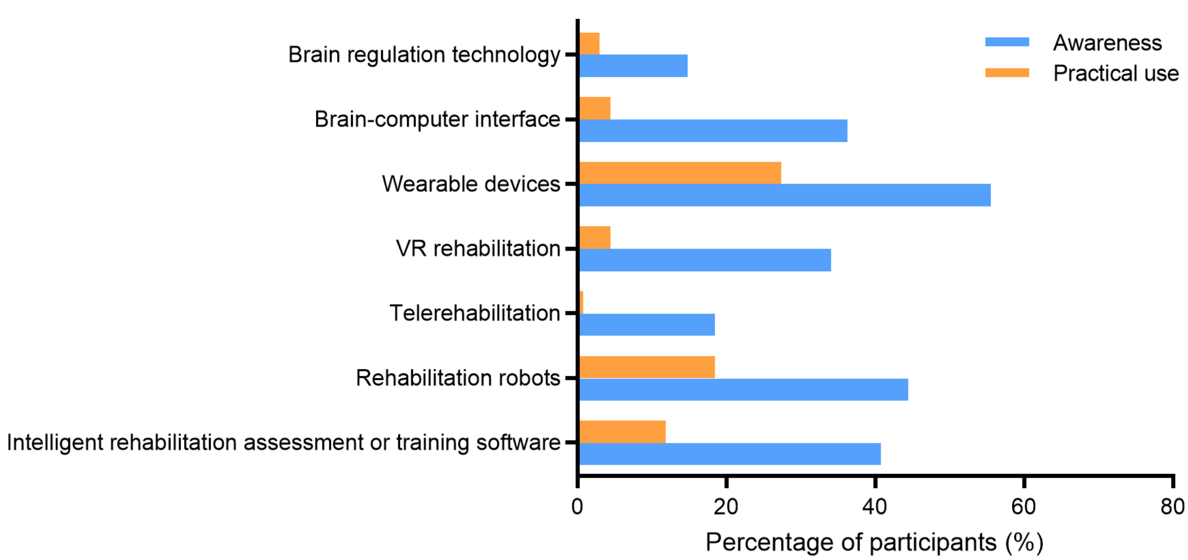
As shown in Table 2, the awareness and self-reported practical use of emerging rehabilitation technologies varied markedly across different technology categories. The highest awareness rate was observed for wearable devices (55.56%), followed by rehabilitation robots (44.44%) and intelligent rehabilitation assessment or training software (40.74%), all of which ranked in the top three. Moderate levels of awareness were reported for brain-computer interface technology (36.30%) and VR rehabilitation (34.07%). In contrast, relatively lower awareness was observed for telerehabilitation (18.52%) and brain regulation technology (14.81%). Wearable devices were the most commonly used technologies, reported by 27.41% of participants, followed by rehabilitation robots (18.52%) and intelligent rehabilitation assessment or training software (11.85%). By contrast, only 4.44% of participants reported practical use of VR rehabilitation and brain-computer interface, while brain regulation technology was used by only 2.96% of participants. Notably, only 0.74% of the respondents reported practical experience with telerehabilitation. Nevertheless, the self-reported practical use rates of these technologies were substantially lower than their corresponding awareness levels, revealing a notable implementation gap (Figure 1).

These findings indicate that emerging rehabilitation technologies have entered the awareness of rehabilitation trainees to some extent but have not been sufficiently translated into hands-on learning or clinical practice. The largest awareness-application gap was identified for brain-computer interface, with a gap of 31.86 percentage points, followed by VR rehabilitation at 29.63 percentage points, intelligent rehabilitation assessment or training software at 28.85 percentage points, and wearable devices at 28.15 percentage points. Rehabilitation robots showed a gap of 25.92 percentage points, while telerehabilitation showed a gap of 17.78 percentage points. The smallest gap was observed for brain regulation technology, at 11.85 percentage points. Exploratory paired comparisons further supported the existence of this gap. Statistically significant differences between awareness and self-reported practical use were observed for all the technology categories. These results suggest that some technologies are relatively well recognized by

Table 1. Demographic and Baseline Characteristics of Participants

		Number	Percentage (%)
Total		135	100
Gender			
	Female	90	66.67
	Male	45	33.33
Age			
	~20	102	75.56
	20~25	28	20.74
	25~	5	3.7
Participant identity			
	First-year undergraduate	47	34.81
	Second-year undergraduate	58	42.96
	Third-year undergraduate	24	17.78
	Others	6	4.44
Specialization			
	Physical therapy	24	17.78
	Occupational therapy	4	2.96
	Speech therapy	25	18.52
	Respiratory therapy	18	13.33
	Rehabilitation engineering	19	14.07
	Hyperbaric oxygen therapy	12	8.89
	Medical radiologic technology	20	14.81
	Others	13	9.63

Figure 1. Awareness, self-reported practical use, and the gap of emerging rehabilitation technologies.



trainees but remain insufficiently incorporated into practical training and clinical learning environments.

3.3 Frequency and depth of exposure to and application of emerging rehabilitation technologies

Further analysis of participants' learning and practice experiences showed that participants' engagement with emerging rehabilitation technologies remained limited across multiple dimensions. To characterize this pattern more comprehensively, we analyzed participants' frequency of exposure to technology-related knowledge, attention to recent technological developments, self-reported understanding, depth of experiential exposure, and frequency of self-reported practical use in clinical learning, internship, or work settings. The detailed results are presented in Table 3 and Figure 2.

In terms of learning interest, 94.81% of participants reported at least some interest in technology-related knowledge. Specifically, 48.15% of participants stated that they would spend some time reading technology-related information if the topic was attractive, 31.11% of participants would read and bookmark such content, and 15.56% of participants would read and then further follow up on the topic. Only 5.19% of participants reported no interest.

However, participants' engagement with emerging rehabilitation technologies was generally limited across multiple dimensions. During the previous year, 60.00% of participants reported no or low exposure to technology-related knowledge, and 49.63% reported no or low attention to recent technological developments. Their self-reported understanding was modest, with a mean score of 2.63 ± 1.00 and a median score of 3 on a 5-point scale; only 15.56% reported a high level of understanding. Similarly, experiential exposure was mainly observational rather than operational. Overall, 65.93% of participants had either no experience or only on-site observational exposure, whereas only 5.19% had participated in basic operational practice.

Participants' self-perceived application competence was moderate. The mean score for rapidly operating new technologies or software was 3.13 out of 5, for integrating technology into clinical application was 3.07, and for analyzing technology-generated data for clinical judgment or outcome evaluation was 2.81. The composite practical technology competence score was at a general level, and the overall Cronbach's alpha of 0.81 indicated good internal consistency. All corrected item-total correlations were above 0.40, and no item deletion would result in a substantial increase in the alpha coefficient.

These findings further demonstrate the "knowing but not using" phenomenon among rehabilitation trainees. Although many participants had heard of or encountered technologies, most lacked repeated, structured, and clinically meaningful opportunities to operate these technologies. Although self-perceived application ability appeared relatively higher than self-reported understanding and exposure depth, this confidence should be interpreted cautiously because it was not matched by sufficient hands-on practice. The observed gap therefore reflects not only limited practical use, but also insufficient training depth, inadequate practice continuity, and incomplete readiness to integrate emerging technologies into clinical rehabilitation practice.

3.4 Self-perceived barriers to and educational supports for applying emerging technologies

Self-perceived barriers and educational support needs for applying emerging rehabilitation technologies were assessed from three complementary perspectives: self-perceived barriers, specific competency-related barriers, and preferred educational supports. The results are presented in Table 4 and Figure 3.

As shown in Table 4, participants reported a generally moderate level of barriers to applying emerging rehabilitation technologies. The barrier items showed acceptable internal consistency, with a Cronbach's alpha of 0.81. Among these domains, rapid technology iteration had the highest mean score (2.90 ± 0.93), with 18.52% of participants reporting high scores. This was followed by insufficient training and practical application (2.89 ± 0.90), insufficient equipment availability (2.83 ± 0.94), and low patient acceptance of emerging technologies (2.81 ± 0.87). The median score for all four items was marginally below 3, indicating that these barriers were self-perceived mainly at a near-moderate rather than high level.

The multiple-response results further identified specific competency-related barriers perceived by participants. As shown in Figure 3A, the most frequently reported barriers were lack of learning resources for emerging technologies and inadequate proficiency in operating new equipment, reported by 60.00% and 59.26% of participants. Other common barriers included difficulty in integrating technology with clinical practice (44.44%), deficiency in data collection and preliminary analysis skills (39.26%), and insufficient knowledge reserve in equipment maintenance (36.30%).

Table 2. Awareness, practical use, and awareness-application gap by technology category

Technology category	Awareness n (%)	Practical use n (%)	Awareness-application gap (percentage points)	Exact McNemar p	BH-adjusted p
Intelligent rehabilitation assessment or training software	55 (40.74)	16 (11.85)	28.85	<0.0001	0.0002
Rehabilitation robots	60 (44.44)	25 (18.52)	25.92	<0.0001	0.0002
Telerehabilitation	25 (18.52)	1 (0.74)	17.78	0.0008	0.0009
VR rehabilitation	46 (34.07)	6 (4.44)	29.63	<0.0001	0.0002
Wearable devices	75 (55.56)	37 (27.41)	28.15	0.0002	0.0003
Brain-computer interface	49 (36.30)	6 (4.44)	31.86	<0.0001	0.0002
Brain regulation technology	20 (14.81)	4 (2.96)	11.85	0.0019	0.0019

Figure 2. Frequency and depth of exposure to and application of emerging rehabilitation technologies among participants.

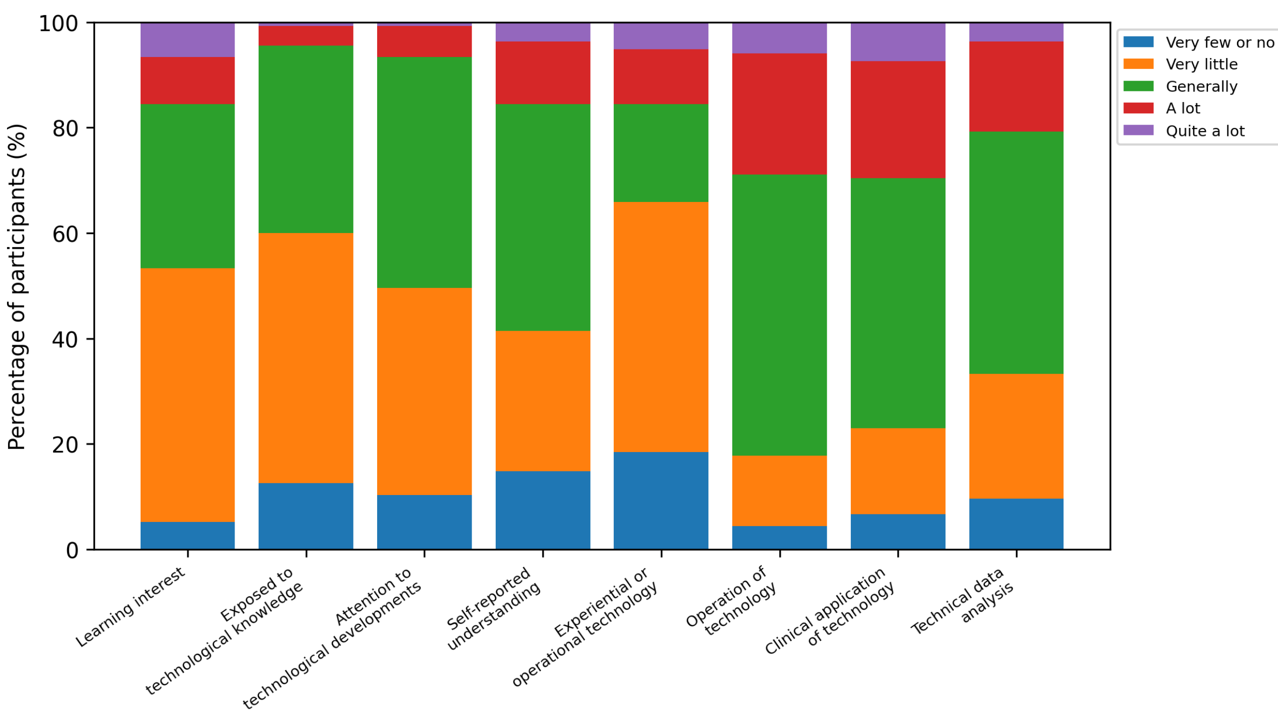


Table 3. Frequency and depth of exposure to and application of emerging rehabilitation technologies among participants

Characteristics		Very few or no	Very little	Generally	A lot	Quite a lot	Low score≤2	High score≥4	Mean ± SD	Corrected item-total correlations	Cronbach's Alpha if item deleted
		n (%)	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)			
Learning interest		7 (5.19)	65 (48.15)	42 (31.11)	12 (8.89)	9 (6.67)	72 (53.33)	21 (15.56)	2.64 ± 0.96	NA	NA
Exposed to technology	Exposed to technological knowledge	17 (12.59)	64 (47.41)	48 (35.56)	5 (3.70)	1 (0.74)	81 (60.00)	6 (4.44)	2.33 ± 0.77	0.44	0.8
	Attention to technological developments	14 (10.37)	53 (39.26)	59 (43.70)	8 (5.93)	1 (0.74)	67 (49.63)	9 (6.67)	2.47 ± 0.79	0.4	0.81
	Self-reported understanding	20 (14.81)	36 (26.67)	58 (42.96)	16 (11.85)	5 (3.70)	56 (41.48)	21 (15.56)	2.63 ± 1.00	0.65	0.76
	Experiential or operational technology	25 (18.52)	64 (47.41)	25 (18.52)	14 (10.37)	7 (5.19)	89 (65.93)	21 (15.56)	2.36 ± 1.06	0.41	0.81
Self-perceived technology application	Operation of technology	6 (4.44)	18 (13.33)	72 (53.33)	31 (22.96)	8 (5.93)	24 (17.78)	39 (28.89)	3.13 ± 0.88	0.63	0.77
	Clinical application of technology	9 (6.67)	22 (16.30)	64 (47.41)	30 (22.22)	10 (7.41)	31 (22.96)	40 (29.63)	3.07 ± 0.97	0.66	0.76
	Technical data analysis	13 (9.63)	32 (23.70)	62 (45.93)	23 (17.04)	5 (3.70)	45 (33.33)	28 (20.74)	2.81 ± 0.96	0.62	0.77
											Overall Cronbach's α：0.81

Correspondingly, participants expressed clear needs for educational support. As shown in Figure 3B, the most preferred support was adding basic training equipment courses (68.89%), followed by integrating tech equipment content into existing courses (60.74%). In addition, 40.00% of participants supported offering technology elective courses and enterprise internship opportunities, respectively. Technology-clinical integration case studies were selected by 35.56% of participants, while 31.85% preferred data processing and preliminary analysis. Clinical assessment software application and lectures on cutting-edge technology trends were each selected by 27.41% of participants.

Taken together, these findings suggest that barriers to applying emerging rehabilitation technologies were not limited to external contextual factors such as rapid technology iteration, equipment availability, or patient acceptance. More importantly, the perceived barriers were closely aligned with participants' educational support needs, highlighting gaps in learning resources, device operation, clinical integration, equipment maintenance, and data-related competence.

Figure 3. Self-perceived barriers and preferred educational support for applying emerging rehabilitation technologies. (A) Self-perceived competency barriers to applying emerging rehabilitation technologies. (B) Educational support for technology-oriented rehabilitation training.

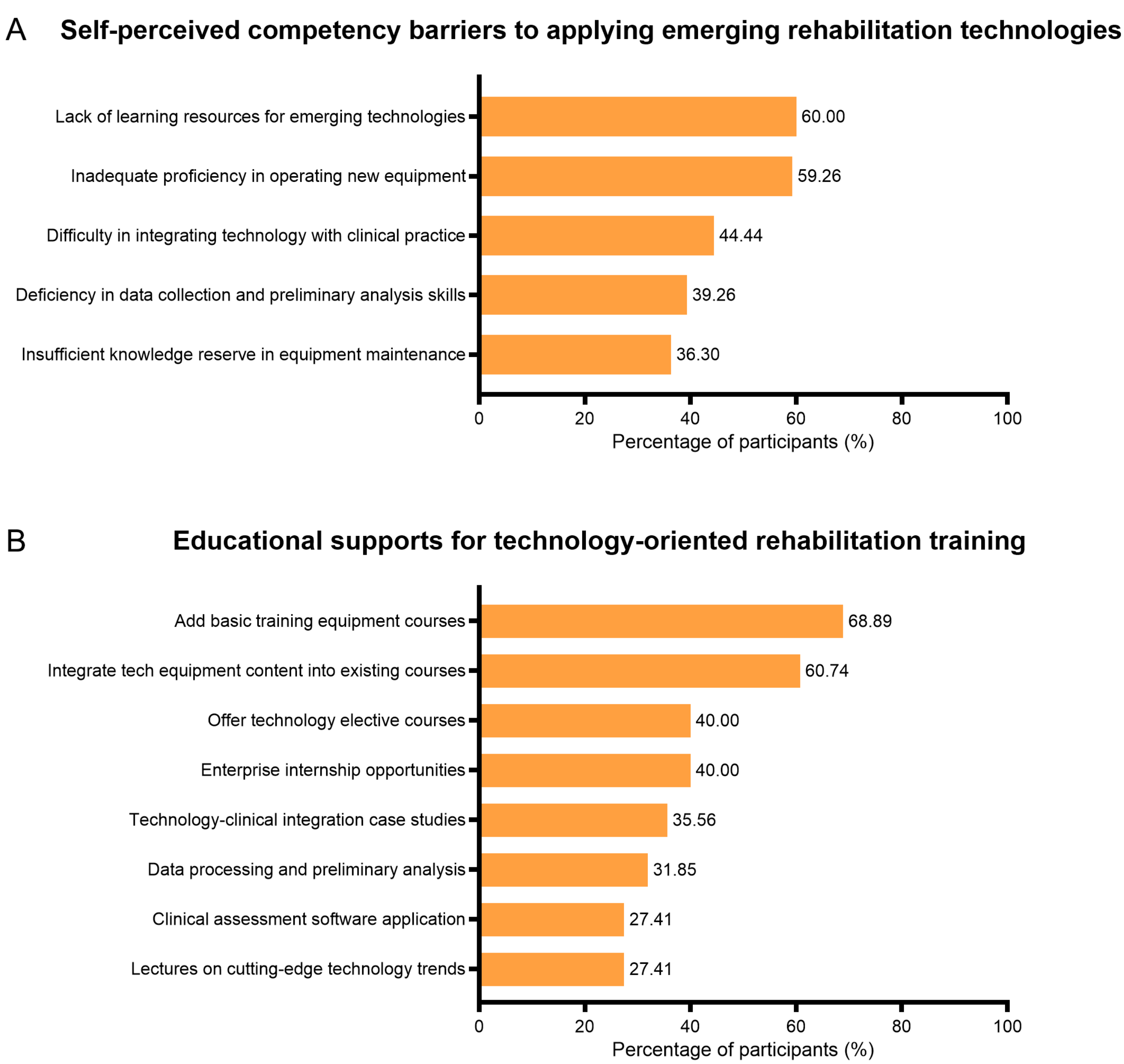


Table 4. Self-perceived barriers to and educational supports for applying emerging rehabilitation technologies among participants

Characteristics	Very few or no	Very little	Generally	A lot	Quite a lot	Low score≤2	High score≥4	Mean ± SD	Corrected item-total correlations	Cronbach's Alpha if item deleted
	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)			
Rapid technology iteration	9 (6.67)	29 (21.48)	72 (53.33)	16 (11.85)	9 (6.67)	38 (28.15)	25 (18.52)	2.90 ± 0.93	0.67	0.74
Insufficient training and practical application	10 (7.41)	26 (19.26)	75 (55.56)	17 (12.59)	7 (5.19)	36 (26.67)	24 (17.78)	2.89 ± 0.90	0.69	0.73
Insufficient equipment availability	13 (9.63)	29 (21.48)	66 (48.89)	22 (16.30)	5 (3.70)	42 (31.11)	27 (20.00)	2.83 ± 0.94	0.62	0.77
Low patient acceptance of emerging technologies	11 (8.15)	29 (21.48)	74 (54.81)	17 (12.59)	4 (2.96)	40 (29.63)	21 (15.56)	2.81 ± 0.87	0.54	0.8
										Overall Cronbach's α：0.81

4. Discussion

This cross-sectional survey provides a multi-dimensional description of rehabilitation trainees' readiness for emerging rehabilitation technologies. The main findings can be summarized in four points. First, trainees had partial awareness of several technology categories, particularly wearable devices, rehabilitation robots, and intelligent rehabilitation assessment or training software. Second, self-reported practical use was consistently lower than awareness, producing a clear awareness-application gap. Third, most trainees expressed interest in technology-related learning, but exposure to technology knowledge, attention to technological development, self-reported understanding, and hands-on experience were generally limited. Fourth, the perceived barriers and preferred educational supports were closely connected: trainees identified insufficient learning resources, limited operational proficiency, equipment maintenance knowledge gaps, clinical integration difficulty, and data-analysis deficits, and they preferred courses and practice opportunities that directly addressed these gaps.

These findings are educationally important because they show that the problem is not simply a lack of curiosity or resistance to technology. Instead, trainees appear to be interested in emerging rehabilitation technologies but are not consistently provided with structured opportunities to transform interest into competence. This pattern suggests a curriculum and practice environment issue: technology is visible enough to be recognized, but not embedded deeply enough in teaching and clinical learning to produce stable operational ability.

The awareness-application gap observed in this study can be understood as an educational translation problem. In clinical innovation, the pathway from invention to routine use is often described as translation from evidence to implementation. A similar process exists in professional education [16]. Learners first encounter a technology concept, then observe its clinical use, then operate it under supervision, then integrate its outputs into clinical reasoning, and finally apply it flexibly and safely in patient-centered care [17]. When education stops at the level of lectures or brief demonstrations, learners may report awareness but lack functional readiness. In the expanded sample, the largest gap was found for brain-computer interface technology, followed by VR rehabilitation, intelligent rehabilitation assessment or training software, and wearable devices. These categories are often discussed in contemporary rehabilitation because they are conceptually attractive and frequently appear in academic, industry, or media contexts. However, they require specific infrastructure, software literacy, data interpretation, and clinical scenario design. Therefore, they may be easy to know about but difficult to practice. This finding supports the need to evaluate not only whether a curriculum includes technology-related content, but also how learners interact with that content. A curriculum that lists emerging technologies in theory classes may increase awareness, but a curriculum that includes case-based software interpretation, simulated decision-making, supervised equipment operation, and reflective clinical reasoning is more likely to build application competence. Practical experience with telerehabilitation remained extremely limited, with only 0.74% of respondents reporting use. Telerehabilitation has expanded internationally as a strategy to improve access, especially when in-person services are limited by geography, mobility, public health disruptions, or service capacity [9]. This may reflect local service patterns, limited exposure during early training, insufficient formal teaching about remote rehabilitation workflow, or uncertainty about legal and professional boundaries. It also suggests that educational programs should not assume that widely discussed technologies are automatically experienced by trainees. It is also important to recognize that an awareness-application gap is not inherently negative in every circumstance. Some advanced technologies should not be used by trainees without adequate supervision, and some may not be appropriate for all educational stages. The problem identified here is not simply that practical use rates were lower than awareness rates; rather, the concern is that the curriculum may not provide a visible pathway from introductory knowledge to supervised practice. A well-designed program can preserve patient safety while still creating graded opportunities for observation, simulation, supervised operation, and reflective integration. In this sense, the gap should be interpreted as a signal for educational scaffolding rather than as an argument for indiscriminate expansion of equipment use [18].

Furthermore, emerging rehabilitation technologies should not be treated as a single homogeneous domain. Rehabilitation robots, wearable devices, VR rehabilitation, telerehabilitation, intelligent assessment software, brain-computer interfaces, and brain regulation technologies differ in clinical purpose and educational requirements [19]. In this study, wearable devices had the highest awareness and self-reported practical use rates, and rehabilitation robots also showed relatively high awareness and use compared with other technology categories. This may be because these technologies are more visible in rehabilitation laboratories, teaching demonstrations, or clinical departments, and because their use is more tangible for trainees. In contrast, brain-computer interface technology and brain regulation technology had low self-reported practical use, probably because these technologies are more specialized, require advanced technical support, and are less commonly available in routine undergraduate training environments. The educational implication is that a tiered training model may be more appropriate than a single technology course [20-23]. Foundational modules could introduce the principles, indications, safety considerations, and ethical issues common to all technologies. Intermediate modules could focus on technology clusters, such as robotic and wearable technologies, immersive and remote rehabilitation, and neurotechnology-assisted rehabilitation. Advanced modules could provide elective or research-oriented training for learners who need deeper competence in data analysis, device calibration, algorithmic assessment, or neurophysiological interpretation. Such a structure would allow all trainees to reach a minimum level of technology literacy while providing pathways for more specialized development. Moreover, technology training should be linked to clinical tasks rather than taught as isolated equipment instruction. For instance, teaching wearable devices should not be limited to how to wear a sensor; it should include selecting clinically meaningful indicators, recognizing measurement error, interpreting longitudinal trends, communicating results to patients, and integrating objective data with subjective symptoms and functional goals. Similarly, robot-assisted training should include patient selection, parameter adjustment, therapist-patient-device interaction, safety monitoring, and progression planning. A clinical task-based approach is likely to reduce the gap between knowing the device and applying it responsibly.

A particularly important finding was the mismatch between learning interest and exposure depth. In the 135-respondent sample, 94.81% of respondents reported at least some interest in technology-related knowledge, yet most had low exposure to technology-related knowledge and limited attention to recent developments. Even fewer had high levels of experiential or operational exposure. This suggests that trainees' interest may be underutilized. In educational design, interest can serve as an entry point for active learning, but it must be converted into repeated engagement. Without structured tasks, feedback, and assessment, interest may remain passive and may not lead to competence [24].

The survey also showed that self-perceived application competence was moderate. The mean scores for operation of technology, clinical application of technology, and technical data analysis were 3.13, 3.07, and 2.81, respectively, indicating that data-related competence and clinical integration still require strengthening. This pattern can be interpreted in several ways. It may reflect general confidence in learning new software and equipment among young trainees. It may also indicate that trainees believe they could learn technologies quickly if given the opportunity. However, self-perceived competence does not necessarily equal actual operational ability. In technology-intensive rehabilitation, overconfidence without sufficient practice can create safety risks, inefficient workflows, or inappropriate clinical use. Educational programs should therefore complement self-reported assessments with performance-based evaluation, such as objective structured practical examinations, simulation tasks, case interpretation exercises, or supervised clinical demonstrations. Exposure depth also matters because technology use in rehabilitation is rarely a one-step skill. A trainee may observe a robot-assisted session and understand its basic purpose, but this does not mean that the trainee can set up the device, adjust parameters, respond to patient discomfort, interpret session data, or decide when technology is clinically inappropriate. Similarly, a trainee may know that VR rehabilitation can increase motivation, but may not know how to manage cybersickness, calibrate task difficulty, select functional outcome indicators, or adapt tasks to patients with cognitive or sensory deficits. Repeated practice in authentic or simulated contexts is therefore essential.

The barrier findings provide direct guidance for curriculum improvement. The highest contextual barrier score was rapid technology iteration, closely followed by insufficient training and practical application; insufficient equipment availability and low patient acceptance were also perceived as near-moderate barriers. At the same time, the most frequently selected competency-related barriers were lack of learning resources and inadequate proficiency in operating new equipment. These responses indicate that trainees need both material access and pedagogical structure. Equipment alone is not enough if students do not receive guided practice; conversely, lectures alone are insufficient if students cannot interact with real or simulated technologies. Accordingly, participants' preferred educational supports were strongly practice-oriented. The most selected option was adding basic training equipment courses, followed by integrating technology equipment content into existing courses. This suggests that trainees value both dedicated technology courses and horizontal integration into the existing curriculum [25]. A balanced model may be most feasible. Dedicated modules can ensure systematic teaching of technology principles and safety, while integration into existing courses can help learners understand how technology supports assessment and intervention across musculoskeletal, neurological, cardiopulmonary, pediatric, geriatric, and speech-language rehabilitation contexts. Technology-clinical integration case studies and enterprise internship opportunities were also supported by a substantial proportion of participants. This is important because many emerging rehabilitation technologies are developed and maintained through cooperation between clinical institutions, universities, and industry. Enterprise or hospital-based internships can expose trainees to real implementation processes, including equipment procurement, maintenance, user training, quality control, and interdisciplinary collaboration. However, such opportunities should be carefully designed to maintain educational independence and patient safety. Trainees should learn to evaluate technology critically rather than simply promote or consume devices. Patient acceptance was perceived as a lower barrier than some training-related barriers, but it should not be ignored. Technology-oriented rehabilitation depends on patient trust, comfort, safety perception, affordability, and perceived usefulness. Trainees who are technically trained but unable to communicate technology benefits and limitations may struggle to achieve patient engagement. Therefore, communication training should be incorporated into technology education. Learners should practice explaining why a technology is recommended, what the patient will experience, what risks or discomforts may occur, and how technology use will be combined with conventional therapist-led care. This patient-centered approach can prevent technology from being viewed as a replacement for professional interaction and may improve acceptance in future clinical practice.

Based on the findings, several practical recommendations can be proposed. First, rehabilitation programs should define minimum technology competencies for trainees. These competencies may include basic technology literacy, device safety, patient-centered communication, data interpretation, clinical decision-making, ethical awareness, and interprofessional collaboration. Second, programs should provide progressive learning pathways that move from awareness to observation, supervised operation, case-based integration, and independent reasoning. Third, programs should use simulation and low-risk practice environments before clinical use. Simulation can allow learners to practice device setup, parameter adjustment, troubleshooting, patient instruction, and emergency response without compromising patient safety. Fourth, technology education should include data literacy. Many emerging rehabilitation technologies generate quantitative outputs, such as movement trajectories, repetitions, force, range of motion, heart rate, gait parameters, engagement indices, or performance scores. Trainees need to understand what these data mean, what they do not mean, and how they should inform rehabilitation goals. Data literacy should be taught together with clinical reasoning rather than as a detached statistical skill. Fifth, programs should establish partnerships with clinical departments and technology providers to improve access to equipment and real-world cases. These partnerships should include clear learning objectives, supervision requirements, and evaluation standards. Sixth, educational assessment should include both self-perception and objective performance. Self-reported confidence is useful for understanding learners' attitudes, but it should be supplemented with demonstrations of competence. Examples include checklist-based equipment operation, interpretation of a technology-generated report, design of a technology-assisted intervention plan, and reflection on safety or ethical issues. Finally, curricula should emphasize that technology is a means to improve rehabilitation quality, not an end in itself. Trainees should learn to select technologies based on patient goals, evidence, feasibility, safety, and equity.

Based on the findings above, a feasible implementation strategy is to construct a staged curriculum map. In the first stage, all students could receive basic orientation to major technology categories, terminology, indications, contraindications, and safety principles. In the second stage, students could complete structured laboratory sessions in which they rotate through representative devices or software platforms and complete guided worksheets. In the third stage, case-based learning could require students to select appropriate technologies for patient scenarios and justify their choices. In the fourth stage, senior students or interns could participate in supervised clinical application and outcome interpretation. Such a map would allow programs with limited resources to start with low-cost modules while gradually expanding access to equipment and clinical practice.

However, this study has several limitations. First, although the sample size was expanded to 135 respondents, the sample was still drawn from a limited educational context, and most respondents were undergraduate students, particularly first- and second-year students. As a result, the findings should be interpreted as exploratory and may not be generalizable to all rehabilitation trainees, institutions, or practicing clinicians. The limited clinical exposure of junior students may also partly explain the low practical use rates observed in this study. Second, the questionnaire relied on self-reported data, which may be affected by recall bias, social desirability bias, and differences in respondents' understanding of technology categories. In addition, awareness and practical use were measured as binary responses, which helped identify broad gaps but did not capture the quality, duration, supervision level, or clinical complexity of practical experience. Third, because this was a cross-sectional study, causal relationships cannot be inferred. It remains unclear whether limited training led to low practical use, whether insufficient equipment availability reduced training opportunities, or whether both factors interacted. Moreover, the psychometric properties of the questionnaire require further validation in larger and more diverse samples.

Future research should address these limitations in several directions. First, larger and more diverse samples should be recruited across multiple institutions, educational levels, specialties, and geographic regions. Comparative studies involving junior students, senior students, interns, and practicing clinicians would help clarify how training stage, clinical exposure, specialty background, and prior technology experience influence awareness and practical use of emerging rehabilitation technologies. Second, future studies should improve the measurement and evaluation of technology-related competence. Rather than relying only on self-reported binary responses, future research could assess the quality, duration, supervision level, and clinical complexity of practical experience. Mixed-methods designs may further explore how trainees, teachers, clinicians, and patients understand and perceive technology readiness. In addition, validated competency-based assessment tools should be developed, including knowledge tests, practical operation checklists, case interpretation tasks, data-literacy exercises, and reflective components. Third, longitudinal and intervention studies are needed to examine whether technology-integrated education can improve awareness, operational competence, clinical confidence, safe clinical behavior, evidence-based decision-making, and patient-centered practice over time. Different educational models, such as lecture-based teaching, simulation-based training, equipment workshops, case-based learning, and clinical placement, should be compared. Future research should also examine institutional factors that influence implementation, including teacher expertise, laboratory infrastructure, cooperation with clinical departments, equipment procurement and maintenance, curriculum time, and assessment policy. These studies would help distinguish learner-level barriers from system-level barriers and guide the development of sustainable technology-oriented rehabilitation education.

5. Conclusion

This study identified a clear awareness-application gap in rehabilitation trainees' engagement with emerging rehabilitation technologies. Although trainees showed considerable interest and partial awareness, self-reported practical use, structured exposure, and clinically meaningful operational experience were limited. The main barriers were not only external factors such as rapid technological iteration, equipment availability, and patient acceptance, but also educational gaps in learning resources, device operation, clinical integration, equipment maintenance, and data-related competence. Rehabilitation education should therefore move beyond introductory technology awareness and build progressive, practice-oriented, and clinically integrated training systems. Such reform may help future rehabilitation professionals use emerging technologies safely, critically, and effectively in patient-centered rehabilitation practice.

Declarations

Ethics approval and consent to participate

This study was conducted as an anonymous educational questionnaire survey. Informed consent was obtained from participants before questionnaire completion.

Consent for publication

Not applicable.

Availability of data and materials

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Conceptualization: Dongfeng Huang and Jingli Liu; Analysis and interpretation of the data: Qian Zhang and Jun Li; Drafting of the manuscript: Qian Zhang and Jun Li; Critical revision and editing of the manuscript: all the authors.

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