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Towards personalised neurorehabilitation: Professional perspectives on technology-driven adaptation to emotional and physical states in the design of new therapies

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Abstract

Background: Stroke rehabilitation requires active patient engagement. However, existing robots typically lack the emotional intelligence to respond to fluctuating patient states, from negative emotions such as frustration or fear to positive states such as over-excitement or excessive drive, which may also pose safety risks. This study analyses clinical professionals' perceptions regarding the integration of patients' emotional states into physical neurorehabilitation, and defines design requirements for emotionally adaptive robotic systems.
Methods: Through semi-structured interviews with 25 clinicians from nine centres, we used Affinity Diagrams to analyze their clinical practice and expectations concerning the impact and utility of rehabilitation robotics.

Results: Motivation is the emotional factor with the greatest impact on success, while fear and frustration are the predominant negative emotions. Professionals prioritized features such as automated task levelling and the generation of comprehensive reports that integrate both physical and emotional patient data. **Conclusions:** There is high acceptability for adaptive robotics as a support tool that enhances the patient-therapist-technology triad without replacing clinical judgement. Clinicians envision emotionally adaptive systems that not only react to negative states (e.g. fear, frustration) but also regulate overly positive arousal (e.g. excessive excitement) to maintain safe, effective training. Multimodal input integration is essential for robust emotional detection and for translating patients' affective states into actionable therapeutic adaptations. The findings provide a framework for engineers to develop robotic interfaces and control algorithms, grounded in clinical praxis, that personalise exercise intensity and task demands based on real-time affective states.

Keywords: emotional, design, therapy, rehabilitation, health

1 Introduction

Effective rehabilitation is the cornerstone of recovery, enabling patients to regain the functional autonomy required for successful reintegration into daily life ([1]). However, current human-based rehabilitation faces significant limitations: it is resource-intensive and often inconsistent, which hinders the long-term functional gains needed for improving motor outcomes ([2]). Moreover, traditional settings often struggle to sustain the patient's continuous motivation and effort—factors that are strongly linked to psychological well-being and the prevention of secondary conditions such as anxiety or depression ([3]). In response, advanced robotic systems, including exoskeletal gait trainers (e.g. Lokomat-type systems) and end-effector devices for both upper- and lower-limb rehabilitation, have been introduced, aimed at intensifying practice dosage and enhancing therapeutic outcomes. However, despite their potential, the adoption of these technologies in real-world clinical practice remains notably limited [4].

The evolution of rehabilitation robotics has transitioned from providing passive, repetitive movements towards more sophisticated "assistance-as-needed" (AAN) frameworks. For a robotic intervention to trigger cortical reorganization, i.e., neuroplasticity, it must deliver high-intensity, task-specific training that maintains an optimal level of challenge [5]. Beyond biomechanics, modern research increasingly characterizes rehabilitation as a biopsychosocial process where patient engagement and motivation are primary predictors of functional recovery ([6]). Recent findings in motor learning reinforce this view, suggesting that emotional responses such as frustration, perceived challenge, or sense of control are not mere side effects but active determinants of behavioural adaptation and physical effort [7]. When robotic platforms ignore these variables, they risk inducing "learned helplessness", a state where the patient becomes a passive recipient of movement rather than an active participant.

A primary cause of the limited adoption of robotic systems is the gap between advanced mechanical design and the complex, real-world dynamics of rehabilitation. While scientific literature highlights that success depends on aligning technology with end-user needs ([8]), most systems currently operate as isolated tools, relying primarily on kinematic data (e.g., joint angles or gait symmetry). This technical focus often overlooks the "assistive-yet-challenging" balance that a human therapist maintains by intuitively reading the patient's non-verbal and affective cues. The clinician remains fully responsible for managing the intricate interplay between the patient's desired physical progress and their actual state, both physical and emotional, throughout therapy. To mitigate this, the literature proposes "bio-cooperative control strategies" ([9]), which aim to close the loop by integrating psychophysiological indicators (e.g., heart rate, skin conductance) into the robot's decision-making process. This approach is supported by established research in affective computing and ergonomic evaluation, which has demonstrated the feasibility of using bio signals such as Electromyography (EMG) and Galvanic Skin Response (GSR) to objectively interpret user states beyond subjective self-reports ([10]). Furthermore, recent advances in automotive and transportation research have successfully applied these physiological models to detect occupant emotions, providing a robust framework for assessing valence and arousal in real time ([11]). Such human-state-aware technologies seek to restore motivation by dynamically rebalancing the challenge–skill ratio ([7]), yet their implementation depends on accurately modelling the clinician's expert ability to evaluate and assess the patient's status in real time, holistically integrating both their physical performance and affective state.

Therefore, the development of user-aware systems represents the next frontier in the field. These systems must be capable of processing multimodal data combining physical indicators such as posture or muscle activation with expressive cues such as facial emotions and tone of voice ([12]). Advances in automatic emotion recognition and deep learning architectures ([13, 14]) provide the technical foundation for this integration. However, the successful deployment of such interfaces hinges on their alignment with real-world clinical expertise and user-centred needs ([15]). This underscores a critical gap in the literature: while computational tools for emotion detection are rapidly advancing, their systematic application within robotic rehabilitation remains limited. There is a significant lack of insight into how professionals currently detect and respond to these emotional cues in practice, and what degree of autonomy a system should have to intervene in such situations ([1]). There is thus a profound need to analyse how clinical experts perceive these emotional variables, and to systematically investigate the needs, expectations, and constraints of practitioners in real-world clinical settings, to ensure that future context-aware designs support, rather than replace, professional judgment.

Based on this premise, the present study aims to analyze the perspectives of healthcare professionals in order to identify key opportunities and challenges, and to derive guidelines and pathways for the development of comprehensive, personalized and

adaptive robotic assistive systems capable of adapting to patients' emotional states and enhancing rehabilitation outcomes. By placing clinical expertise at the centre of the design process, this work seeks to align system design with professional workflows and requirements, contributing to usable tools that embed advanced robotic capabilities into routine clinical care and support both patients' functional recovery and clinicians' daily practice.

2 Study Design

We present the results of a qualitative study aimed at understanding how clinical professionals perceive the role of emotional states in physical rehabilitation and the potential integration of emotionally adaptive robotic systems into their practice. Specifically, we analyse how clinicians interpret and respond to patients' evolving physical and emotional states, and how these assessments inform their therapeutic decisions and interactions Furthermore, the study examines current clinical attitudes towards the emerging field of assistive robotics, specifically identifying the expectations, concerns, and workflow requirements that must be addressed to ensure that such systems function as effective, trustworthy tools in a real-world clinical environment. Data were collected through semi-structured interviews with clinical professionals as shown in section 2.2.

2.1 Participants

We recruited 25 clinical professionals (21 female, 4 male), aged between 25 and 50 (M = 39.68, SD = 7.82), to participate in the study. This sample size is consistent with prior qualitative research indicating that data saturation is typically achieved between 12 and 24 interviews, depending on the depth and diversity of the data ([16, 17]). The study was approved by the Research Ethics Committee of Mondragon Unibertsitatea (Internal code: IEB-20251110). All methods were carried out in accordance with relevant guidelines and regulations, including the Declaration of Helsinki. Written informed consent was obtained from all participants prior to their inclusion in the study.

To ensure a diversity of perspectives and reduce potential institutional bias, participants were recruited from eight different clinical centres. (see **Table 1**).
Before the interviews, each participant completed a preliminary questionnaire capturing their educational background, years of professional experience, and familiarity with robotic technologies. Analysis of these profiles revealed a high degree of technical literacy within the group; only two participants reported no prior experience with robotics. To mitigate any technical gaps and establish a common baseline, these two individuals were provided with standardized visual materials—including images and demonstration videos during the interviews. This instructional phase ensured that all experts, regardless of their initial background, possessed a consistent understanding of robotic capabilities, allowing them to provide informed feedback on the system's design.

Table 1: Detailed Profile of Clinical Participants (n=25)

Characteristic	Category	Total (n=25)
Professional Role	Physiotherapist	15
	Occupational Therapist	7
	Rehabilitation Doctor	1
	Other (Nurse/Assistant)	2
Clinical Experience	0–5 years	3
	6–10 years	6
	>10 years	16
Work Setting	Public Hospital	10
	Private Hospital	3
	Rehabilitation Center	8
	Outpatient Clinic	4
Familiar with Robots	Yes	11
	No	14
Primary Pathologies treated	Neurological (Stroke, SCI, TBI)	21
	Musculoskeletal	3
	Paediatrics, Respiratory physiotherapy	1

2.2 Data Collection and Analysis

The interviews followed the guide questions shown in **Table 2** and **Table 3** in Appendix **A**. The interview protocol was designed to explore (i) current rehabilitation practices, (ii) how clinicians perceive and interpret patients' emotional and physical states, (iii) the strategies used to adapt therapy based on these observations, and (iv) clinicians' attitudes towards the integration of emotionally adaptive robotic systems into their workflow.

The semi-structured format was chosen to balance consistency across interviews with the flexibility to explore emerging insights in depth. The interview script was internally validated and covered key thematic areas, including therapeutic methodologies and adjustment parameters (e.g., force, speed, range of motion), patients' emotional experiences, current strategies for identifying affective states, and expectations toward emotionally adaptive robotic systems. Interviews lasted approximately 30 minutes and were conducted by two researchers to support observational triangulation. Open follow-up questions were used to further explore relevant aspects of participants' responses. All interviews were audio-recorded and transcribed verbatim to preserve the richness of the clinical discourse.

We analysed the interview data using affinity diagramming ([18]), organizing participants' responses into clusters to identify recurring themes and patterns. The overall analysis workflow is illustrated in **Figure 1**. First, transcripts were segmented into meaningful units capturing individual ideas or observations. These units were then reviewed and iteratively grouped based on conceptual similarity, without predefined categories.

The analysis involved multiple rounds of discussion and refinement, allowing themes to emerge progressively and be structured into higher-level categories reflecting common practices, perceptions, and expectations. The process was conducted collaboratively by both researchers ensuring consistency and reducing individual bias.

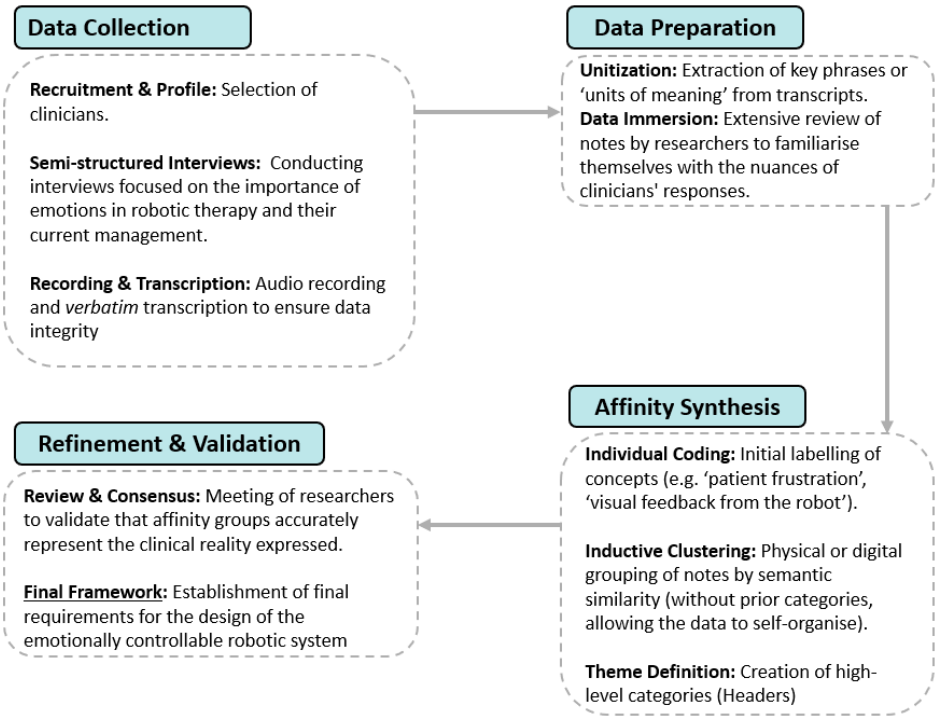


Fig. 1: Methodological workflow of the qualitative data analysis using Affinity Diagramming for the clinical requirements of an emotionally-controlled robotic system.

3 Results

The thematic analysis derived from the affinity diagramming process allowed for the articulation of findings into a structured framework, defined by the intersection between clinical praxis and the technical requirements of robotic rehabilitation. To facilitate the interpretation of the dense qualitative data gathered, the results of the Affinity Diagram have been synthesized into two main representative graphs: Human to Human Rehabilitation and Rehabilitation Systems. It is important to clarify that while these figures constitute the conceptual representation of the study's taxonomy (**Figure 2**), they are not the Affinity Diagram itself, but a streamlined visualization designed to map the professional requirements more clearly. This first major division reflects a clear distinction made by the interviewed professionals between the human-centric variables of therapy and the functional capabilities of the technology

itself. The first block, Human to Human Rehabilitation, encompasses the clinical interaction and the human factors that determine the exercise's effectiveness. Within this dimension, the data indicate a clear distinction between exercise modalities and the specific parameters for determining a person's condition. Professionals prioritize functional and dynamic movements to ensure the ecological validity of the therapy, identifying force exerted by the therapist to the person (interaction), movement type, and repetitions as the most cited parameters for manual adjustment. However, this block also reveals that the success of the therapy is not purely mechanical, it is deeply influenced by a specific sub-dimension of factors influencing motivation. This suggests that any adaptive robotic system must transcend physical assistance to address the psychological and emotional engagement of the patient as a core driver of recovery.

In contrast, the second block, Rehabilitation Systems, focuses strictly on the technological infrastructure and its operational requirements. This dimension evaluates the benefits of robotic integration and the future improvements necessary to bridge current clinical gaps. From a functional perspective, this block categorizes the flow of information through System Input and System Output, while also identifying the various information recipients such as therapists, patients, or caregivers who must interact with the data generated. By separating the human-relational factors from the system's technical architecture, this diagram provides a roadmap for designing a robot that is not only physically precise but also clinically aligned with the reality of professional practice.

First block: Human to Human Rehabilitation

The first major branch of the taxonomy, Human to Human Rehabilitation, encompasses the clinical interaction and the human factors that determine the effectiveness of the therapy. As shown in **Figure 3**, this dimension is structured into four main axes: *Type of exercise and Settings to adjust, Parameters for determining a person's condition, Factors contributing to the success of therapy, and Psychology.*

Regarding the first axis, the results distinguish between the nature of the physical activity and the variables required to modulate it. For the Type of exercise, clinicians specifically emphasize the importance of functional and dynamic exercises as the most beneficial for recovery. In parallel, the Settings to adjust branch identifies the key parameters that professionals manipulate to tailor the intervention: intensity, difficulty, time, repetitions, movement, and force. These elements represent the "dosage" of the therapy that clinicians adapt in real-time based on the patient's performance.

The second axis, ***Parameters for determining a person's condition*** (**Figure 4**), focuses on the clinical indicators that professionals monitor to evaluate the patient's status during the session. The results categorize these indicators into two critical sub-sections: Subjective values and Target values. Clinicians strongly emphasize the importance of Subjective values, which are qualitative parameters used to intuitively determine the patient's state. These include the patient's willingness to talk (talkative), the ability to hold a conversation, the overall appearance, and changes in their facial expression. Furthermore, therapists monitor the patient's gaze,

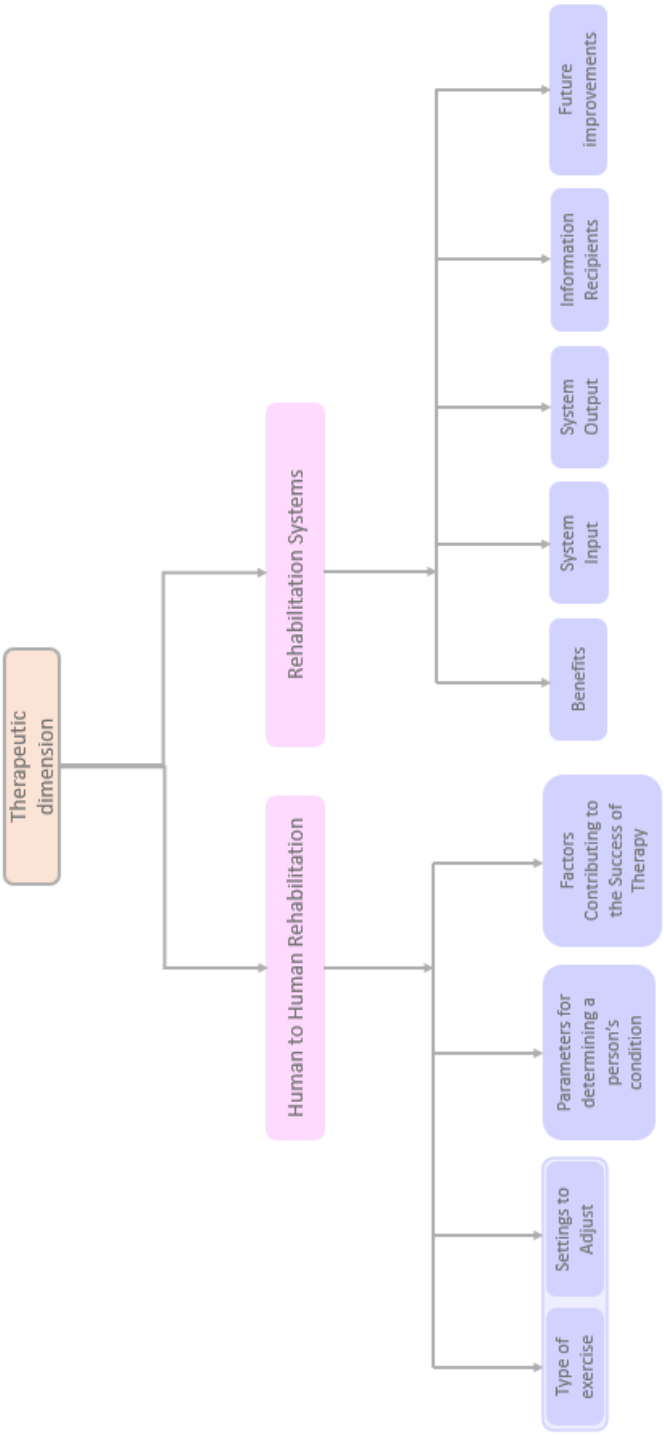


Fig. 2: General taxonomy of the therapeutic dimension derived from the affinity diagramming process.

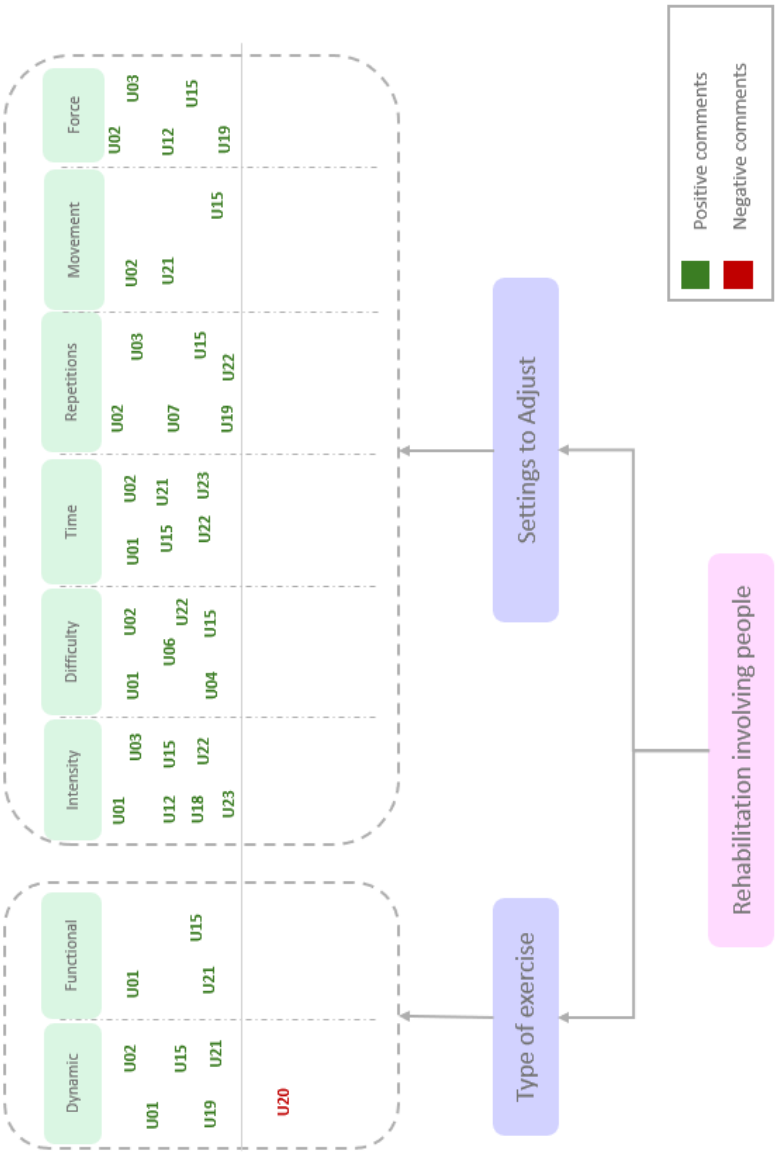


Fig. 3: Graph based on the affinity of participants' statements: Therapeutic dimension – Exercise modalities and prescription parameters in rehabilitation.

postural alignment, and the quality of task execution as primary signs of their clinical condition. In contrast, the Target values sub-section groups objective and quantifiable physiological parameters. These include body temperature (T Body), blood pressure, heart rate, and respiratory rate, as well as physical signs of exertion or stress such as shakiness and sweating. Despite the technical nature of these biological facts, the analysis reveals that professionals tend to prioritize subjective indicators over objective physiological data when performing real-time clinical assessments, as the former provide more immediate insight into the patient's engagement and comfort.

The third axis, ***Factors contributing to the success of therapy***, identifies the multidimensional elements that determine the effectiveness of the rehabilitation process. The results reveal two primary thematic clusters within this category. *The first cluster* of this axis (**Figure 5**) focuses on external and methodological variables, highlighting the importance of external support such as family and friends working outside of sessions, and the implementation of demanding tasks. Clinicians also emphasized the necessity of connecting with the patient, managing expectations, and addressing complex social dynamics such as managing envy. Notably, the concept of motivation was so consistently mentioned as a pillar of success that it led to the creation of a dedicated sub-dimension.
The second cluster (**Figure 6**) within this axis examines the emotional landscape that contributes to therapeutic outcomes. Professionals identified a wide spectrum of emotional states that patients experience, ranging from positive drivers such as happiness, being motivated, or expectant, to challenging states such as fear, sadness and frustration. Understanding these emotions is considered vital for maintaining the trajectory of the recovery.

Within this framework, the subsection ***Factors influencing motivation*** (**Figure 7**) details the specific strategies used to ensure patient engagement. According to the analysis, key factors include the ability to adjust the difficulty, providing psychological therapy, and using persuasion or the use of technology to maintain interest. The emotional state and the introduction of new tasks are also decisive. Furthermore, clinicians highlighted that motivation is heavily driven by the capability of the patients to reach the objectives set and, crucially, by designing tasks focused on personal goals such as being able to walk a dog, hold a grandchild, or get into a car. Finally, the strategy of pushing patients to their physical limit was identified as a clinical tool to foster a sense of achievement and progression.

Second block: Rehabilitation systems

In the second major block it shifts the focus toward the technical and functional requirements of the technology based on clinical experience and patient interaction. This dimension is analysed through four primary axes: *Benefits, System Input, System Output, and Information Recipients* (**Figure 8**). Together, these categories provide a framework for how future robotic platforms should be designed to align with professional practice.

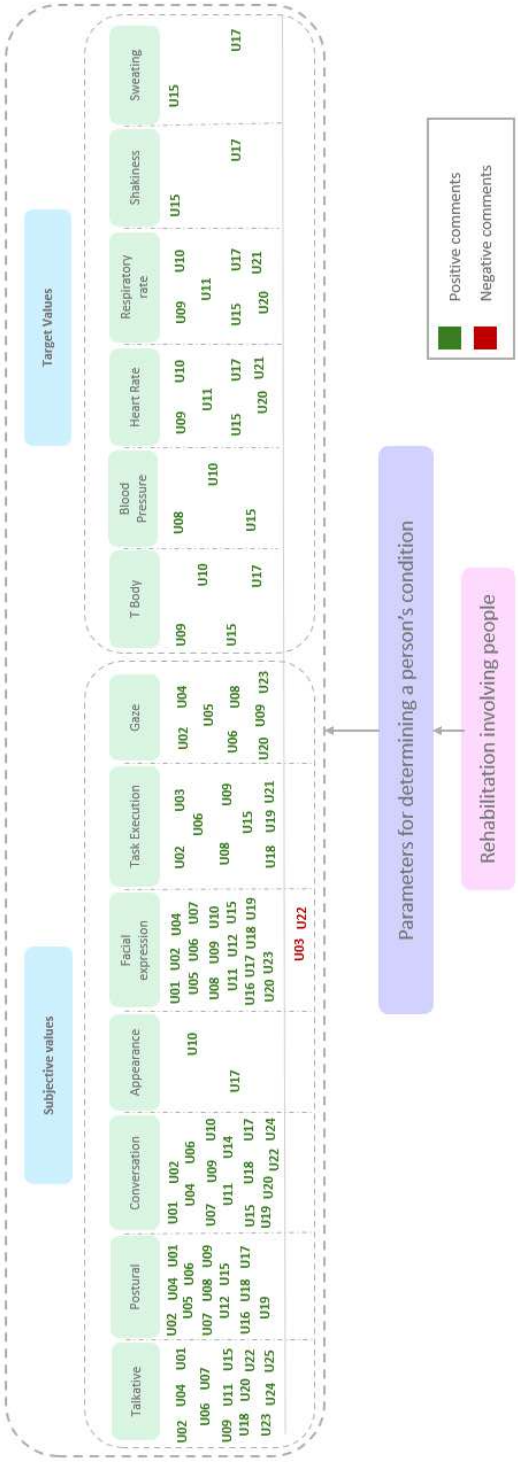


Fig. 4: Graph based on the affinity of participants' statements: Therapeutic dimension – User parameters assessed by the professional to determine their condition and tailor rehabilitation.

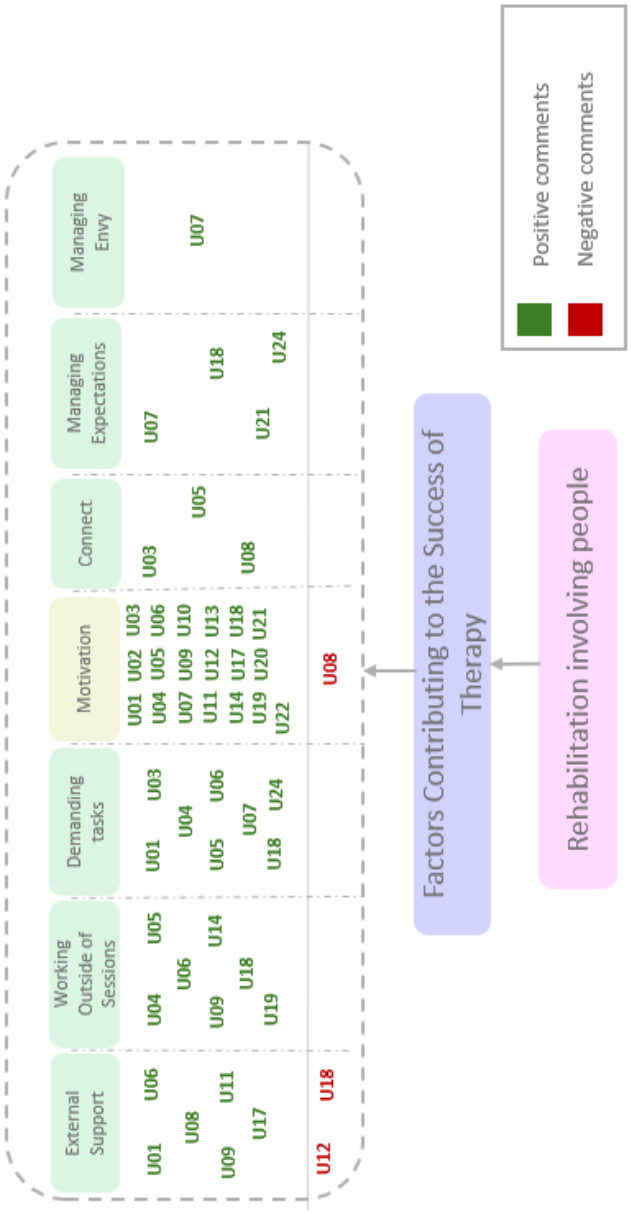


Fig. 5: Graph based on the affinity of participants' statements: Therapeutic dimension – Key factors in treatment effectiveness: Clinical parameters and contextual support.

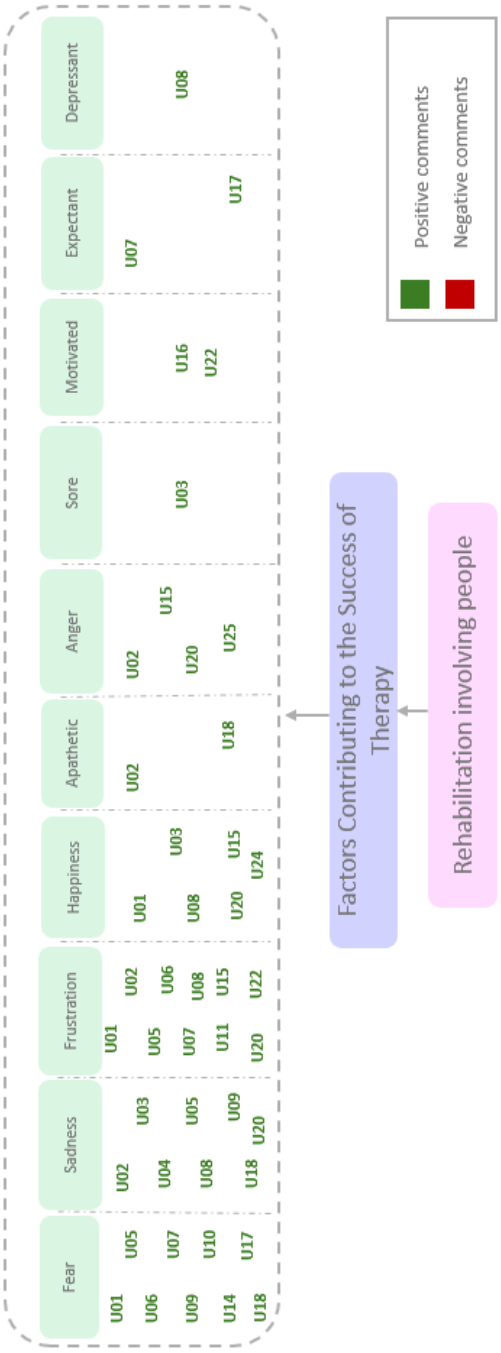


Fig. 6: Graph based on the affinity of participants' statements: Therapeutic dimension – Key factors in treatment effectiveness: The role of emotional and other psychological states in treatment effectiveness.

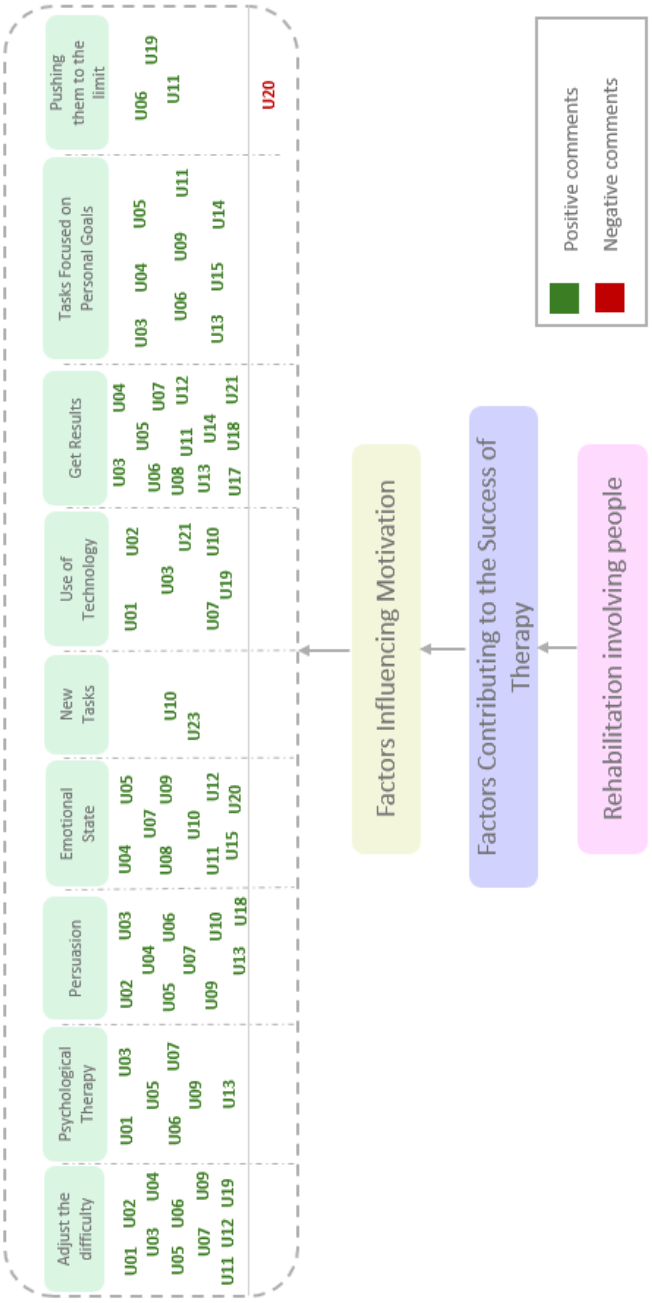


Fig. 7: Graph based on the affinity of participants' statements: Therapeutic dimension – Key factors in treatment effectiveness: Analysing the motivational component

Regarding the ***Benefits*** of integrating these systems, clinicians emphasize their ability to provide high-intensity training, specifically by enabling precise movements and a significantly higher number of repetitions than manual therapy alone. Additionally, within this framework of technology assisted rehabilitation, the innovative and novel nature of these devices acts as a powerful psychological catalyst, increasing patient motivation. To achieve these benefits, the ***System Input*** axis identifies the data that should feed the robotic platform. Professionals highlight facial expression and force as critical variables, alongside direct input from the rehabilitation specialist. Furthermore, the results point to a multi-input approach, where the system integrates diverse data streams such as physiological signals, facial cues, and speech to form a comprehensive understanding of the patient's state.

Correspondingly, the ***System Output*** axis describes the information the system should return to the health professional. Clinicians expressed a need for multidimensional feedback, including physical parameters, the emotional state of the patient, and a real time information (of the emotional state) during the execution of the tasks. Additionally, the generation of a final report is considered essential for long-term clinical monitoring. Finally, the ***Information Recipients*** category addresses the privacy and utility of this data. The debate among professionals suggests two primary configurations: systems where the information is for rehabilitation specialists only, or a shared model involving both the therapist and the patient, ensuring that the data serves as a motivational and clinical tool for both parties.

Finally, the ***Future Improvements*** axis (**Figure 9**) identifies the strategic advancements required to evolve current robotic platforms into more effective clinical tools. Based on the professionals' feedback, a primary requirement is the development of systems capable of facilitating natural movements, moving away from "robotic" or rigid trajectories to better mimic human biomechanics. Clinicians also highlighted the importance of registration outside of sessions, noting that tracking a patient's activity in their daily environment provides essential data to optimize in-person therapy.

To enhance functional recovery, the results suggest the integration of Extended Reality (XR) to simulate everyday tasks, which allow patients to practice personal goals in a safe, controlled environment.Furthermore, several technological avenues are identified as promising for increasing both patient autonomy and treatment efficacy, including autonomous service robots that assist with routine and logistical tasks in the therapy setting, music and rhythm-based interventions to enhance engagement and motor learning, and predictive systems that anticipate patient performance to adapt therapy parameters in advance. Lastly, the analysis underscores the need for accessible technology; professionals pointed out that current systems are often prohibitively expensive, suggesting that future design must prioritize cost-effectiveness to ensure these advanced therapeutic tools can reach a broader population of patients.

4 Discussion

The results of the thematic analysis provide a comprehensive blueprint for the next generation of personalised rehabilitation systems. By structuring the findings into the *Therapeutic Dimension*, this study reveals that professional practice is not merely

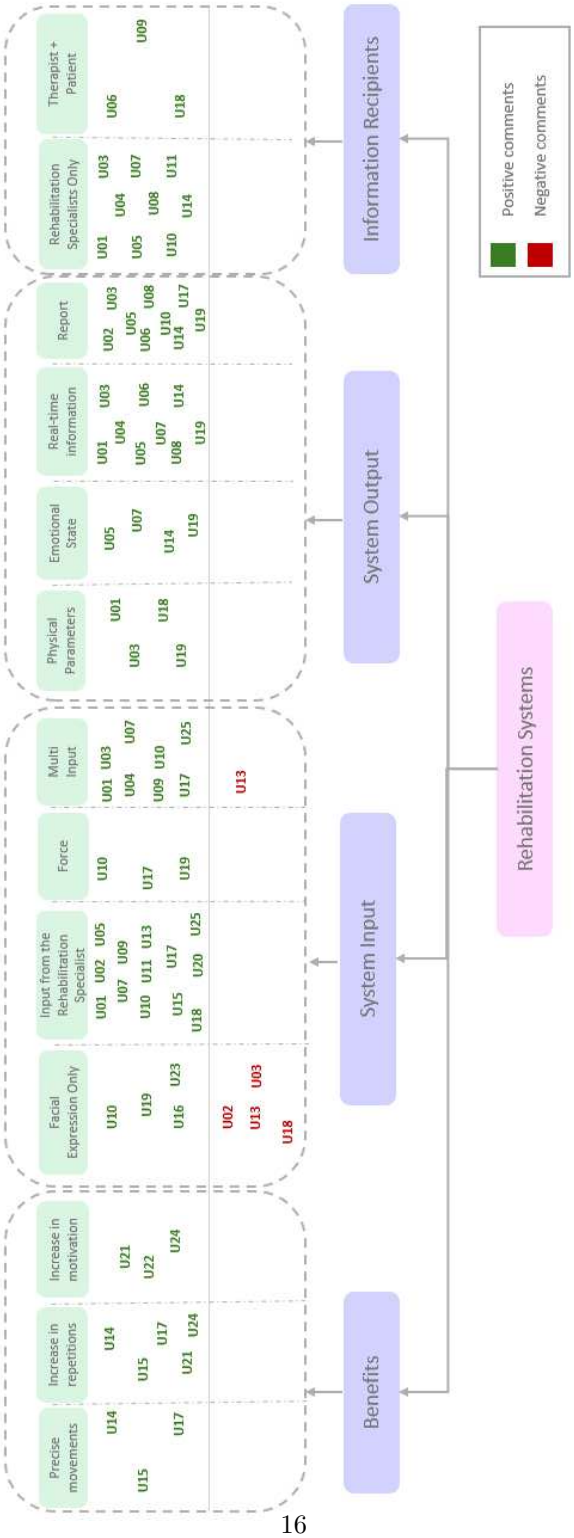


Fig. 8: Graph based on the affinity of participants' statements: Therapeutic dimension – Functional framework for rehabilitation systems and clinical effectiveness

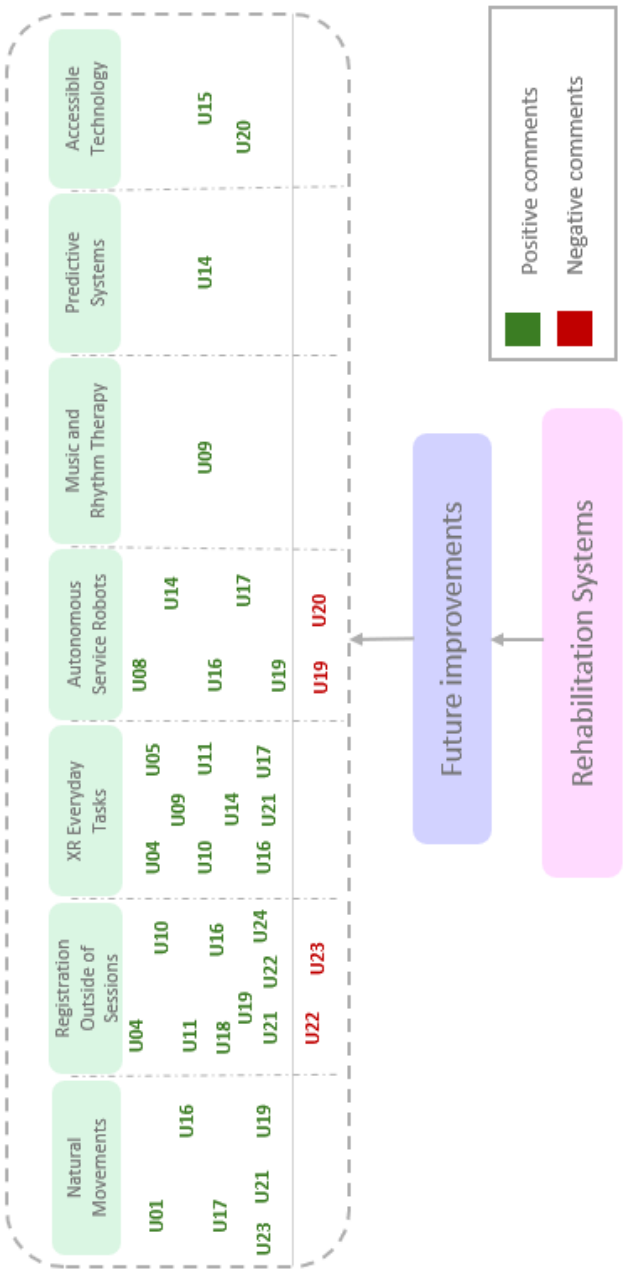


Fig. 9: Graph based on the affinity of participants' statements: Therapeutic dimension – Future improvements to rehabilitation systems.

a sequence of physical exercises, but a complex, adaptive process where emotional and human factors are as critical as the biomechanical ones. The clear bifurcation between *Human to Human Rehabilitation* and *Rehabilitation Systems* suggests that technological advancement must not only focus on mechanical precision but also on the robot's ability to integrate into the patient-therapist dyad. The high frequency of mentions regarding subjective indicators and motivational drivers underscores a clinical demand for systems that "perceive" the patient beyond their physical output. Current robotics, often limited to objective data, frequently fail to capture the holistic "clinical intuition" that professionals use to tailor interventions. The following sections interpret these findings to define how robotic design must evolve from mere mechanical execution to an empathetic, adaptive framework.

First section

Within the *Human to Human Rehabilitation* framework, professionals strongly prioritised functional, task oriented movements over static or purely repetitive mechanical exercises when discussing the type of exercise (**Figure 3**). Analysis of the participants' input shows that 5 clinicians explicitly advocated for dynamic exercises, while 3 highlighted the necessity of functional tasks, both receiving exclusively positive feedback. This preference suggests that robotic systems should not be limited to rigid, predefined trajectories, but should instead facilitate ecological movements that mimic daily life. As one participant noted: *"In rehabilitation, we focus on movement"*, reinforcing the idea that the value of therapy lies in the fluidity and purpose of the action rather than in displacement alone. Aligning with this, the robotic controller must prioritize bio-inspired fluidity over industrial precision, as static trajectories are perceived by clinicians as less effective for functional recovery.

Regarding the Settings to adjust, the high level of agreement among clinicians highlights the multi-parametric nature of physical therapy. A strong consensus was found for intensity, difficulty, repetitions, and force, each supported by 5 participants. Additionally, 6 clinicians favoured the adjustment of time, while 3 focused on the specific movement parameters such as range of motion, speed, or trajectory. The qualitative data reveals that these adjustments are not static. They are reactive to the patient's immediate state. For instance, regarding intensity, a clinician suggested a top-down approach: *U03: "But if you start at a fairly high level and then lower it as the patient can no longer cope"*. Such an approach mirrors the "human-in-the-loop" strategy where the therapist continuously monitors and scales the load to reflect real-time fatigue or performance loss. This indicates a need for robotic controllers that can sense fatigue or loss of performance in real-time.

Similarly, the adjustment of difficulty is perceived as a tool for emotional management as much as a physical challenge. One of our professionals highlighted the psychological risk of poor adjustment: *U06: "If someone comes to me feeling frustrated right from the start, I'm not going to give them something difficult"*. This insight is crucial

for robotic design, as it justifies the integration of emotional sensing to prevent frustration through automatic difficulty scaling. Difficulty should not be a fixed variable of the exercise, but rather a dynamic output of an affective computing model that recognizes the user's emotional baseline. Finally, the focus on variables that depend on "individual daily needs" such as strength, flexibility, coordination, and balance underscores that the success of the system depends on its versatility to adapt to the patient's evolving physical and mental state.

Second section

Within the same framework of *Human to Human Rehabilitation*, the analysis of how clinicians determine a patient's condition reveals a significant preference for qualitative indicators over purely physiological data (**Figure 4**). The sub-section of Subjective values received the highest density of professional consensus. Notably, facial expression emerged as the most critical parameter, with 18 clinicians favouring it positively (and only 2 negative mention), followed closely by postural cues (14 clinicians) and the ability to maintain a conversation (16 clinicians). Other relevant factors included the patient's willingness to be talkative (14 mentions), task execution (9 mentions), gaze (8 mentions), and appearance (2 mentions). These findings expose a clear misalignment between current robotic sensors—which prioritize vitals such as heart rate—and clinical practice, where social-sensing is the preferred method to assess engagement and mental fatigue.

The qualitative insights explain why these subjective values are prioritized. Clinicians use verbal and non verbal cues as a real-time proxy for physical exertion and mental state. Regarding the *"talkative"* and *"conversation"* codes, one professional noted the importance of monitoring *U06: "Breathing, and especially the face, and whether they stop talking when they exercise"*, while another highlighted that patients often provide direct feedback during dialogue *U01: "They might tell you, 'I'm really tired, I haven't slept'..."*. Integrating natural language processing and voice analysis would allow robots to capture the subjective states that currently escape automated systems. This suggests that a robotic system must not only track movement but also possess social sensing capabilities to interpret voice and silence as indicators of fatigue.

The physical presence of the patient, captured through postural and facial cues, provides immediate diagnostic value. As one participant remarked, "If I see him standing up, we'll just start working from there straight away", emphasizing that the assessment starts the moment the patient enters the room. Professionals also stressed that "non-verbal communication says a lot", particularly through gaze and eye contact: *"U05: You need to pay attention to... whether she looks down or looks you straight in the eye"*. Even the quality of task execution is filtered through the clinician's subjective lens. For example, execution speed is an objectively measurable parameter, but clinicians interpret it as a sign of progress or difficulty. Effectively, the system's intelligence should act as an extension of the therapist's own observational expertise, interpreting these complex signals in real-time.

With respect to facial expressions, clinicians use these cues to dynamically adapt the therapy sessions. As one professional explained, *U23: "Emotion is a reason to readjust. It's not just about muscle failure which is obvious, of course, as there's no doubt about that, but often, if you see that the patient is doing something yet seems unenthusiastic, isn't motivated or isn't putting in the effort as they should, then it doesn't make sense either, because there won't be any transfer."* This reflects why the majority of clinicians view facial data positively. However, it also presents challenges, as noted by another participant who highlighted the limitations of this metric, stating that *U22: "But it is true that sometimes facial expressions don't say enough either."*

Conversely, the *Target values* (objective physiological data) showed a much lower frequency of mention, with heart rate and respiratory rate supported by 7 clinicians each, followed by T-Body (trunk posture) (4), blood pressure (3), and shakiness or sweating (2 each). While these are recognised as "measurable indicators", clinicians often group them as secondary checks to their visual observation, as illustrated by the quote: *U09: "Heart rate, respiratory rate, body temperature and, of course, facial expression."* Here, physiological signals are listed alongside facial expression as additional cues, rather than as the primary basis for assessment. Failing to shift focus toward subjective indicators risks producing robots that are technically accurate but clinically irrelevant.
This hierarchy of information is crucial for the design of personalized systems: while sensors for vital signs are necessary for safety, the system's primary intelligence should be capable of interpreting the complex, subjective signals that human therapists prioritize.

Third section

The third pillar of *Human to Human Rehabilitation* examines the holistic elements that drive recovery. Within the Factors contributing to the success of therapy, the results show a clear mandate for extending care beyond the clinical setting (**Figure 5**). A significant consensus was found for working outside of sessions (7 clinicians) and implementing demanding tasks (8 mentions). Professionals emphasized that recovery is a continuous process, noting that *"U04: It would be good if we could keep a record when we're not working with them"*. Systems must therefore be able to monitor and document patients' activity outside formal therapy sessions to maintain this therapeutic thread. This highlights a design opportunity for portable or home based robotic extensions that support continuity of care beyond the clinic. Furthermore, the role of external support (6 positive mentions) and 2 negative ones, in which clinicians explain that the relationship with external support can sometimes be complicated *U08: "His family would say to him, 'Dad, you don't look well,' and that made him sad"* and *U12: "Sometimes family life can be really stressful, so they come here to unwind"*. For the last two parts, the ability to manage expectations (4) and envy (1) underscore the social complexity of rehabilitation.

However, the most prominent factor identified was motivation, with an overwhelming consensus of 19 clinicians. Professionals describe motivation not as a static state, but as a result of constant reinforcement: *U05: "Even if it's just a small step, we... make them understand just how important that change is for achieving the ultimate goal"*. This qualitative evidence suggests that robotic systems must provide meaningful feedback that translates small physical gains into progress toward the patient's goals. When motivation dips, clinicians use a "pushing" strategy: *U02: "Come on, let's give it another go... we need to push them a bit further"*. Emulating this motivational loop through gamification or AI-driven encouragement could trigger engagement at the moment of peak cognitive load, rather than just delivering quantitative data. Interestingly, there is one professional who views him in such a negative light that it could distract him from his objectives with that patient exposing: *U08: "Sometimes someone comes into therapy really motivated and focuses on walking, and doesn't pay any attention to you"*.

Third section - second part

This motivational drive is inextricably linked to the patient's emotional landscape (**Figure 6**). The analysis reveals that therapy is often a journey through negative states before reaching positive ones. Clinicians frequently identified fear (9 mentions), frustration (10), and sadness (8) as the primary emotional barriers. As one participant reflected: *U05: "At first, they were mainly terrified and trying to come to terms with everything that had happened to them"*. The transition from being *"down, sad and frustrated"* to becoming *"hopeful"* is the core of the therapeutic success. Other mentioned states such as happiness (6), apathy (2), anger (2), expectancy (2), and depression (1) complete a spectrum that the system must be able to recognize to adapt its intervention. Emotional intelligence becomes a prerequisite for design; without detecting this spectrum, the robot remains blind to the primary barriers of recovery.

Third section - motivation subsection

The subsection *Factors influencing motivation* (**Figure 7**) provides the technical "cues" to manage these emotions. The most cited strategies include reaching the goals of the therapy (13 clinicians) and adjusting the difficulty (11). The latter is particularly critical, as clinicians recognize that physical load is also an emotional load: *U01: "When I push you physically, I push you emotionally too"*. To manage this, professionals employ persuasion (10 mentions) sometimes through "pious lies" to boost confidence (*U18: "I tell them they've reached [the goal]... and that's how I get them to reach 4"* and psychological therapy (7 mentions), emphasizing that sometimes patients clearly state this need *"U01: just needed 10 minutes to talk to someone and get things off my chest"*. These empathetic, affective focused strategies indicate that robots should incorporate adaptive verbal feedback and motivational-behavioural prompts to support patients during moments of emotional vulnerability.

With clinicians repeatedly reporting what they perceived as a "100% correlation"

between the patient's (physical and emotional) state and their performance, the findings suggest that both tasks focused on personal goals (9 mentions) and the use of technology (7) must be modulated by the patient's emotional state (10). A robot that ignores the fact that patients who present with clear signs of sadness or low mood typically show reduced performance is destined to fail in a real clinical environment. Integrating this emotional information into the control loop helps prevent the "performance trap", in which physical demand is increased regardless of the patient's mental readiness.

Fourth section

The transition from human factors to technical architecture is defined by the *Rehabilitation Systems* axis (**Figure 8**). Regarding the *Benefits* of these systems, a balanced consensus was found among 3 clinicians who prioritized the achievement of precise movements and another 3 who highlighted the increase in repetitions (even though there are five clinicians who have spoken positively about this). These technical advantages are seen as a necessary complement to manual therapy, allowing for a level of intensity that is difficult to sustain physically by the therapist alone. The robot's primary role is thus the augmentation, not the substitution, of the therapist's labour. Furthermore, another group of 3 clinicians highlighted that a major benefit of these rehabilitation systems is their capacity to increase patient motivation. This psychological advantage is illustrated by *U21: "As far as robotic systems are concerned, I do think it plays a role, in terms of motivation, for example. Speaking of the patient, this is very important, because there are people (and I'm not suggesting it's a placebo effect, far from it) for whom that motivation, the fact that someone who likes technology sees that it can help them, or simply has that positive attitude towards this new device, is already going to be a very positive thing."*

However, the design of the *System Input* reveals a clear preference for human-centred control. While facial expression as a direct system input is debated (4 in favour, 4 against), clinicians acknowledge its diagnostic power in their own practice, stating for example: *U19: "It's mainly the face that gives me the most information"* and *U10: "Facial expressions tell you a great deal"*. Conversely, those who oppose using facial expressions as a direct input raise concerns about both the robot's role and the reliability of patient expressions. On one hand, some clinicians believe that adaptation is unnecessary, with *U13 arguing: "I don't think it should adapt to a person's emotional and physical states. The robot is like a game or anything else you might have."* On the other hand, others point out the physiological limitations of relying on such cues, as noted by *U18: "There's a wide range of patients in our field who have 'poker faces' – whatever their emotion, you won't be able to tell."*

Despite this, there is a strong consensus for input from the rehabilitation specialist (13 clinicians) to remain the primary control signal, as therapists rely on their own intuition to manage the technology: *U17: "As a therapist, I rely first and foremost on my own judgement, and I adjust any type of device based on that"*. Therapists

view robots as instruments for their own intuition. Consequently, the most successful systems will provide actionable, transparent data rather than autonomous, "black-box" decisions. Other inputs identified include a multi-input approach (8 clinicians), in which the system combines several sources of information instead of relying on a single signal, and the direct measurement of interaction forces (3 clinicians).

Regarding the System Output, the demand for real-time information (9 clinicians) and a detailed report (9 clinicians) is driven by the need for immediate adjustment and long-term motivation. Clinicians also identified physical parameters (4 clinicians) and the emotional state of the patient (4 clinicians) as necessary outputs. The importance of the report is directly linked to the patient's progress: *U17: "Changes happen gradually over time, and I believe the patient is motivated when they look back and see everything they've achieved"*. Furthermore, the technical performance must ensure zero latency: *U01: "Because with delays, you can't analyse it as you should, but the fact that it can give me instant information is what allows me to adjust that session"*. Low latency is a clinical necessity for real-time responsiveness, which the robot must facilitate to earn the professional's trust.

Regarding the distribution of clinical data, the *Information Recipients* axis shows a marked preference for specialized management. A total of 9 clinicians stated that the data should be for rehabilitation specialists only, while 3 clinicians favoured a shared model involving both the therapist and the patient. This distribution indicates that, while progress should be shared to motivate the user, the core clinical data must remain under professional interpretation. A hierarchical data architecture is required where the robot serves the therapist's diagnostic process first, and the patient's motivational process second.

Fifth section

Looking ahead, the *Future Improvements* reported by the participants reflect a clear ambition to overcome current technological constraints (**Figure 9**). The most significant consensus for future development is the integration of VR (Virtual Reality) for performing everyday tasks, supported by 8 clinicians. While professionals acknowledge that *U17: "VR can be distracting"*, they emphasize its therapeutic value because *U17: "it helps with motivation"*, allowing patients to practice functional goals in immersive environments. This vision is complemented by the demand for registration outside of sessions (9 clinicians), which would allow for a continuous monitoring of the patient's exercise performance. The future of rehab robotics lies in an ecosystem that bridges the hospital and the patient's daily environment. As one participant noted: *U04: "It would be good if we could keep a record when we're not working with them"*, adding that if home sessions could capture that data, *"that would be wonderful"*, allowing therapists *U21: "to have eyes where we are not"*. However, this continuous monitoring outside the clinic also raises mixed opinions regarding its suitability and psychological impact. On one hand, *U22* highlighted both the potential and the limitations depending on the individual, stating: *"As regards the use of technology in*

sessions, I think there are certain types of patient for whom it might not be entirely suitable, whilst for others it might actually be quite motivating". On the other hand, the risk of patient resistance and the artificiality of feeling monitored was raised as a negative factor by *U23: "Some people have that feeling of being constantly watched, don't they? It's happened before. Yes, yes. And it's tricky because there's really no point in doing it just because I tell you to. At the end of the day, the clinic isn't a real-life setting; what we need to do is transfer it to real life. But if you're only doing it because the physio tells you to... That's no good."*

Another critical frontier is the physical interaction itself. A total of 6 clinicians advocated for the development of natural movements, expressing a core limitation of current technology: *U17: "As a clinic, our greatest ambition would be to design a device that fits the human body perfectly, but none do"*. This highlights a clear engineering challenge for future exoskeletons and robotic platforms to move away from rigid mechanical design and prioritize bio-inspired fluidity. Furthermore, the role of autonomous service robots (5 in favour, 2 against) reflects an interest in systems that can assist patients independently, although the single dissenting voice suggests persisting concerns about safety or the loss of the human touch. The dissenting voices regarding autonomous service robots act as a warning: they must never sacrifice the human touch, which remains the ultimate therapeutic factor.

Finally, the results point toward specialized and inclusive innovations. Although mentioned by individual clinicians, the inclusion of music and rhythm therapy, predictive systems, and accessible technology represents the diverse needs of the field. The call for accessibility is particularly relevant, as high costs currently limit the reach of these advanced tools. By evolving toward more natural, immersive, and data continuous systems, the next generation of rehabilitation robots can transition from being mere exercise machines to truly integrated clinical partners. Ultimately, the value of the technology lies in its ability to support the clinician's unique ability to read, understand, and push the human patient toward recovery.

5 Design Guidelines

The synthesis of clinical expertise and the aforementioned methodological principles points to a set of key aspects that should be considered in the design of the next generation of rehabilitation robots:

Multimodal input for robust patient assessment:

Future systems must implement a hybrid evaluation model that mirrors the clinician's multi-sensory intuition. Design should prioritize facial expressions as the primary subjective window into the patient's internal state. However, to ensure reliability and cross-validate these visual cues, the system must integrate objective physiological data, specifically heart rate and respiratory rate, which clinicians identify as the most trustworthy indicators of physical effort and internal stress during therapy.

Motivational control and affective adaptation:

Given that intrinsic motivation is the central pillar of recovery, robotic control algorithms must transcend simple kinematic assistance. The system should be designed to actively foster engagement by dynamically rebalancing the challenge-skill ratio in real-time. This involves the automatic adjustment of intensity parameters such as force, speed, and repetitions, to pre-emptively mitigate states of frustration and fear, which are the most prevalent emotional barriers identified by professionals in this study.

Transparency and Human-in-the-Loop integration:

The clinical acceptance of adaptive robotics hinges on a design that enhances, rather than replaces the "human touch." Systems must maintain a human-in-the-loop architecture where the robot operates under the direct supervision of a specialist. Operational transparency is vital. Thus, the system must provide real-time physico-emotional reports to both the therapist and the patient, ensuring that clinical judgment remains the final arbiter of the therapeutic process.

Ecological and functional relevance:

To facilitate the transition from clinical centres to the patient's home, design guidelines must favour functional movements that are representative of daily activities. Integrating activities of daily living (ADL) through accessible interfaces such as extended reality ensures that the exercises performed with robotic assistance have high ecological validity and contribute directly to the patient's functional autonomy.

6 Limitations and future work

While this study provides a robust qualitative framework for understanding the clinical requirements for emotionally adaptive rehabilitation robotics, several limitations must be acknowledged to contextualize these findings. First, the sample size, though representative of specialized clinical perspectives, reflects a specific regional practice. Future research should aim to expand this study to a more diverse international clinical population to determine if cultural variations in patient-therapist communication patterns affect the perception of robotic feedback. Second, the reliance on subjective professional insights, while invaluable for identifying the human-in-the-loop requirements, should be complemented by longitudinal data. Future studies should quantify the correlation between the emotional cues identified by clinicians (such as facial expressions and conversational tone) and the actual physical performance metrics of patients during robotic-assisted sessions. This would allow for the development of validated *emotional-to-physical* mapping algorithms that are currently missing in the literature.

Regarding future developments, our findings highlight the importance of transitioning robotic design from reactive to proactive systems. The clinical requirement for "social-sensing" and real-time fatigue monitoring suggests that the next generation of rehabilitation devices should move beyond simple biomechanical measurement. Future

work should prioritize the integration of multimodal sensory inputs, specifically computer vision and natural language processing, into a unified control architecture that can interpret subtle shifts in a patient's emotional state. Furthermore, the growing emphasis on extending care beyond the clinical setting offers a compelling design opportunity for home-based robotic-assisted rehabilitation. Developing compact, accessible interfaces that maintain the therapeutic thread between hospital sessions could improve recovery outcomes.

7 Conclusions

This study investigated the clinical integration of emotionally adaptive robotic systems, aiming to bridge the gap between advanced mechanical rehabilitation and the nuances of real-world clinical practice. Through twenty five semi-structured interviews, we explored the intersection of physical performance and emotional well-being, identifying the key factors that currently hinder the adoption of robotic platforms. Our findings reveal that clinicians prioritize patient motivation as the primary predictor of recovery. A key insight from our study is that while current robotic systems excel at kinematic precision, they lack the affective intuition that therapists use to assess fatigue, frustration, and engagement in real-time. Consequently, the success of future systems depends on their ability to act as collaborative agents that support, rather than automate, the therapeutic decision-making process.

This work contributes to the field by proposing a framework of design guidelines intended to steer developers toward more intuitive, user-centred robotics. Future systems must implement hybrid evaluation models that combine subjective cues, such as facial expressions, with objective physiological data like heart rate to mirror the clinician's multi-sensory diagnostic approach. Furthermore, control algorithms must transcend simple kinematic assistance by dynamically rebalancing the challenge-skill ratio to foster intrinsic motivation and pre-empt emotional barriers like frustration. To gain clinical acceptance, these robots must operate within an architecture that empowers the therapist with real-time physico-emotional feedback, ensuring that clinical judgment remains the final arbiter of the therapeutic process. Finally, future design must evolve toward ecological validity, integrating activities of daily living through interfaces like XR to ensure that therapeutic gains translate effectively from the clinical setting to the patient's home.

Taken together, these guidelines provide a roadmap for developing the next generation of rehabilitation robot technologies that are not only technically robust but also clinically trusted, usable, and aligned with the complex reality of human-based recovery. By placing the clinician and the patient at the centre of the design process, we can transition from current isolated robotic tools to holistic care partners, significantly enhancing the efficacy and human-centrality of modern neurorehabilitation. Looking ahead, the future of this field lies in creating systems that are not just mechanical exoskeletons, but integrated, empathic partners capable of modulating

their intervention strategy in real-time, thereby moving closer to the clinical ambition of fitting the complex, evolving needs of the human body and mind.

List of abbreviations

AAN: Assistance-As-Needed
ADL: Activities of Daily Living
EMG: Electromyography
GSR: Galvanic Skin Response
ROM: Range of Motion
VR: Virtual Reality
XR: Extended Reality

Declarations

Ethics approval and consent to participate

This study was approved by the Research Ethics Committee of Mondragon Unibertsitatea (Internal code: IEB-20251110). All methods were carried out in accordance with relevant guidelines and regulations, including the Declaration of Helsinki. Written informed consent was obtained from all participants prior to their participation in the study.

Consent for publication

Not applicable.

Availability of data and materials

The interview script used to collect data during this study is included within the article as Appendix A (Tables 2 and 3). The interview transcripts generated and/or analysed during the current study are not publicly available due to confidentiality agreements with participants but 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

I.S.B, A.S.M and V.R.G conceived and designed the study. I.S.B and A.S.M conducted the interviews and performed the affinity diagramming analysis. I.S.B drafted the manuscript. All authors read and approved the final manuscript.

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Table 2: Complete Semi-structured interview script for clinicians

ID	Interview Questions / Topic
Block 1: Introductory Questions	
1.1	Could you briefly describe a typical rehabilitation session? *Follow-up:* What types of exercises do you use most frequently (e.g., rhythmic, 2D/3D, assisted/resisted)? *Follow-up:* Which parameters do you adjust to modify intensity (e.g., force, speed, Range of Motion (ROM))?
1.2	What do you look for to determine if a patient is ready for a session? *Follow-up:* How do you decide which methodology to apply in each case?
1.3	What objective and subjective measures do you use to evaluate patient progress?
Block 2: Emotional Experience in Rehabilitation	
2.1	Which emotions do you observe most frequently at the start and during sessions? *Likert:* Frequency of positive/negative emotions observed (1–5).
2.2	What differences do you perceive in results when the patient presents different emotions? *Likert:* Influence of emotions on physical performance (1–5). *Likert:* Influence of motivation on treatment adherence (1–5).
Block 3: Current Strategies and Emotional Perception	
3.1	Which signals help you identify the patient's emotional state (e.g., facial expression, speech)? *Likert:* Ease of identifying the patient's emotional state (1–5).
3.2	Do you adjust the therapy based on the emotions or sensations observed? *Follow-up:* If yes, how? If no, why? *Likert:* Effectiveness of these adjustment strategies (1–5).

Table 3: Complete Semi-structured Interview Script for Clinicians

ID	Interview Question / Topic
Block 4: Perception of Emotionally Adaptive Robotic Systems	
4.1	What role do you think technology can play in supporting your work and patient recovery?
4.2	Should a robot adapt to emotional variations (e.g., frustration, fatigue) in addition to physical ones? *Follow-up:* If yes, how? If no, why? *Likert:* Perceived utility of such a system (1–5).
4.3	What signals would be useful for a system to identify emotional state or effort (e.g., HR, EMG, posture)? *Likert:* Degree of reliability attributed to these signals (1–5).
4.4	If the system detects frustration or exhaustion, what response would be most appropriate? *Likert:* Importance of the system adapting its response in real-time (1–5).
Block 5: System Design and Control	
5.1	What level of autonomy would be appropriate (e.g., automatic intensity adjustment)? *Follow-up:* What parameters would you consider when assessing this autonomy?
5.2	Would you like to receive alerts or reports on the patient's state during system use? *Likert:* Desired level of detail for these reports (1–5).
5.3	How do you imagine the ideal role of an emotionally adaptive robot in the future? *Likert:* Desired level of integration with clinical practice (1–5).
Closing	Is there anything you would like to do with your patients that technology cannot currently do? *Likert:* Relevance of such a function for your clinical practice (1–5).

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