Research Article

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# Exploring technical implications and design opportunities for interactive and engaging telepresence robots in rehabilitation – results from an ethnographic requirement analysis with patients and health-care professionals

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**Abstract:** This paper explores technical implications and design opportunities that are conceptualized to inform a socio-robotic system with digital applications to support the recovery process of patients within a rehabilitation facility. By conducting observations and interviews with patients and therapists, we identified key challenges and design opportunities in a specific orthopaedic rehabilitation context and process. The findings indicate the design potentials of a socio-robotic system to enhance patient engagement and recovery by providing personalized activities, a meaningful interaction and a motivating surrounding by using music-based exercises. Our research suggests that integrating digital applications with robotic systems may be used in the long-run to offer tailored exercises, stimulating concepts to motivate and maintain patients in therapy process, real-time feedback, and data-driven progress tracking, thereby improving the overall therapeutic outcomes. By addressing these factors, our proposed socio-robotic system aims to create a more interactive and engaging orthopaedic rehabilitation experience and environment, ultimately supporting patient recovery and improving overall treatment.

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## 1 Introduction

In our ageing population, on the one hand there is a steadily increasing demand for healthcare workers, but on the other hand there are fewer and fewer employees to meet this demand. While 6.8 percent of the jobs needed in the healthcare sector were already unfilled in 2022, this proportion is expected to rise to 35.4 percent in 2035.[1] While 20 percent of the population of Germany was over 60 years old in 1990, today 30 percent of the population is already over 60. This proportion is expected to rise to 35 percent by 2050.[2] A similar trend can be observed around the world, which according to Sander et al. brings with it the following challenges: "*the biological challenge is to retain a high level of physical and mental capacity in late stages of life; the social challenge is to optimize the retirement age and the cultural challenge is to provide older individuals with the opportunity to live with purpose and dignity*".[3] Sander et al. also state that new solutions are therefore needed to meet these challenges.[3] As a result of the shrinking workforce, demographic transition and aging societies, the need for long-term care, therapy and rehabilitation is increasing.

Especially rehabilitation is a complex, multifaceted process that involves overcoming numerous challenges.[4] For patients, these include managing the treatment and administrative obligations, maintaining motivation, and navigating access to recovery.[5] For therapists, the challenges encompass addressing individual patient needs, managing workload and daily changes in staff constellations, and staying current with changes in therapy recommendations. Furthermore, high patient loads, long hours, and the emotional situations of working with individuals who had an accident, trauma or may have slow or difficult recoveries contribute to physically demanding and mentally challenging situations for therapists.[6]

In Germany, where the study takes place, rehabilitation is integrated into the social insurance system and is predominantly managed by the German statutory pension insurance (GPI), statutory health insurance, or private health insurance.[7] Unlike other countries where outpatient interventions are more common, Germany primarily conducts rehabilitation as 3- or 4- week inpatient programmes in specialized facilities, though outpatient or semi-inpatient options closer to patients' homes are becoming increasingly available.[8]

One possible approach in solving some of these challenges lies in assistive technology and even more specific in the research field of social robotics. In recent years, further development in this area has already led to numerous investigations into how assistive technology and especially social robots can help with work in the healthcare sector.[9–13] However, the focus has mainly been on the use of robots in the field of care in hospitals and nursing homes.[14,15] These areas are also the focus of political decisions, while rehabilitation facilities have so far played a rather subordinate role.[16] Nonetheless, the ageing population is also leading to a similar overload in the rehabilitation sector as in other areas of healthcare.[17] As the need for rehabilitation services rises sharply, especially in old age, the situation is expected to become more severe.[18]

One of the biggest challenges in developing and implementing socio-robotic systems in rehabilitation is acceptance by patients and therapists. It is therefore important that these systems are perceived as supportive tools and not as a substitute for human interaction. Ethical considerations regarding data protection, autonomy and the potential misuse of robots must also be taken into account.[19–21] However, as Dewsbury et al.[22] argue in their critique of existing disability models, assistive technologies often risk reinforcing institutional barriers or being developed without adequately addressing the lived experiences and diverse needs of disabled individuals. To address this concern, this research aims to incorporate participatory and inclusive design principles by analysing the experiences of the target group.

In this paper, we report on results from an exploratory study that aimed at better understanding of individual and institutional requirements and deriving technical and design-related implications for a robotic-prototype to support both, the motivation and engagement of patients in their individual recovery process as well as health-care professionals in their daily work in orthopaedic rehabilitation. To this end, the authors conducted semi-structured interviews and observations in an orthopaedic rehabilitation facility in <anonym city> to gather insights into the everyday life of patients and therapists. The cooperating rehabilitation institution is an interdisciplinary rehabilitation and health facility that offers a wide range of services focused on prevention, therapy, and recovery. It is closely connected to the <anonym> Hospital, ensuring seamless medical care and access to specialized expertise. The facility specializes in ambulatory rehabilitation, including orthopaedic and cardiological rehabilitation, and provides post-therapy programs to support recovery and reintegration into daily life. Services also include physiotherapy, manual therapy, rehabilitative sports (such as heart and lung training), and fitness programs aimed at both recovery and prevention.

Based on our qualitative findings, we highlight technical features, their interactive implications and design opportunities that informed our final system design and technical infrastructure. Afterwards, our system was designed and developed to be deployed in the cooperating rehabilitation facility to accompany orthopaedic patients between their 3–4 weeks rehabilitation-program. Our work in particular focuses on three research questions: (1) How can a socio-robotic system be designed to address the individual needs and preferences of patients undergoing orthopaedic rehabilitation? (2) What are the key institutional requirements for successfully designing a socio-robotic system in an orthopaedic rehabilitation facility? (3) What are the technical challenges and opportunities in developing a socio-robotic system with integrated digital applications for orthopaedic rehabilitation?

# 2 Related work

Our work is informed by research on the use of social robots and music in the context of rehabilitation. We define rehabilitation as all therapeutical, care-focused and medical services that serve to "avert, eliminate, reduce or compensate for a disability or need for care, or to prevent its worsening or mitigate its consequences".[23]

## 2.1 Social robots in rehabilitation

Socio-robotic systems are interactive robots that are designed to interpret and respond to social signals.[24] Social robots in rehabilitation and care can interact with humans using various sensors such as cameras, microphones and touch sensors.[21] They are able to recognise and respond to gestures, facial expressions and speech, making them valuable tools in therapy.[25] Socio-robotic systems can for example be used in motor rehabilitation to help patients regain their movement skills. In recent years, the use of robotics in rehabilitation has increased significantly. Socio-robotic systems in particular, which combine social interactions and practical applications, open up new possibilities for supporting patients with different health challenges.[14,26] These systems combine technological innovation with social relevance to develop effective and user-friendly rehabilitation methods. A socio-informatic and practice-based approach is particularly relevant in the development of technology and robots, as it takes into account the social, cultural and individual needs of users. This promotes the acceptance and effectiveness of the technology, as the systems are directly tailored to the real-life conditions and requirements of patients. In rehabilitation, it is crucial that the technologies are not only functional, but also take into account the social dynamics and therapeutic needs of patients.

Compared to other devices, social robots can increase the engagement of patients. This is due to embodiment, mobile navigation and multimodal and interactive capabilities.[27] The high engagement of the patients, along with positive feedback, was seen in Ref.[28] where a long-term intervention with the robot Pepper was conducted. However, social robots assist the therapist, but cannot replace them.[29] An important aspect of rehabilitation with social robots is persuasiveness, i.e. the robot must encourage the patient to perform certain activities. In this context, a goodwill or similar character is advantageous.[30] To encourage patients to become more active, social interaction may be important, and here experiencing fun on the side of the patient may be especially beneficial.[31] In this context, also trust of the patient in the robot is relevant.[29]

Polak et al. developed a guideline based on experts evaluation for the use of social robots in rehabilitation.[28] Main aspects of the guideline are that a variety of tasks with different levels of difficulty should be available and the feedback should be given in an appropriate manner. Moreover, the interaction should be personalised to the patient. This was also addressed by Winkle et al., where improving the ease of access is also mentioned.[27] In addition, studies have shown that interactive robots such as NAO and PARO can be used effectively in post-stroke rehabilitation. These robots offer exercises, provide feedback and motivate patients through their social interaction. A study by Fasola et al. showed that socio-robotic systems can increase patient motivation and engagement, leading to better therapy outcomes.[32]

Social robots that provide emotional and physical support are playing an increasingly important role in the rehabilitation of older and disabled people.[33] These robots not only contribute to physical recovery, but also to the emotional well-being of patients. The COVID-19 pandemic has further emphasised the importance and potential of social robots, as they are able to provide social interactions and support in times of isolation. A study by Bemelmans et al. showed that the use of robots such as PARO in care facilities led to a significant improvement in the emotional well-being of residents.[34]

## 2.2 Creative interventions and the role of music in rehabilitation

In the field of human-computer-interaction, design for emotional engagement and psychological well-being is becoming increasingly important.[35–38] This is especially crucial in contexts such as rehabilitation, where fostering motivation can significantly impact therapy success.[39]

Various technology-supported activities have already been implemented to facilitate interaction between people, including sports activities that enable running together over a distance.[40–42] Research has shown that such technology-enabled approaches can have a positive impact on participants. One therapy with significant potential in rehabilitation is music therapy. Studies have demonstrated that it can not only reduce perceived pain and effort but also alleviate social isolation while enhancing self-efficacy and mood.[43–45]

There is a wide range of literature on HCI in the context of music. Much of it covers aspects of music production (e.g. Ref.[46,47]) which is clearly beyond the remit of this paper. A similarly divergent literature is interested in how computer systems might contribute to aspects of performance (e.g. Ref.[47–49]), composition (e.g. Ref.[50]) and more musicological interests such as genre classification (e.g. Ref.[51]). In this respect, and somewhat closer to our own interests, is a small body of research that looks at how to relate music to fitness-based activities[52,53] and rehabilitation (e.g. Ref.[54]). Some work has also taken a design perspective on the relationship between music, auditory cues and cognition.[55]

The interface between music and HCI, also known as music interaction, has made significant progress in recent decades.[56] This design implication explores, how music can be used as a medium to enhance user interaction with digital systems. It analyses the cognitive, emotional and behavioural effects of music on the user experience and develops new technologies and methods to apply these findings in practice. Current fields of research include adaptive music systems, music-based gamification, therapeutic applications, the integration of AI into music systems and multisensory music interaction.[57]

It was shown by[58] that music listening can improve recovery after stroke, which may include cognitive, emotional and anatomical aspects. Furthermore, a positive effect of music on mood and arousal has been demonstrated. It was shown that music can be a motivator to do activities[59] and reduce the discomfort and difficulty perceived with activities.[60] The potential of music in rehabilitation was shown in for example[61] where musical rhythm could be used to train movement pattern in patients with movement-related disorders.

# 3 Methods

## 3.1 Research approach, setting and objectives

Within our research framework we conduct a design case study following the methodology as Wulf et al.[62] originally articulated. This research approach is characterized by three ideal stages: (1) a pre-study to develop an understanding of people's experiences, needs, and expectations, (2) a design-phase to iteratively design, evaluate and re-design the prototype, and (3) an appropriation study in which we investigate how residents and caregivers used our system. Beyond this, our approach was shaped by a particular praxeological understanding of design research – Ref.[63] that is based upon the conjoint pursuit of design case studies and grounded design.[64] Following the suggestions of Dewsbury et al., our aim is to place the needs of stakeholders at the centre of the system's design.[22] Here, we focus on the results of the pre-study, for which we followed an ethnographic approach[65] to better understand the context in which the prospective technology might be deployed. This qualitative approach consists of field notes from three observation days in a rehabilitation facility, where three researchers were each able to accompany a physiotherapist through their daily routine and ask questions if necessary, and semi-structured interviews with rehabilitation patients. The aim was to cover the views of both patients and professionals. Our research aim on a close collaboration between the targeted application area and the diverse stakeholders involved.[66] The participatory inclusion of users and stakeholder takes a special focus in this context. The practical partner institution in <anonym> is an interdisciplinary rehabilitation and health facility that offers a wide range of services focused on prevention, therapy, and recovery. Established in 2005, it is closely connected to the <anonym> Hospital, ensuring seamless medical care and access to specialized expertise. The facility specializes in ambulatory rehabilitation, including orthopaedic and cardiological rehabilitation, and provides post-therapy programs to support recovery and reintegration into daily life. Their approach emphasizes personalized therapy plans tailored to individual needs, with a focus on integrating rehabilitation into patients' everyday routines for sustainable health outcomes. The facility is certified for high medical standards and collaborates with various health insurers to ensure accessible care.

### 3.1.1 Project background and objectives

Our project in the orthopaedic rehabilitation facility followed a participatory research approach to ensure that the system addressed the diverse needs of all stakeholders involved. Through a series of information events, interviews and workshops with the facility's management, we also actively engaged key decision-makers to collaboratively identify and prioritize technical functionalities and to develop a long-term strategy. This process allowed us combine the perspectives and design a system tailored to the rehabilitation context and follow long-term objectives and serving multiple purposes, such as: navigating in large environments, enabling meaningful interactions with patients through music, detecting exercises performed by patients in front of the robot, and analysing these exercises to provide valuable feedback to professional therapists. To meet these diverse requirements, we selected the robot temi which fulfils all the demands and features specified by the management and stakeholders.

## 3.2 Data collection and analysis

In our pre-study we explored the existing individual perspectives of patients, as well as the multi-professional practices, organisational and individual work-flows and social routines in the multi-professional teams as well as challenges that various professionals in rehabilitation-facilities face in their everyday surroundings. In this way, participant observations could be methodologically flexible and open in order to capture emergent phenomena in the field. At the same time, the observation was guided by the clear interest of finding out what a helpful technical system could look like and how it could be implemented. Notes and memos were taken continuously and systematically to support reflection and data analysis.[65] This process led us to 15 pages of field notes in total and included a broad interview study conducting 14 semi-structured interviews with patients of the cooperating rehabilitation facilities.

The interviews were conducted on several days in presence at the rehabilitation facility. All interviews were scheduled into the patients' rehabilitation program. These interviews covered four areas: Firstly, personal rehabilitation training was addressed: (How) are specific exercises, for example, successfully taught to patients and is there sufficient supervision and feedback when performing them? What does the latter ideally look like for the patients? Secondly, the individual influence of music on motivation was analysed before the subjective affinity for technology was briefly surveyed. Finally, the project plan to temporarily introduce a music-induced, robotic movement system was presented, and attitudes and ideas about how this could be designed were asked.

The transcripts were coded and categorised using the MAXQDA program[67] and then evaluated using qualitative content analysis.[68] For this purpose, the transcripts were analysed in an iterative process, statements were categorised and then a hierarchical category system was created as described in the inductive categorisation method by Kuckartz & Rädiker.[68] Based on that the subsequent summary and analysis was done in a category-oriented manner according to the qualitative content analysis.

The field notes and the interviews complement each other, as they create a sound basis for our design on two levels. On the one hand, the participant observation enabled us to understand on a general level how the robot can be used profitably in the daily routine and which exercises are both helpful and safe for all patients. For example, the research team quickly realised that the robot should be used during a so-called active break, and some exercises were identified that could be performed by knee, hip as well as shoulder patients, for example. On the other hand, in addition to these general social conditions, the interviews made it possible to determine the individual technical needs of the patients, as the technological design had to be adapted to the needs of a group that consists mostly of older individuals, which led, for example, to the use of a sans-serif typeface and a large font size on the tablet. In general, it can be said that the participatory observation served as a generator of context knowledge by personal experience.[65]

### 3.3 Sampling and participants

Both the treatments observed on the observation days and the people interviewed were selected by the rehabilitation employees. Care was taken to ensure that all rehabilitation treatment areas relevant to this study were covered. These included the introductory session, physiotherapy, group exercises and fitness training. The observed treatments within the treatment areas were selected randomly and according to the availability of staff and patients. The patients for the guideline interviews were also selected at random according to patient availability, but care was taken to cover all relevant clinical pictures of orthopaedic rehabilitation. As the interviewees were questioned at different times during their three-week rehabilitation, it is possible that a lack of experience due to the short duration of treatment may have influenced the rehabilitation-specific answers. Interviews were conducted with a total of 14 patients, of which only 13 could be analysed due to one person refusing to be considered and evaluated in the study. This person seemed generally suspicious of using IT in the field of healthcare sector and did not want to support the research team in "*rationalising*" people away. Based on discussion with the data protection officer, we were not allowed to collect any personalised health data according to the data protection declaration. We insisted that the sample should be as heterogeneous as possible in terms of age, gender, socio-economic background, degree of current movement restriction, rehabilitation needs and anticipatable technical attitude. Ten participants had undergone surgery prior to rehabilitation, while three participated without prior surgery. The reasons for rehabilitation varied: six participants were recovering from hip problems, three from slipped discs, two from shoulder issues, one from a knee operation, and one from a broken arm. One participant had already received physiotherapy before starting rehabilitation, and five participants had undergone multiple rehabilitation cycles due to previous joint replacements. Additionally, one participant reported a planned operation in the future. Rehabilitation was therefore a familiar environment for many participants, though their levels of physical activity varied significantly – from highly active individuals to those with sedentary lifestyles or severely restricted movement. Some patients are very sporty, while others are not active at all. Both the additional motivation and the different sporting levels of the patients could be covered by offering different levels of difficulty for the exercises. This diversity highlighted the need for adaptable and inclusive robot functionalities to effectively support the wide range of participant needs and abilities.

### 3.4 Ethical considerations

In this study, patients were informed in advance for ethical reasons and were only observed and interviewed with their consent. Treatments were partly observed passively, but we also interacted with patients and staff in the form of conversations in order to obtain more contextual information. We ensured the privacy and data security of the participants by conducting interviews with them in accordance with various documents that uphold the privacy of personal data and comply with legal regulations. These documents were only applicable upon obtaining consent, which participants could revoke at any time. It was very important for managers of the rehabilitation institution not to record and publish any personal data, which is why demographic data is not provided in tabular form here.

# 4 Results

In the qualitative results, which are divided into four aspects, a current challenge in the rehabilitation institution is described first, followed by a socio-robotic solution approach. The initial problems resulted from the participant observations made during the observation days, while the solution approaches were mainly developed through the interviews with the patients.

Building on these findings, the patient statements were then grouped into six distinct themes, as shown Table 1. Each main category is further divided into subcategories, which may include additional classification levels. For example, a statement in which a patient discusses their motivation to exercise could be categorized as follows: Sport → Motivation → Motivating → Intrinsic → Pain as motivation.

## 4.1 Individual patient needs, work-related routines and therapeutic practices

### 4.1.1 Initial observations

The rehabilitation plan is drawn up individually depending on the patient's clinical picture. Most of the group exercises took place in a gymnastics room. These consisted of around 10 participants. Aids such as sticks or "Thera-bands" (elastic resistance bands widely used in physical therapy), were also used for the exercises. The exercises were aimed at strengthening coordination and muscles. In some exercises, all participants did the exercises at the same time, while in others a circuit was set up and the exercises were performed one after the other. In some cases, a distinction was also made within the group between different diseases and individual exercises or restrictions were performed. The different requirements and limitations of patients, as well as the availability of aids, should therefore also be taken into account when selecting exercises for this study.

**Table 1:** Main categories derived from patient statements, based on the analysis of interviews and observations during the rehabilitation process.

| Category | Description |
|---|---|
| People | General personal and medical information about the participants. |
| Employees | Statements regarding developments that could impact employees of the rehabilitation facility. |
| Digital | Personal experiences and opinions on digitalisation and robotics. |
| Music | Statements about the use of music in both personal contexts and rehabilitation. |
| Sport | Statements on physical activities in and outside rehabilitation, and motivation to engage in them. |
| Rehabilitation | Statements about the rehabilitation facility and its programs. |

In the fitness room, patients received an introduction during which they were shown and adjusted the equipment. The training plan was individually tailored to the patient's disease. Younger patients implemented these independently. Older patients were moved from the current machine to the next one after each exercise. There were numerous fitness and training machines in the fitness room, similar to a gym. In addition, each patient was given a Near Field Communication wristband (wearable device allowing it to perform wireless communication over short distances (typically a few centimetres)), which stored the progress and settings of some devices. There was also a balance board. This is connected to a laptop and the exercises are combined with games. The gym setting made it clear that in this orthopaedic rehabilitation setting, age is an important sociodemographic characteristic because many older patients need more guidance and supervision with fitness exercises than younger patients. For this reason, it was decided to implement both an auditory and a visual guidance system.

### 4.1.2 Towards a solution

So, some digital devices are already being used in rehabilitation, particularly fitness equipment. During the interviews, five participants reported that some fitness equipment saves the user's individual settings and progress. This was rated positively, as "staff no longer need to be asked to set the equipment". Additionally, the resulting relief for staff and the improved possibility of self-monitoring were emphasized. Providing a device with which patients can practise independently could therefore be a way of using the lent agency to address individual needs for faster or slower movement or testing one's own limits.

However, one participant referred to using a balance board in conjunction with games on a laptop as "pseudotechnology". They noted that the control mechanism had a negative impact on their motivation, though they acknowledged that this effect was highly individual and that the games might benefit others. Conversely, another participant found that the games made the exercises more engaging. Some participants shared a rather negative opinion on the topic of digitization in general in their interviews. This was made clear, for example, by the statement "nothing works without it these days, but apart from that I've always distanced myself a bit from it". One participant reported that their father avoids digital devices due to fears of being spied on. Therefore, digitization is also perceived as a compulsion rather than a benefit. Additionally, concerns about over-reliance on digital devices were raised. Consequently, not all patients will be able to be mobilized by the system. This makes it important to ask them whether they are open for the work with a robot or not.

Moreover, five participants noted that digitization is a generational issue, emphasizing the need to consider older people. For example, "there are many older people who have neither a cell phone nor a computer and then stand in front of it and don't know what to do with it". It was also stated from an older participant that digitization can act as a barrier; for example, some older people have ceased donating blood because digital registration is required. When asked what they expect from the operation of a robot, nine participants answered that they expect it to be easy to use, especially for older patients. Three participants expect the robot to be self-explanatory and that it is not necessary to read instructions beforehand. Also, someone should be there to help older people. Thus, not only missing openness can be a problem but also the missing ability to handle the device. But because patients will never be alone with it, the project can also be seen as a chance to teach people how to cope with a robot which could give them even more agency.

Although music is already used in rehabilitation, it tends to partially play a subordinate role. During the interviews, five participants reported using music in group exercises or in the fitness room. However, a participant described the music in the fitness room more as background music. The other participants did not notice any use of music during exercises. Seven of the participants mentioned that they do not listen to any music during sport. There are numerous reasons for this. Two participants argued that their everyday life is already loud and stressful enough and they therefore want peace and quiet during sport. Two other participants sometimes listen to audio books instead of music, although one participant does music for simple exercises such as cardio training, which do not require much concentration. Two other participants reported to watch television while exercising. Four of the participants like to listen to music a lot when exercising, but also in their other free time. One participant listens to music whenever the exercises allow in order to "break up the monotony". Another one always has the radio on and therefore usually has music on. One participant likes to listen to music during sport and in everyday life. She described "music and movement" as "the most beautiful", while another one "definitely" listens to music when doing sport.

When asked whether music can motivate during sport, only one participant answered that music has no motivating effect on them. Twelve of the participants, and thus almost all participants who listen to no or little music during sport, said that music can have a motivating effect. However, most of the participants linked this to conditions. Four participants noted that the music played was crucial and therefore wanted a choice of music that suited their taste. Two participants were particularly sceptical about group exercises, as everyone can have different tastes in music. One participant believes that music is particularly motivating for younger patients and less so for older patients and that both the type of sport and the location are decisive for motivation. For example, music motivates them when dancing or working out, but not when running in nature. For one participant, music is motivating and they can "join in", but only if they have "memorized the sequence [of the exercise]", as otherwise the music is too distracting. So, it is important for the patients to be able to choose the music they want to listen to and to also give them the opportunity to turn it off.

## 4.2 Socio-robotic requirements for motivation, monitoring and progress in rehabilitation

### 4.2.1 Initial observations

Our fieldnotes reveal a diverse range of clinical conditions among patients in rehabilitation, with the majority undergoing therapy following knee, shoulder, or hip replacement surgeries. One therapist mentioned that "*motivation is an important aspect of rehabilitation. Most of the time motivation comes from success and progress. However, the lack of progress can be very demotivating and can also lead to depression*". We also observed that many patients were in pain, which sometimes demotivated them to perform exercises. However, the relief of pain through exercise was also observed and reported to also be motivating. To address demotivation, therapists employ strategies like small talk and music, observed to create a more engaging and less clinical environment. The use of music was mentioned to have a similar effect. Additionally, age-specific challenges were noted in the fieldnotes. Therapists often observed that older patients struggled with home exercises. This leads to slower healing or long-term movement restrictions which is particularly problematic for patients recovering from hip, shoulder, or back surgeries as the muscle areas require consistent muscle activation to prevent long-term movement restriction. By making it possible for the patients to control the music with their movement, it is our aim to foster motivation and offer patients an interesting new stimulus that can distract from the subjective sensation of pain and provide fun. The exercises should easily be able to reproduce at home, even if the robot cannot be taken there.

#### 4.2.2 Towards a solution

In general, intrinsic motivation refers to behaviour that arises from internal incentives, interests or personal beliefs. People who are intrinsically motivated perform an action because they enjoy the activity itself, feel that it is personally important to them or because they feel the need to improve their own skills.[69] During the interviews two participants reported that "*sport* [serves] *as a relief from everyday life, to reduce stress and to clear their heads*". The motivation therefore serves to improve personal well-being and to feel better.

Five other participants were motivated by an increase in their performance or the achievement of goals. These goals included traveling to certain places or setting benchmarks such as kilometres covered or weights lifted, using these targets to motivate themselves. The drive primarily comes from challenging themselves and improving their personal performance.

Three participants also mentioned pain as a motivation, as the exercises bring them relief. They mentioned to integrate exercises into their daily routine to remain "as pain-free as possible". The focus is therefore on the inner need for well-being.

Another participant is motivated by the fact that they want to "get fit again" and needs "no extra motivation". A total of eight participants cited the recovery or improvement of their mobility as their motivation for rehabilitation in general. Here too, the reasons for motivation are individual and both intrinsic and extrinsic in nature or cannot be clearly categorised. The motivation ranged from "wants to get back to work" to becoming "fit for everyday life". They therefore have the need to remain independent. The goal of going back to work could be due to the expectations of society or to avoid disappointment in their own social environment. Likewise, the goal of becoming fit for everyday life again may be motivated by not being a burden on others. However, there is a lack of data for a precise classification.

As two participants stated that pain was particularly demotivating, causing them to stop doing exercises when they experienced pain. Pain can therefore not only motivate, but can also have a demotivating effect. Another participant is also demotivated if they are controlled too much by technology, as they are annoyed by the control.

Five participants have little to no motivation to exercise at home. The reason given were that the rehabilitation program is sufficient for them or they simply do not feel like it. One participant of them mentioned that they do exercises at home when there is acute pain, not preventively.

So, in order to motivate patients intrinsically in a socio-robotic way through an external motivator, it is essential that they have fun during the active break, remember it, and then recreate the situation at home even without being able to control the music themselves. The challenge with regard to interventions with the system must therefore be to create engagement that has a lasting effect.

### 4.3 Daily challenges in therapeutical practice

#### 4.3.1 Initial observation

From the therapists' perspective, it was reported that staffing levels and workload emerged as significant challenges. While one therapist mentioned that she has "*a lot of pressure to work without gaps*", there are also too few breaks and the staff therefore have less cohesion than before. During the observation days, staff shortages were perceivable. For instance, on the first day, therapists reported reduced staffing due to employees taking time off to reduce overtime. On the second day, absenteeism due to illness intensified the workload and pressure. One therapist appeared especially stressed, juggling treatment sessions and organisational tasks, such as scheduling and patient follow-ups. During a group exercise, this stress became more pronounced. With patients presenting varied clinical conditions, the therapist had to provide individualized instructions while managing the group as a whole. Although we cannot relieve the therapists of any work through the active break, our aim was to strengthen their therapeutic performance. It may also be motivating for the therapists if more patients do their exercises at home and thus recover more quickly.

#### 4.3.2 Towards a solution

In the interviews, all participants reported to consider the use of the robot to relieve staff and the possibility of doing additional exercises to be a good idea. One participant sees potential for the robot to absorb peak loads, e.g. due to an increased number of accidents or problems due to illness of co-workers. One participant cannot yet imagine that the robot will initially relieve the staff, but sees it only as a “supplementary opportunity”. However, if improvements mean that staff are no longer required for care in the future, she sees potential for relief. However, she cannot imagine that the robot is suitable for “all age and experience groups”. One participant also thinks the relief provided by the staff is good, but only as long as it is optional to use the robot. Particularly mentioned by one participant was that she likes the opportunity to do additional exercises, as she sometimes has longer breaks and does not come to rehabilitation for “sitting around”. One participant therefore also likes the idea, but only if use is voluntary, even though he thinks that the use of robots “will become more and more common”, as robots do not get sick and do not have vacations.

In general, some interviewees see the increased use of robots as unavoidable and therefore are willing to use it. One participant sees the idea as “completely okay and legitimate, otherwise the market wouldn’t be booming”, “especially in these areas [healthcare sector], there are simply too few people for far too many patients”, which is why it makes sense to use them to relieve the burden. One participant highlights also that “something has to be done”. Both the need on the part of professionals and sufficient acceptance on the part of patients are therefore given, which paves the way for the introduction of a robotic system in this setting.

## 4.4 Need for an adaptive and feedback-oriented system

### 4.4.1 Initial observation

During rehabilitation, patients engage in sport exercises under various supervision levels: one-on-one with physiotherapists, in group settings and independently using equipment in a fitness room. Generally, participants reported that the exercises were clearly explained and demonstrated by the therapists, so that there were no problems with understanding. For example, one participant mentioned that “everything is explained well”.

Participants expressed the perception that their exercise implementation was adequately monitored. One participant who had previous experience as a therapist argued that the supervision and feedback from the therapists is “good” and “adequate”. It was explained that the employees “always have an eye […] for each individual” during group exercises. This was also be seen by the statement that in the fitness room “someone is always walking around” and “there is always someone there to check”.

However, it was also mentioned that not every mistake could be noticed immediately, as one person is responsible for several patients at the same time. Despite this, the level of supervision was described as “okay” with no desire for increased control. Nevertheless, two participants reported at least a temporary lack of staff in the fitness room, noting that the staff “had so many people [patients] standing in front that they didn’t even get there” and “the number of supervisors is absolutely not enough”. They also pointed out the increased supervision required for older people, as they tend to have less experience with fitness equipment. Thus, for the design phase it is important to develop a system which has some kind of feedback and user-oriented correction mechanism.

### 4.4.2 Towards a solution

The ideas on how the robot could provide feedback to patients varied greatly. The majority of interviewees suggested that errors should be indicated acoustically, either by a warning tone or a voice message. However, some could also imagine warnings on the display. According to some interviewees, the correction of the exercise should be shown on the display, according to others it should be explained by voice message.

Three participants suggested using colours for this. Red for incorrect execution, green for correct execution. One participant suggested displaying a comic figure to show what you are doing wrong. Two participants suggested using symbols such as smileys or ticks and crosses. One participant would like to see a combination of feedback by voice announcement and visual display. The voice prompt should point out errors and the screen should show how to do it correctly. One participant mentioned that he does not want to have to look at the tablet, but wants the robot to say what was wrong and how to do it better. Another one also wants to be corrected by voice prompt, but would also like positive feedback in the form of praise. As important was also suggested by one participant that the music goes off when mistakes are made or that a warning tone is played. One participant also suggests a sound “that is absolutely wrong” to point out mistakes.

Two participants also consider it important that the robot documents the progress of individual users and that it is possible to adjust the difficulty of the exercises, for example by varying the number of repetitions.

For this reason, two levels of difficulty were developed and a feedback mechanism was developed to indicate possible errors in the execution. In addition, incorrectly performed repetitions are not counted, which has an impact on the score that is reflected in the ranking list in order to strengthen ambition and commitment through competition and game.

#### 4.4.3 Ethical considerations

However, three of the participants were also critical of the idea of using robots, as there is a risk that jobs could be rationalized as a result. One participant was unsure because "a human being [would be] important" and "many people are unemployed". On the other hand, she is also in favour of "research or technology [...] moving forward". One participant thinks that "where a robot can step in, personnel can also be saved". She therefore takes a rather negative view of the development. One participant also poses the question "is this staff relief or is it staff rationalization". For them, the problem is that "more and more jobs are being lost due to more technology", as the robot, unlike a real person, cannot become ill.

## 5 Implications and design opportunities

This chapter summarizes the findings from the observation days and interview results and present the different levels of technical implications and requirements for our system. This involved generating ideas for how the technological implications and design opportunities were conceptualized to enhance the rehabilitation experience.

### 5.1 User and system requirements – design, explanation, feedback, monitoring and control

By far the most important point that almost all participants mentioned as an expectation of the robot was that the operation should be simple and as self-explanatory as possible. Even though all participants have a basic knowledge of how to operate touchscreen-based devices, this is not always the case, especially for older patients. In addition, older patients may have limited motor skills, vision and hearing. The design and menu navigation of the application should therefore be chosen so that as few steps as possible are required to start an exercise. The controls should all be easy to reach. Orientation towards validated design guidelines for older adults, such as those outlined in ISO 9241-210:2019,[70] would be useful. This standard emphasizes that the system should be designed to achieve the intended goal with minimal effort, and that the design should minimize both physical and psychological harm. For instance, it should avoid causing cognitive overload.

One of the patients' main requirements is that the robot explains the exercises well. As all interviewees are also satisfied with the explanations used in rehabilitation to date, it is appropriate to use the previous methods of explanation as a model. The professional therapists employees argued that demonstrating the exercise and verbal explanations are most effective. One way of illustrating this on the robot would be explanatory videos in which the exercise is demonstrated and explained.

Almost all patients mentioned the control of the exercises by the robot during execution as a further requirement. This prevents incorrect training and, above all, prevents negative consequences/injuries. Patients who had knee surgery, for example, should not kneel too low. The application should therefore be able to recognize when exercises are performed incorrectly, notify the user and correct them. However, it was not clear from the interviews what this notification and correction should look like. One possibility would be to play a warning tone or an error description via an announcement to indicate incorrect performance. Optionally, a symbol or red signals could also be shown on the display to indicate this. The correct procedure should then be explained. This could be done verbally via an announcement or visually on the display.

Some patients also asked for a direct feedback – during and after the exercise. The feedback should show how well the exercise was performed, what was done wrong, but also what can be improved in the future. One person suggested that the exercise be graded. To ensure this, a score could be calculated after the exercise to determine how well the exercise was done objectively. At the same time, the number and type of errors should be shown and possibly also included in the calculation of the grade. As this is also intended to motivate, a form of praise could also be displayed for good performance.

The progress of the exercises in the previous rehabilitation is not always recorded. However, some digital devices in the fitness room already do this, which is positively received. Some participants also wanted the robot to have this function in order to motivate them and help them to improve. By assigning an individual ID and saving and displaying past results, it would be possible to fulfil this requirement.

## 5.2 Feature and innovation requirements – difficulty, implementation, exercises and music training

For some patients, improving their performance is a motivation that drives them to exercise. The possibility of different levels of difficulty in order to be able to improve was also desired by users in the context that progress is recorded. In addition, the potential patients are very diverse in terms of their performance. One reason for this is that the age range is very wide, as is the sporting background of the patients. Some patients are very sporty, while others are not active at all. Both the additional motivation and the different sporting levels of the patients could be covered by offering different levels of difficulty for the exercises.

Patients often have breaks in their program. In addition, staff are particularly busy when both rehabilitation groups are present. It therefore makes sense to offer the exercises with the robot during these times. Some patients would also like to do more exercises during these breaks. The offer should initially only be optional, as not all patients want to operate a robot with this type of introduction. Nonetheless, it would be questionable whether this would relieve the burden on staff or whether it would lead to an additional workload, as some of the staff fear.

It is also important that therapists are available to give patients an introduction and are available to answer questions. Older patients in particular saw this as a prerequisite for use. The handling of the robot would thus be similar to that of the equipment in the fitness room. This would also meet the desire of employees to use the mobile robot as a tool rather than independently. This would require staff training. However, as the employees are open to new technology and do not feel overburdened by it, this should not be seen as a problem.

Five exercises were identified together with the therapists that should be implemented for the robot. A ski jumping exercise, balance exercise, calf stretch, squats and lunges. These are exercises that are suitable for all groups of patients. Some of the exercises can be made more difficult or simplified using aids. This means that two levels of difficulty can be offered and consideration can be given to patients with mobility impairments. Almost all participants and staff agreed that music can have a motivating influence. The idea of adapting music to the rhythm of the patients was also received rather positively. The use of music in the application can therefore be rated as positive. However, it should be possible to select the music or at least the genre, as some patients are only motivated by music that they like. As the application is only intended for individual exercises, the resulting conflicts of interest between patients in group exercises do not play a role, but should be taken into account when considering functional enhancement. It should also be possible to carry out the exercises without music, as some patients feel disturbed by this. As some rooms are very quiet, this should also influence the choice of location so that other patients and staff are not disturbed.

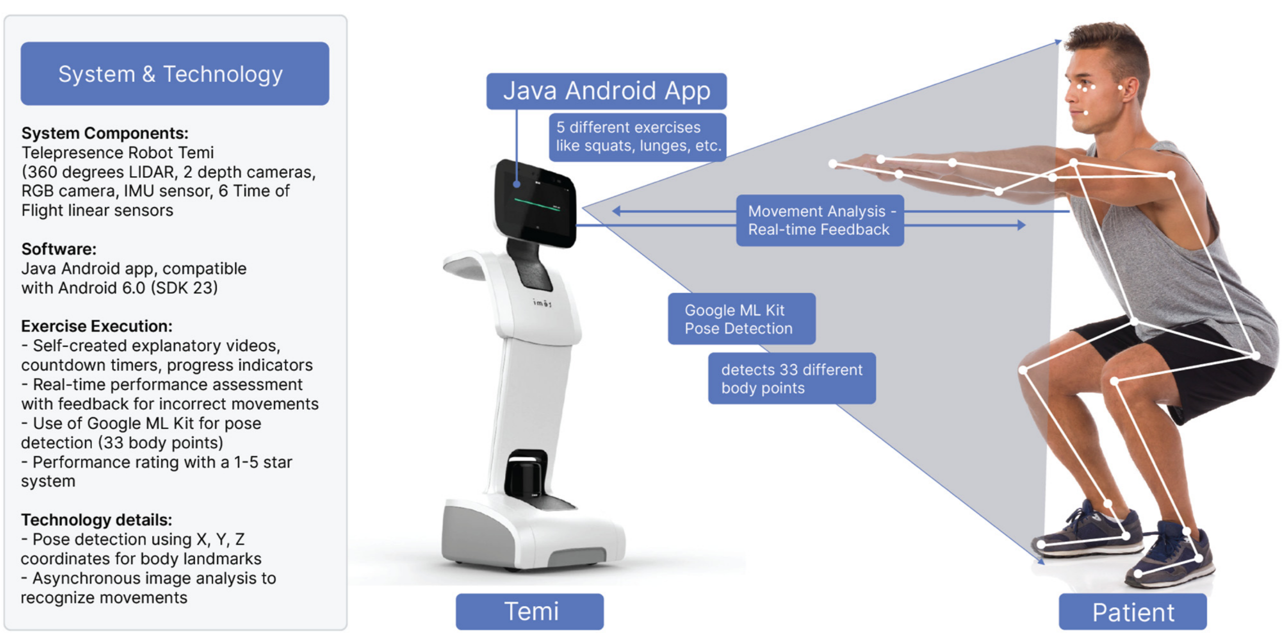



**Figure 1:** Illustration of the technical setup. For pose detection, the Z-coordinate was ignored.

# 6 Designing the prototype

## 6.1 General design objectives and technical infrastructure

Inspired by the related work and building upon the implications we conceptualized and designed a system that integrates four primary technical components: a mobile telepresence robot (developed by temi-robots[71]), a pose detection module, an application program with different exercise training activities and adaptive music software, as illustrated in Figure 1. The system is designed to be operated through the Tablet of the telepresence robot temi via the internal Android system (Android version 6.0 onwards (SDK23)). The Android app acts as the control hub, managing pose detection and communication with the external music software as well as providing feedback and instructions to the users.

The mobile telepresence robot temi serves as the mobile physical interface for the user. It is equipped with an internal camera that we use to track the user's movements and provide real-time feedback to the system and users. The robot's mobility allows it to be remotely controlled, move and follow the user or position itself optimally to capture the user's movements during exercise routines. The system was designed to be used in single-user mode, meaning that only one person can be detected. The UI is designed to be intuitive, providing users with real-time feedback on their movements and progress during exercise routines. The application displays a visual representation of the user's body points and highlights any incorrect postures or movements, aiding in self-correction. Additionally, the user-interface was developed with older users in mind. To this end, the developer guidelines for the user-friendliness of apps for older individuals were followed (Ref.[72]). This includes the use of simple language, intuitive navigation to achieve the aim, high contrast between background and text, large buttons, a simple design, avoiding technical terms, and providing a tutorial. To individually Log-In and keep track of the individual session we integrated a User-Login via IDs that were also the participant ID within the study design to ensure anonymity.

Combined with our design implications, it was clear in our own work that the following considerations needed to be borne in mind in designing the applications: (1) creating an emotive design that would make the participants feel comfortable; (2) ensuring minimum complexity so that participants would not be overwhelmed and harmed by the tasks; (3) making a good first impression to increase the likelihood of acceptance and use; (4) providing positive feedback from the system to put the participants at ease and make them feel that they were proceeding correctly; (5) keeping instructions and things to be learnt as simple and short as possible, with the option to repeat them as many times as necessary in case of doubt; (6) provide a musical atmosphere to support engagement and motivation; and (7) maintaining a simple, high-contrast design to ensure easy readability. Therefore, we overall designed and developed the following five digital exercises.

## 6.2 Digital exercise applications

Within our empirical studies, we also focused on the content and physical challenges of our applications. The exercises implemented, and also the underlying training and progression plan for the robot were co-designed with therapists to ensure they align with standard orthopaedic rehabilitation practices, are non-risky for patients, and cater to a broad range of abilities. Five exercises were selected: ski jumping, balance, calf stretches, squats, and lunges. These exercises, as shown in Figure 2, are fundamental in rehabilitation, suitable for all patient groups, and can be adjusted in difficulty using aids, allowing for personalization based on patient mobility. The empirical feedback highlighted that music could be a motivating factor, with participants suggesting the ability to choose or adapt the music to individual preferences and levels of activity during the session.

1. **Ski Driver** – To correctly recognize the skier's movement, the user must stand to the side of temi in order to correctly recognize the arm movement. An important point in exercises in which the users stand to the side of the camera is the recognition of the direction of gaze. On the one hand, this is important because the landmarks on the side facing the camera are more accurate, as the body may prevent the other side of the body from being seen. On the other hand, it is necessary to determine what is behind and what is in front from the person's point of view. A skier's execution consists of taking his arms in front of him at shoulder height in a squat position and then pulling them behind him at the side of his body.
2. **Squats** – Squat detection works in a similar way to skier detection. Here, too, the person's line of vision must first be recognized, as the exercise is also performed sideways to the camera. A repetition is counted when the person has reached the lower knee bend position and then stands upright again. The lower position is reached when the knee angle is less than 105°. The person stands upright as soon as the angle is greater than 165°. An activity value is then calculated on the basis of the repetition time.

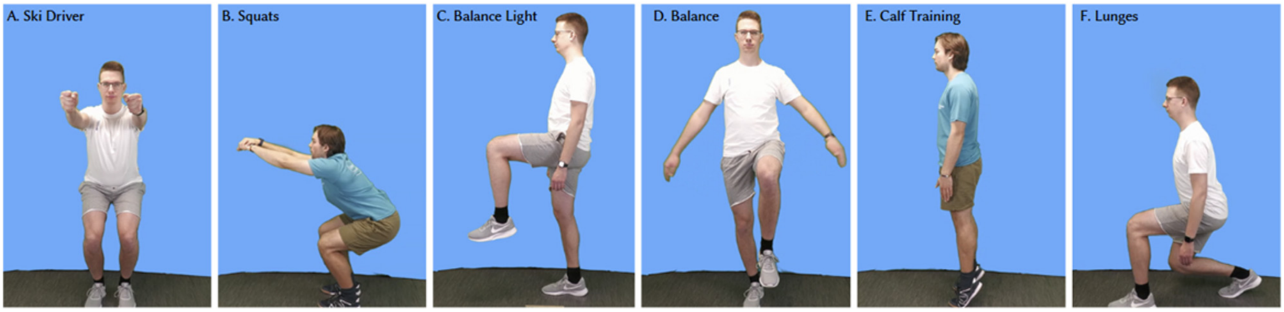



**Figure 2:** Visualization of the rehabilitation exercises.

3. **Balance** – In the balance exercise, the person stands facing the camera. The balance position is achieved when the person stands on one leg and raises the other leg at a right angle in front of them. To do this, check that the $Y$ value of one knee is at least 40 pixels above that of the other. In addition to standing on one leg, it is also necessary to check how straight the person is standing. To do this, the height difference between the two shoulder landmarks is calculated. If the difference is less than 30 pixels and the person is standing on one leg, the balance position is reached and the balance score is counted up for each second. If the difference between the shoulders is greater, this is counted as an error. The activity value is also calculated on the basis of these two characteristics.
4. **Calf Training** – During calf training, the person also stands sideways to the camera and the direction of view must be determined accordingly. A repetition is counted when the person has pushed themselves up standing on their toes and then goes down again. It is counted as up if the difference between the $Y$ value of the tip of the toe and that of the verse is greater than 35. It counts as down if the difference is less than 10. The time between repetitions is also measured here and an activity value is calculated from this.
5. **Lunges** – Even with lunge steps, the person only stands to the side of the camera, which is why the direction of gaze must first be recognized. A repetition is counted when the person has reached the lower lunge position and then stands up again.

While the exercise is being performed, the image from the front camera is displayed, allowing users to see themselves. The time remaining for the exercise is displayed in the top right corner. An exercise-specific progress value is displayed in the bottom right corner. For most exercises this is the number of repetitions, for the balance exercise it is a score depending on how long and how straight you stand on one leg. As the user stands to the side of the display for most exercises, the remaining time is also announced by voice output with 1 min remaining and the last 5 s. While the exercises are being performed, the user's movement is evaluated in real time and the performance is assessed based on exercise-specific criteria and incorrect movement patterns are also recognized. If the exercise is performed incorrectly, the user is notified by voice message. As soon as the time is up, the results screen is called up.

## 6.3 Training schedule and tutorial

After logging in, the five exercises and the level of difficulty can be selected. Users can choose between the difficulty levels "Normal" and "Difficult". "Normal" is selected by default. The selection is indicated by a change in the background colour and a green border. Pressing on an exercise starts it. The training schedule was designed with respect to needs, request and recommendations from the therapists and practitioners in the pre-study that were conducted and incorporated as final digital training activities. The exercises can be made more difficult or simplified with aids. This means that two levels of difficulty were offered and consideration can be given to patients with restricted mobility. The difficulty level can be adjusted according to the patient's performance and progress. This approach allows to maintain, advance, or reset the difficulty level without sending any discouraging notifications to the player. Additionally, the system enables users to revisit previously completed levels, making it adaptable to their daily condition or desire to replay their favorite exercises.

Once you have selected an exercise, an self-created explanatory videos matching the selected exercise appears, as illustrated in Figure 3. In the video, the exercise is demonstrated from two perspectives. At the same time, the exercise is explained verbally. The instructions depend on the previously selected level of difficulty. The video is played in a loop until the "Start exercise" button is pressed. A countdown then starts, during which the person operating the device

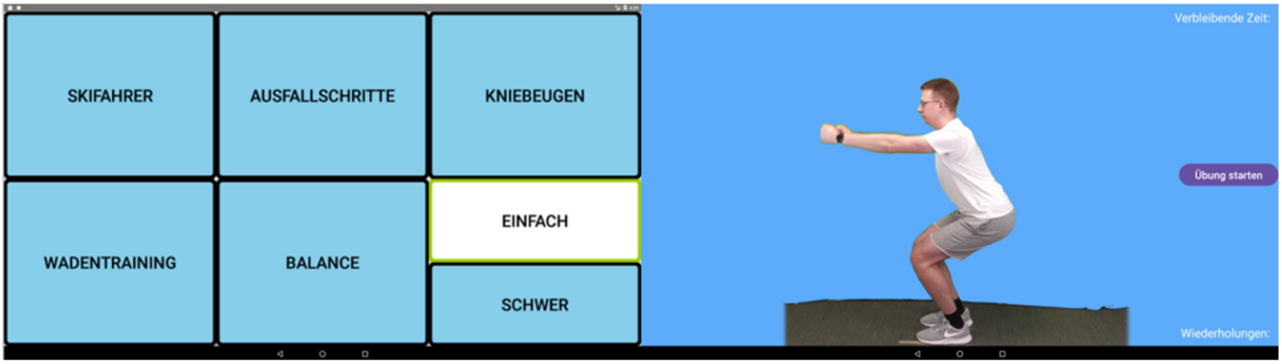



**Figure 3:** Left: user interface displaying the exercises in German for users to select; Right: tutorial video.

has time to get into the starting position. The countdown counts down from 10 and is shown on the display as well as counted down by voice announcement. In addition, the screen is set to a 5° angle so that the user's entire body can be better recognized.

## 6.4 Results and leaderboard

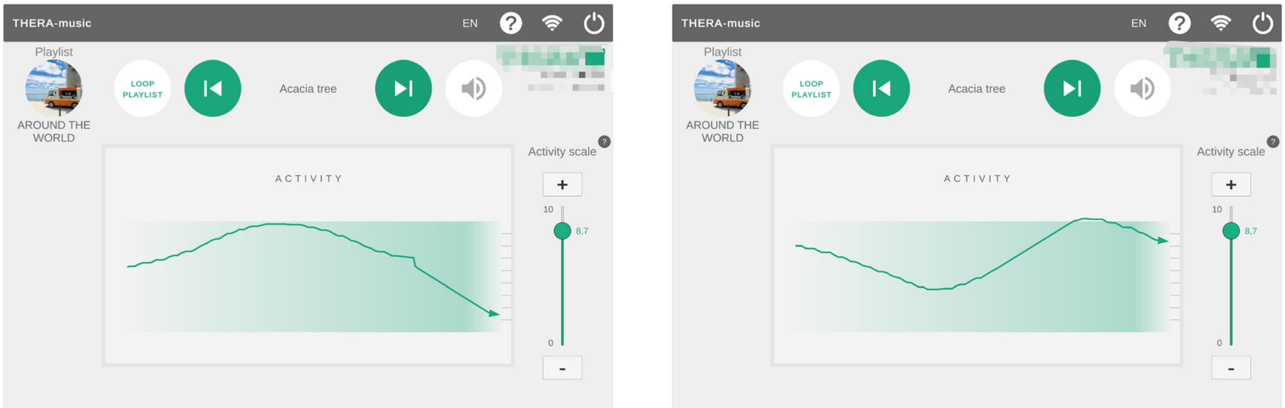
In the results section the user is shown a rating of between one and five stars for their exercise and is used to monitor their performance. The results are also saved permanently together with the ID and the time the exercise was performed. The calculation of the rating depends on the type of exercise and is usually based on the time of the exercise, the exercise-specific value (repetitions etc.) and the number of errors. The exercise-specific value and the number of errors are therefore displayed separately in addition to the score. By pressing the "Continue" button, the app starts again from the beginning (login). Alternatively, the ranking list can be called up beforehand. All saved executions of the specific exercise by all users are displayed in the ranking list. The "best" exercises are displayed at the top of the ranking list. All entries of the currently logged in user are highlighted in colour for better recognition.

## 6.5 Pose detection

The pose detection module is a crucial component that utilizes Google ML Kit's pose detection API to recognize and track the user's body movements. The ML Kit can identify 33 distinct body points, each assigned $X$ and $Y$ coordinates, which allows for precise tracking of body posture and motion. The Google ML kit pose detection was therefore used instead in this study to count repetitions and detect errors.[73] Various predefined body points, so-called landmarks, are recognized and located on a two- or three-dimensional coordinate system. However, for this study, a two-dimensional approach was chosen, using only the height ($Y$) and width ($X$) coordinates, while the depth ($Z$) coordinates were ignored. This decision was made because a two-dimensional approach is computationally less intensive and sufficiently accurate for the purpose of counting repetitions and detecting errors in exercises.

## 6.6 Music-based control and feedback

The integration of adaptive music feature was identified and designed to enhance the user's motivation and create a stimulating training environment. We integrated a software called JYMMiN[74] into our system to combine the intensity and adapt to users movement of the exercises with music. JYMMiN is an innovative technology and training concept that integrates musically expressive performance with physical exercise.[75] The music adaptation logic is based on the analysis of movement data. The music software is connected to the system via a REST API, allowing real-time communication and adaptation based on the user's detected movements. For instance, if the user is performing high-intensity exercises, the system would increase the level of arousal of the music to match the pace. Conversely, for slower exercises or cooldown periods, the music may become softer and more relaxed. The user interface can be seen in Figure 4. Users can choose from nine different playlists, which are sorted according to themes such as "Around the world" or music genres such as "Classical" (1). Individual songs can be played in a continuous loop or otherwise the entire playlist (2). There is also a forward and back button to navigate through the playlist (3). The current song title is displayed at the top center (4) and the music can be muted (5). The current activity level and progression is displayed graphically using an arrow on a time scale (6). The level of difficulty can be set using the activity scale (7).




(a) (b)

**Figure 4:** High activity. (a) Low activity. (b) Tablet.

We combined the music-based software with the rehabilitation robot to detect and translate patients' movements into dynamic music feedback. The system uses an activity value – a numerical score ranging from 0 to 100 – calculated based on the patient's movement during exercises in front of the camera. This value determines the complexity and intensity of the music. As the activity value increases (when performing exercises correctly, which is detected by the pose detection), additional musical layers or instruments are added, creating a richer and more voluminous sound. At lower activity values (when the activities are performed incorrectly), an equalizer muffles the sound to provide less stimulating feedback. The system is adaptable: for example, an activity scale of 10 requires the maximum activity value of 100 to achieve the full musical experience, whereas an activity scale of 5 requires only a value of 50. The music-based software and exercise application operate on separate devices and communicate through an interface. For the current implementation, only the transmission of the activity value is needed. This value is continuously calculated during the exercise to provide real-time audio feedback reflecting the user's performance. The system is designed to not only provide movement feedback but also support and initiate the positive effects of music in rehabilitation. However, the interface could be expanded in the future to integrate new functions. The programming interface was developed in C++ according to the REST principle. It therefore enables a C#-based Windows application such as our music-based software to communicate with our Java-based Android application. The system's data flow is designed to be seamless, with low latency to ensure real-time feedback and interaction. The camera captures video frames, which are processed by the pose detection module. The movement data is then sent via the Android app to the music software using the REST API. The music software adapts the audio output and sends feedback to the user via the speakers of the robot, closing the loop.

## 7 Conclusion and future research activities

The qualitative work presented in this paper explored and reported empirically grounded technical implications and design opportunities that were conducted and conceptualized together with patients and therapists to inform the socio-robotic system with digital exercise applications to support the recovery process of patients for the deployment in a rehabilitation facility. The involvement of stakeholders in the process enabled us to develop a system that actually improves the quality of therapy of the patients and took their needs into account. The results indicate the design potentials of socio-robotic systems to enhance patient engagement and recovery by providing personalized activities, a meaningful interaction and a motivating surrounding by using music-based exercises. We can conclude here that integrating digital engaging applications with robotic systems may be used in the long-run to offer tailored exercises, stimulating concepts to motivate and maintain patients in therapy process, real-time feedback, and data-driven progress tracking, thereby improving the overall therapeutic outcomes.

Reflecting on the work presented in this paper, it is evident that our approach has laid a practice-oriented foundation for integrating socio-robotic systems into orthopaedic rehabilitation. By actively involving patients and therapists in the design and development process, we ensured that the system directly addresses the practical and emotional needs of its end-users. This methodology underscores the importance of empathy in designing healthcare technologies and highlights the potential for these systems to elevate therapy experiences and outcomes. However, while the results point to promising design potentials, several challenges lie ahead in ensuring the system's scalability, adaptability, and long-term efficacy. Moving forward, the planned mix-method evaluation will be crucial in capturing the nuanced interactions between patients, therapists, and the system, while also providing quantifiable evidence of its benefits.

In the next step of our research, we will conduct a mix-method evaluation study within the cooperating rehabilitation facility. Here, we will assess qualitatively the individual interaction and user experience and investigate the quantifiable effects of the system usage on physical, cognitive, and psychological conditions on the rehabilitation patients. Afterwards, we plan to expand the evaluation and deployment of the socio-robotic system to diverse healthcare settings, including care centres, day-care centres, and hospitals to further explore it's possibilities. This process will be crucial to understand its broader applicability and impact in health-care. These studies will consider the unique challenges and needs of each setting, adapting the system to different patient needs and environmental context factors.

Our socio-robotic system will also be technically further developed, so that the content can be individualized and therapy plans can be individually prepared by professional therapists and doctors and controlled to move to patients in various environments. The specific therapy activities and progress will then be tracked and documented so that the content can also be adapted regarding the difficulty level, intensity and duration of the training. In addition, automated reports – based on therapy progress and assessments – will be created to document and monitor the course of therapy that we be forwarded to professional therapists and doctors for their reporting scheme. As part of further development, we are also planning additional content modules so that the system can also be adapted for more (chronic) clinical pictures. The new content will then be linked to an integrated assessment tool, such as balance and coordination test after the exercises, so that the system can systematically propose treatment adjustments as a decision-support tool.

**Research ethics:** The study was conducted in accordance with the Declaration of Helsinki.
**Informed consent:** Informed consent was obtained by all involved entities.
**Author contributions:** The authors have accepted responsibility for the entire content of this manuscript and approved its submission.
**Use of Large Language Models, AI and Machine Learning Tools:** None declared.
**Conflict of interest:** The authors state no conflict of interest.
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**Data availability:** The raw data can be obtained on request from the corresponding author.

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