

Article

Tele-Rehabilitation Versus Local Rehabilitation Therapies Assisted by Robotic Devices: A Pilot Study with Patients

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Abstract: The present study aims to evaluate the advantages of a master-slave robotic rehabilitation therapy in which the patient is assisted in real-time by a therapist. We have also explored if this type of strategy is applicable in a tele-rehabilitation environment. A pilot study has been carried out involving 10 patients who have performed a point-to-point rehabilitation exercise supported by three assistance modalities: fixed assistance (without therapist interaction), local therapist assistance, and remote therapist assistance in a simulated tele-rehabilitation scenario. The rehabilitation exercise will be performed using an upper-limb rehabilitation robotic device that assists the patients through force fields. The results suggest that the assistance provided by the therapist is better adapted to patient needs than fixed assistance mode. Therefore, it maximizes the patient's level of effort, which is an important aspect to improve the rehabilitation outcomes. We have also seen that in a tele-rehabilitation environment it is more difficult to assess when to assist the patient than locally. However, the assistance suits patients better than the fixed assistance mode.

Keywords: master-slave; neurologic rehabilitation; robotic rehabilitation; stroke; teleoperation; tele-rehabilitation

1. Introduction

The term tele-rehabilitation in medicine encompasses the delivery of remote rehabilitation services in a wide variety of fields such as physical and occupational therapy. In general, tele-rehabilitation reduces the costs of both health care providers and patients compared with traditional inpatient or person-to-person rehabilitation [1]. However, further clinical and scientific evidence is needed to promote the acceptance of this telemedicine technique.

This work focuses on the motor rehabilitation of the patient's upper extremities as a result of a variety of medical conditions, such as stroke. More specifically, it aims to provide further clinical and scientific evidence in the use of robotic devices for delivering therapy. In the literature, there are already many studies that have shown that the performance of robotic treatment in subjects with subacute stroke is similar to conventional therapy [2,3]. These tele-rehabilitation robotic systems are conceived to support the independence of the patient when rehabilitating, even allowing home rehabilitation. In some cases, the doctor can remotely configure certain parameters (e.g., range of motion, assistance level) of the robot controller allowing the modification and personalization of the therapy to the patient. The robot controller can also modify the behavior of the robot and the serious virtual games as a result of the patient's performance (e.g., based on objective robot measures

and AI methods). However, there is a robotic rehabilitation modality that has received little attention in literature but can provide an additional assistance modality, which is teleoperation.

Robotic teleoperation is usually performed by using a master and slave robot model communication. With regards to rehabilitation, this control modality would not only allow the therapist to modify the patient's robot controller parameters but to directly control its movements.

Up to now, literature has focused on comparing rehabilitation outcomes of robotic vs. in-person therapies, but there is not any knowledge of what happens when the therapist interacts physically with the patient through the robot. A few works have already presented this teleoperated modality [4–6], but their research was more focused on the design and control of the robotic system rather than evaluating the advantages and disadvantages of this modality compared to traditional robotic or in-person therapies. Therefore, this work addresses the objective and subjective performance implications of this novel interaction method. Furthermore, it analyzes the differences between interacting through the same robot that the patient is managing or through a teleoperated robot.

There are multiple assistance controllers in the literature that differ in the strategy or assistance level provided to the user [7,8]. In most cases, the level of assistance in a robotic neurorehabilitation system such as the one used in this study (Rubidium) is usually defined based on a previous evaluation of the patient [9]. With the information collected, certain parameters are defined that are maintained throughout the exercise so that the patient can carry it out successfully. With the proposed master-slave teleoperation method, assistance can be further modified in real-time and remotely by the therapist.

Our hypothesis is that the real-time assistance provided by a therapist is better adapted to the needs of the patients; thus, it maximizes the effort of the patient. This aspect may improve performance on patient recovery. Furthermore, the final acceptance of any robotic rehabilitation system is dependent on many factors such as cost, patient functional outcomes, patient satisfaction and compliance. Therefore, we also seek to explore if this type of strategy is applicable in a tele-rehabilitation environment, where the social interaction with the patient is more limited compared to being in direct contact with the patient at the clinic. To evaluate our hypothesis, we have carried out a pilot study with 10 patients that have performed typical point-to-point exercises under three assistance modalities: fixed assistance (no therapist interaction), local therapist assistance and remote therapist assistance (teleoperated). Robotic measures and user subjective feedback were gathered to evaluate the performance and usability of each modality.

2. Materials and Methods

2.1. Patients

The study was performed in La Pedrera Hospital (Denia, Spain) with patients suffering from neurological conditions. The rehabilitation therapists were responsible for including patients who were receiving treatment. The experiment protocol was approved by the Ethical Committee of La Pedrera Hospital. All patients were informed properly by the rehabilitation team and the researchers in charge of doing the experimentation, and they gave written consent before starting, pointing out they understood the purpose and requirements of the study.

The inclusion criteria were: adults with hemiparesis/hemiplegia, oriented to the three spheres (social, temporal and spatial) with the capacity of collaboration and understanding the tasks instructions and all relevant information from the study. In addition, two indexes were included with the aim of knowing the patient's arm strength and mobility. The muscular conditions of the upper-limb were (i) present muscular and strength with Demeurisse motricity index (0—no movement; 9—palpable contraction in muscle, but no movement; 14—visible movement, but not full range and not against gravity; 19—full range of movement against gravity, but not resistance; 25—full movement against gravity but weaker than the other side; 33—normal power) [10], (ii) patient's coordination, functional

voluntary movement and range of motion was evaluated with STREAM test [11]. Only the score obtained from the upper limb was taken into account. The scores are divided between the amplitude of active movement and movement quality been none = 0, partial = 1a and complete = 1c for marked deviation and grossly normal. Both indices were not inclusive or excluding criteria of the patients; they were only considered to assess the assistance level.

The inclusion of patients with the following injures was avoided: painful shoulder, apraxia, uncontrolled trunk in seating system, severe perceptual deficits, linguistic deficits that prevent useful communication (Wernicke's aphasia) visual deficits (aperceptive visual agnosia) and attention deficits. Table 1 shows the 10 patients that took part in the study. Due to the inclusion criteria, we were only able to count on 9 males and 1 female; it was not possible to have more female participants in the study.

Table 1. Information of the patients.

Patients	Sex	Age (Years)	Diagnostic	Laterality	Demeurisse MI	STREAM
1	Male	72	Abdominal Dystension	Right	N/A	10/16
2	Male	51	Basal Ganglia hematoma	Right	33.5	11/16
3	Male	70	Bilateral SARS-CoV2 pneumonia	Left	N/A	N/A
4	Male	78	Ischemic stroke atherothrombotic	Right	84.5	11/16
5	Female	84	Ischemic stroke	Right	17.5	7/16
6	Male	69	Protuberance ischemic stroke	Left	31.5	7/16
7	Male	69	Thalamic capsule-lacunar stroke	Right	15	0/16
8	Male	62	Chronic ischemic heart disease	Right	59	8/16
9	Male	54	Ischemic stroke in ACM	Right	17.5	0/16
10	Male	72	Atherothrombotic stroke	Right	N/A	9/16

Note. *N/A*, not available value; *ACM*, artery cerebral middle; *DEMEURISSE*, shows the strength deficit in upper and lower limbs; *STREAM*, Stroke Rehabilitation Assessment of Movement, this value indicates the score obtained for the upper limb movement.

2.2. Neurorehabilitation System

In this study, a new version of the upper-limb rehabilitation robotic device called Homerehab was used [12,13]. The new version is called Rubidium (Figure 1). Rubidium is commercialized and distributed by the spin-off iDRhA [14]. This rehabilitation robotic platform is a portable, desktop-type, upper-limb rehabilitation robotic device with two actuated degrees of freedom. It consists of an articulated-parallelogram mechanism driven by two electric motors that perform movements in a horizontal plane. The patient rests the arm on an orthosis anchored to the end effector, supporting the weight of the forearm.



Figure 1. Upper-limb rehabilitation robotic device called Rubidium. Rubidium is commercialized and distributed by the spin-off iDRhA.

Among the different control modes implemented by Rubidium, it incorporates an assistive mode based on force fields. These force fields provide guidance and assistance to the patient during therapy. They can be adjusted according to the level of assistance required by the patient. In this study, we used two kinds of force fields in the form of a tunnel with ends (Figure 2). In both cases, the ends of the tunnel are defined based on the initial position of the patient (origin) and the target position (destination).

The first force field (Figure 2a) serves to help the patient to make a linear movement. However, it does not help to reach the target. In this case, we need to help the patient to reach the target, and we used another version of this force field where we move the origin of the tunnel at a constant velocity (Figure 2b). Forward velocity is determined based on the amount of time the patient has to reach the target. With this type of force field, the system will provide assistance only when the patient is unable to move towards the target, as it allows to move freely toward the target (Figure 2a).

The Rubidium device is able to connect to another Rubidium device to perform multiplayer therapies or master–slave control strategies.

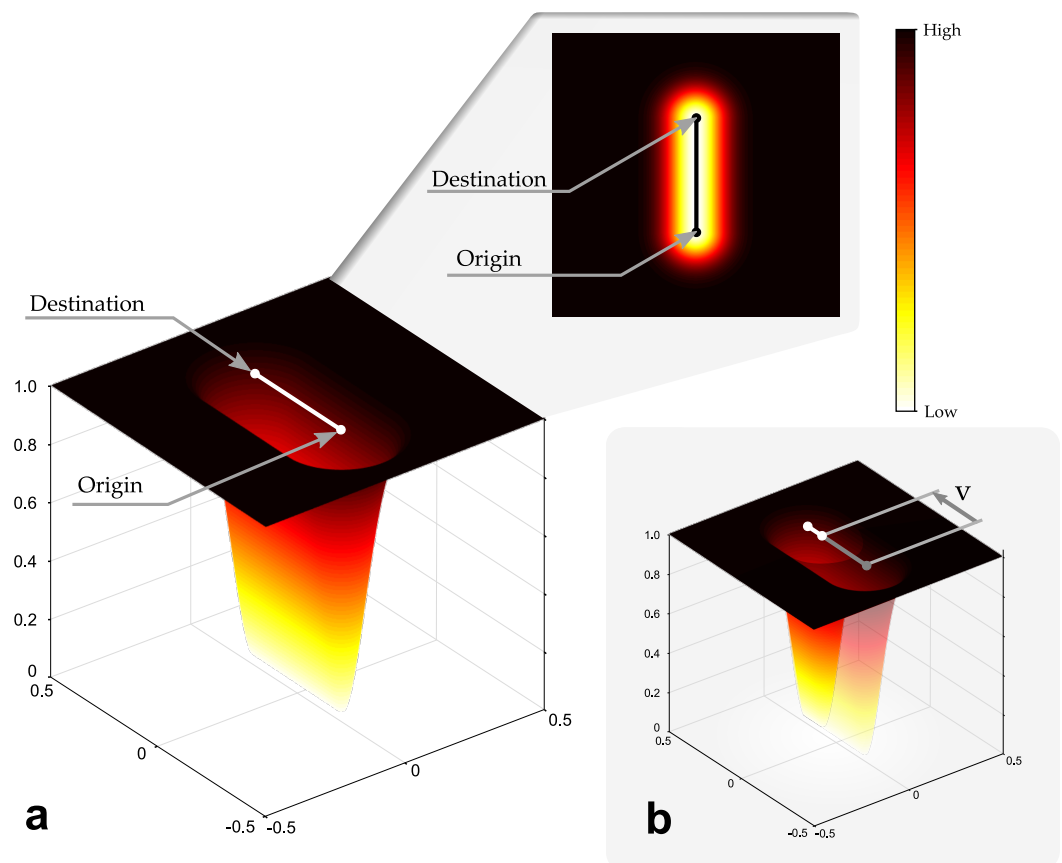


Figure 2. Graphic representation of the force fields used in this study. (a) Force fields in the form of a tunnel with ends. (b) Version of the force field in the form of a tunnel where the origin moves at constant velocity in order to help the patient to move towards the target. The scale represents the normalized assistance force magnitude applied in each position. The maximum assistance force value is configured by means of the assistance level of the robotic rehabilitation device.

2.3. Virtual Task

Figure 3 shows an overview of the game, which consists of a point-to-point modality. The player cursor is represented by a white circle whose center corresponds to the patient's current position. Figure 3d presents the possible movement of the robot in correlation with the proposed game.

In every trial, the patient has to wait in the center of the roulette until a target lights up (Figure 3a), then he will try to reach it before the time runs out and then return to the center. In the upper left hand of the screen, the time remaining to reach the current target is indicated. In the upper right hand of the screen, the remaining targets to finish the game are indicated.

A target is considered reached when the distance of the player's cursor to the target, d , is less than or equal to the r distance (Figure 3b). The distance r is adapted according to the assistance level that each patient will need to carry out the exercise properly.

The targets to be reached are selected randomly while guaranteeing all targets are reached an equal amount of times.

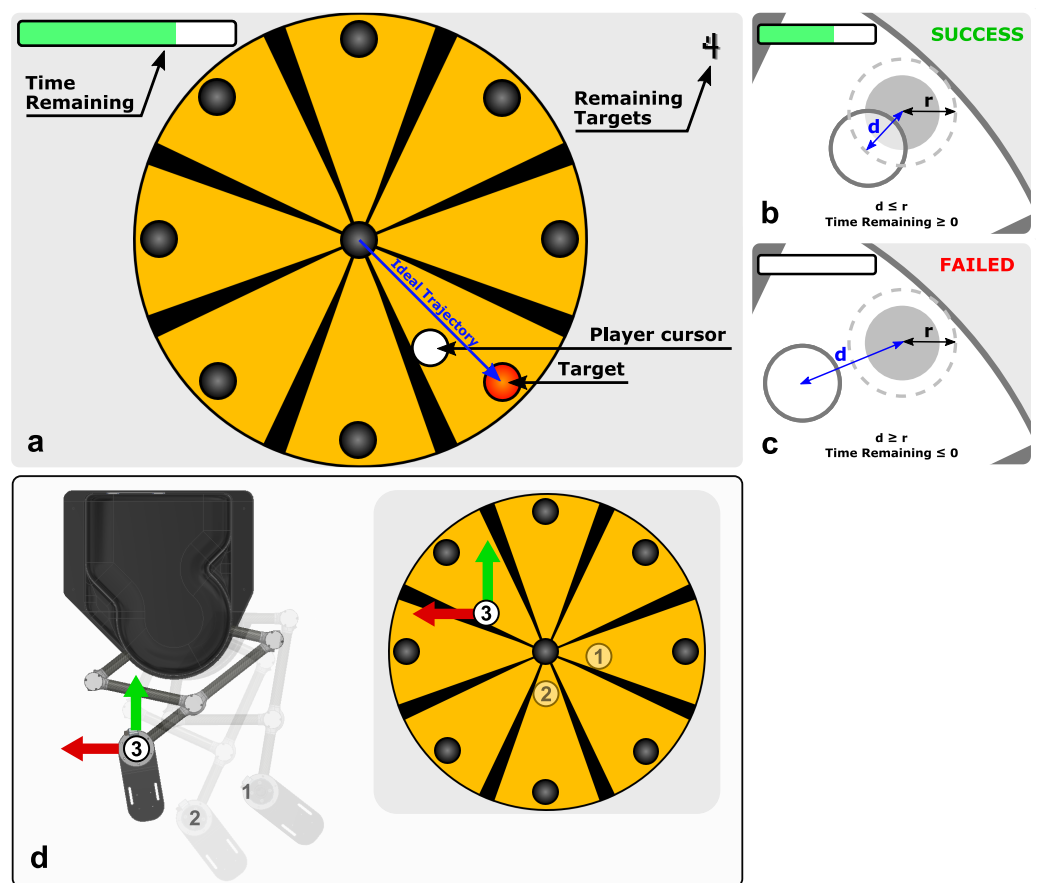


Figure 3. Overview of the game. (a) A screenshot of the game. (b) Condition to successfully reach the target, where d is the distance of the player cursor to the target and r is the minimum distance to reach the target successfully. (c) Condition to fail the reach of the target. (d) Movement of the robot in correlation with the proposed game.

2.4. Setup and Protocol

The experimentation was performed in a single session. The study consists of three different conditions (Figure 4):

- Fixed Assistance. Fixed assistance level provided by the robot by the use of a force field.
- Local Therapist Assistance. Assistance provided by the therapist.
- Remote Therapist Assistance. Assistance provided by the therapist remotely (approach to a tele-rehabilitation environment).

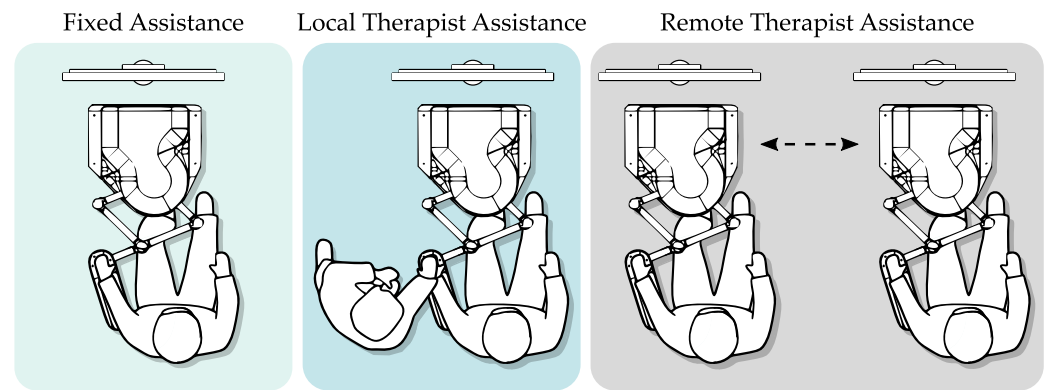


Figure 4. Graphical representation of the different assistance modes evaluated.

In this study, in addition to using a force-field-based assistance mode, two different master–slave strategies were implemented for the therapist to assist the patient. This technique is similar to that used in other studies [15]

In both modes, the patient uses a Rubidium device configured with a control algorithm based on force fields (Figure 2a). This force field will help the patient to perform a linear trajectory but will not help the patient to reach the target. It will be the therapist who will assist the patient to reach the targets.

In one case, the therapist applies forces on the end effector of the Rubidium device the patient is using (Local Therapist Assistance, Figure 5). For this purpose, the system was provided with a force sensor placed on the end effector to measure the force applied by the therapist to assist the patient.

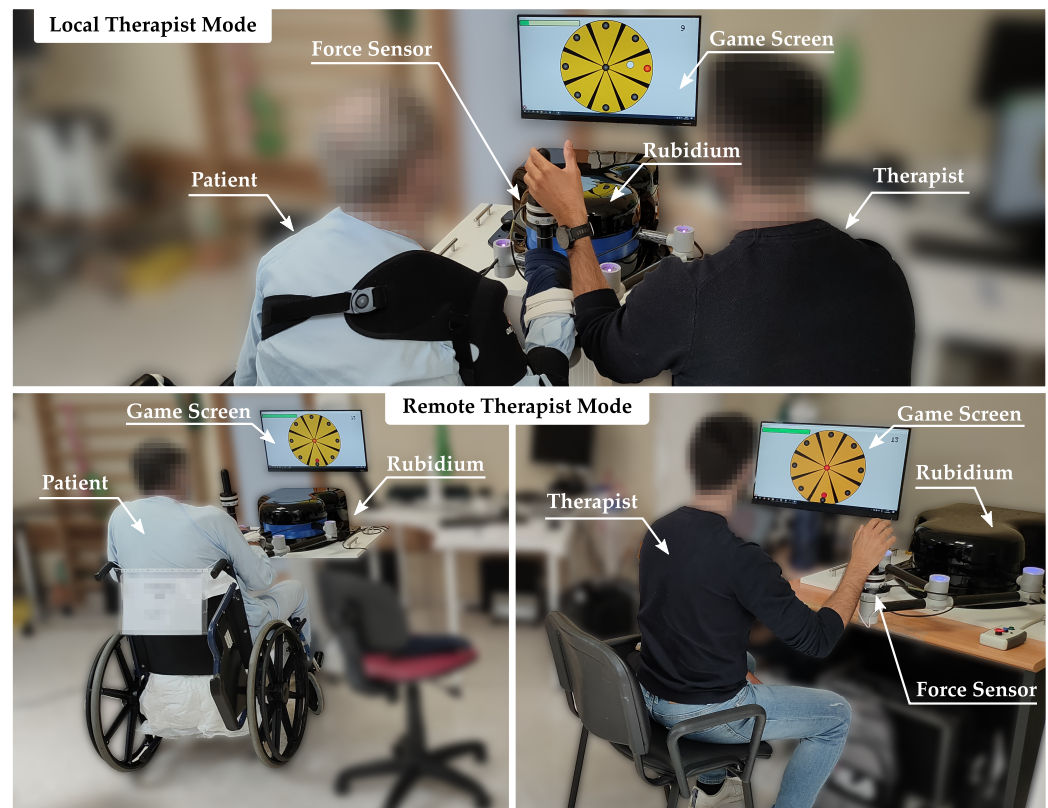


Figure 5. Image of the experimental setup taken during the local and the remote therapist assistance condition.

In the other case, the therapist interacts remotely with the patient through another Rubidium device (Remote Therapist Assistance, Figure 5). The Rubidium device is also provided with a force sensor on the end effector to measure the assistance force that the therapist wants to apply to the patient. The device with which the therapist interacts replicates in real-time the current position of the patient. The forces applied by the therapist will not be able to move the position of the robot with which he is interacting.

Figure 6 summarizes the study protocol carried out during the experimentation. Before starting the session, the patient is placed in front of the robotic device in a comfortable position. Firstly, we carry out a familiarization period where we explain how the game works and take the opportunity to make a general evaluation of the patient to establish some parameters such as the range of movement, the maximum time to reach the targets, or the magnitude of the force fields. This parameter will be used to configure the force fields and establish an adequate assistance level in the case of the fixed assistance mode.

After the familiarization period, we start with the experimental session. The conditions of the study were performed in random order. In each of them, the patient will have to perform 32 trials, and in each trial, the patient will have to randomly reach one of the 8 roulette targets before the time is up and then return to the center.

Before each trial, the patient must hold the player cursor (Figure 3) within the center of the roulette for 2 s. Then, one of the circles on the outer edge of the roulette lights up, indicating the next target to be reached. The time to complete the movement was adapted based on the initial evaluation of the patient, and once the target has been reached (or the time has expired), the patient has to go back to the roulette center. For this movement, there is no time limit.

Each of the conditions lasts about 7–8 min. After each condition, the patient will have a 3–5 min rest. This rest period is also used to fill in the questionnaires.

All the sessions were carried out with the same therapist so that the strategy for assisting patients is the same.

At the end of the experimental session with each of the patients, a member of the hospital's clinical staff was invited to test the different assistance modes and they were asked to fill in the SUS questionnaire.

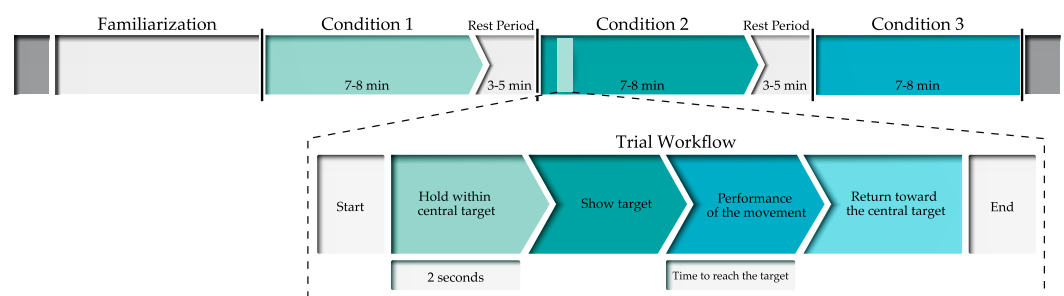


Figure 6. Diagram of the study protocol. The conditions are performed sequentially in random order. After each condition, a rest period of 3–5 min is carried out. This rest period is also used to fill in the questionnaires.

2.5. Estimation of the Assistance Level

The most intuitive way for a therapist to assist a patient in a point-to-point exercise modality is to grasp the end effector of the patient and help him in reaching the targets and making the movements as linear as possible.

In the rehabilitation robotic platform used in this study, a force field was implemented to help patients to carry out the movements as linearly as possible. Therefore, in our case, the assistance from the therapist consists of making a force towards the current target when necessary to help the patient to reach it.

In each of the assistance modes, the therapist is completely free to choose the magnitude and direction of the assistance force that he considers appropriate. This is the case except for the fixed assistance mode, where assistance will be provided by the robot. Therefore, to estimate the assistance level provided to patients, we calculate the magnitude of the force that helps them to move toward the target. To do this, we use Equation (1).

$$F_{assist} = |F| \cdot \cos \alpha = |F| \cdot \frac{F \cdot V_{trajectory}}{|F| \cdot |V_{trajectory}|} \tag{1}$$

We will call the force that helps the patient to move towards the target the assistance force, F_{assist} . In Figure 7, a diagram of the assistance force vector calculation is shown.

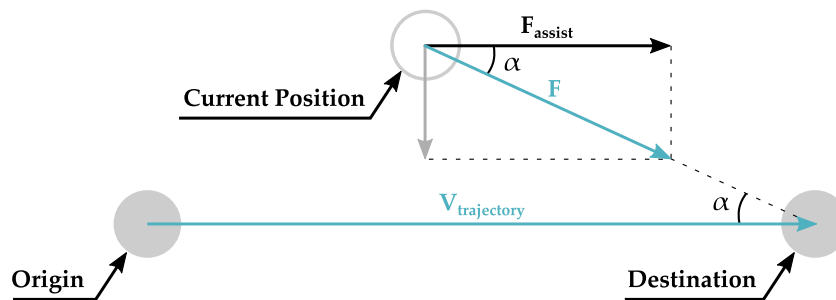


Figure 7. Diagram of assistance force vector calculation, $F_{assist} \cdot V_{trajectory}$ corresponds to the vector defined by the origin and destination of the trajectory towards the current target and F is the current force that the Rubidium is applying to the patient.

2.6. System Usability Scale

Additionally, the System Usability Scale (SUS) survey [16] was used. The SUS is a popular measure of perceived usability that determines the compliance level from the user expectations, satisfaction level, and system performance. It is a 10-item questionnaire. In this study, after testing the system, a survey was delivered to each patient. They had to answer their level of agreement or disagreement with every question using a 5-point Likert-type scale (from 1 to 5; [17]).

The SUS can be interpreted in different ways to facilitate understanding of the results. Figure 8 shows some of these interpretations. On the one hand, Bangor et al. [18] associated SUS scores with a 7-point adjective scale to use words instead of numbers to describe an experience. This scale contains adjectives that users loosely associated with the usability of a system. Additionally, in [19], Bangor et al. defined another way of using words to describe the usability of a system, this time in terms of what is “acceptable” or “not acceptable”.

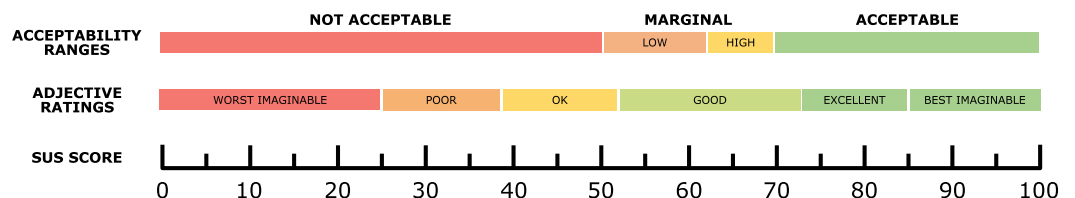


Figure 8. A comparison of mean System Usability Scale (SUS) scores by adjective ratings, and the acceptability of the overall SUS score.

2.7. Subjective Assessment of Experience

Several assessment tools are currently available to evaluate patient motivation and satisfaction during technology-assisted rehabilitation. One of the most widely used is the Intrinsic Motivation Inventory (IMI) [20]. This subjective questionnaire measures four aspects of engagement: enjoyment/interest, effort/importance, perceived competence, and pressure/strain. We chose to use a shortened version of the IMI used in other studies [21–23], although there are different versions [24].

2.8. Statistical Data Analysis

A normality test was carried out through the Shapiro–Wilk test. The results indicate that all the parameters are normally distributed, except in the case of the parameters from IMI.

One-way repeated-measures ANOVA (Analysis of Variance) was employed for the normally distributed parameters. To evaluate whether the sphericity assumption was violated, Mauchly's test of sphericity was used. If it was violated, a repeated-measures ANOVA was corrected using the Greenhouse–Geisser correction when the epsilon is $\epsilon \leq 0.75$ or the Huynh–Feldt correction when the epsilon is $\epsilon > 0.75$. In the post hoc analysis, Bartlett's test was employed to study the assumption of equal variances across groups (homoscedasticity or homogeneity of variances). Depending on the Bartlett's test result, Tukey post hoc tests or the Games-Howell post hoc test were used for the pairwise comparison.

If the parameters were not normally distributed, the Friedman test was used. In the post hoc analysis, the Holm–Bonferroni method was used to adjust for family-wise error rate correction.

3. Results

3.1. Assistance Force

Example trajectories for two patients with overlaying density plots indicating the location and amount of the offered assistance are shown in Figure 9. These two patients were specifically selected to illustrate two types of patients.

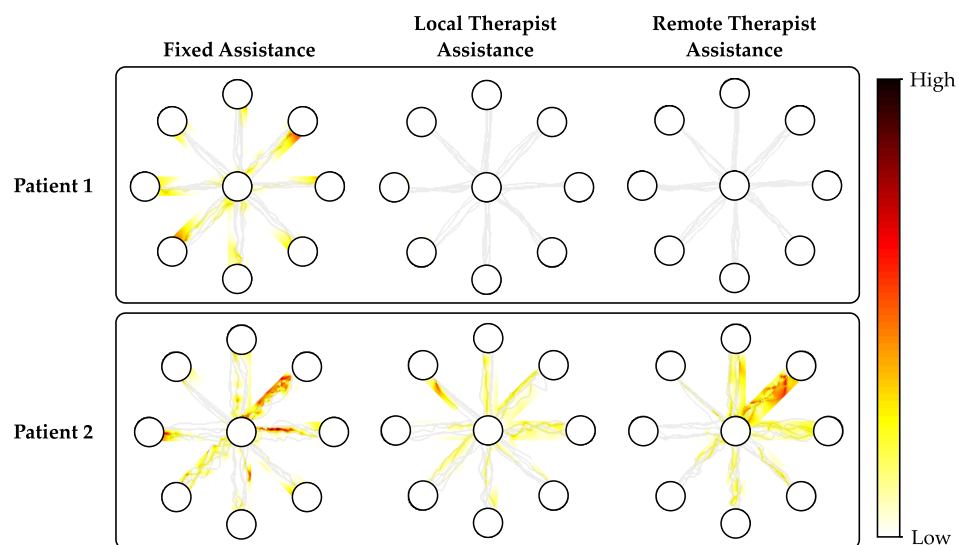


Figure 9. Example trajectories for two users, with overlaying density plots indicating the location and amount of the offered assistance. Darker areas indicate higher amounts of assistance.

Patient 1 is the case of a patient capable of performing the exercise with a very low assistance level, as observed in the local and remote therapist assistance modes. However, in the fixed assistance mode, higher assistant forces are applied.

The results of patient 2 illustrate the most common type of patient of this study. They suggest that the fixed assistance mode provided higher assistance forces than the local and remote therapist assistance modes. We also observe that the therapist assisted more remotely than locally. Therefore, the local therapist assistance was the mode in which the lowest assistance level was applied.

Mean and maximum assistance forces values in every condition for all patients were computed (Figure 10a). The mean assistance force results show significant differences between groups (one-way repeated measure ANOVA $p < 0.0001$). Paired comparisons

show that the fixed assistance mode is significantly different concerning local and remote therapist assistance modes ($p = 0.0002$ and $p = 0.002$, respectively). In the assistance modes in which the therapist is involved, the mean assistance forces are similar ($p = 0.18$). The analysis also shows significant differences between modes for the maximum assist forces (one-way repeated measure ANOVA $p < 0.0001$). Paired comparisons show that all modes are significantly different, except in the fixed assistance mode concerning the local therapist assistance mode, where a reliable trend toward significance is observed ($p = 0.05$).

In Figure 10b, the mean assistance force value in every condition for each patient is shown. In all cases, the mean assistance force value is higher in the fixed assistance mode. Furthermore, we can also see that in most cases, the therapist assists more remotely than locally.

Results suggest that in fixed assistance mode, the robot assists equally towards all targets. However, this is not the case of the assistance modes where the therapist is involved where the assist forces seem to be better adapted to the patients.

The percentage of targets successfully reached was also computed as a measure of exercise performance (Figure 10). A very high level of performance was obtained in all modes.

These results indicate that the assistance level provided to the patients in all modes is sufficient to perform the exercise correctly.

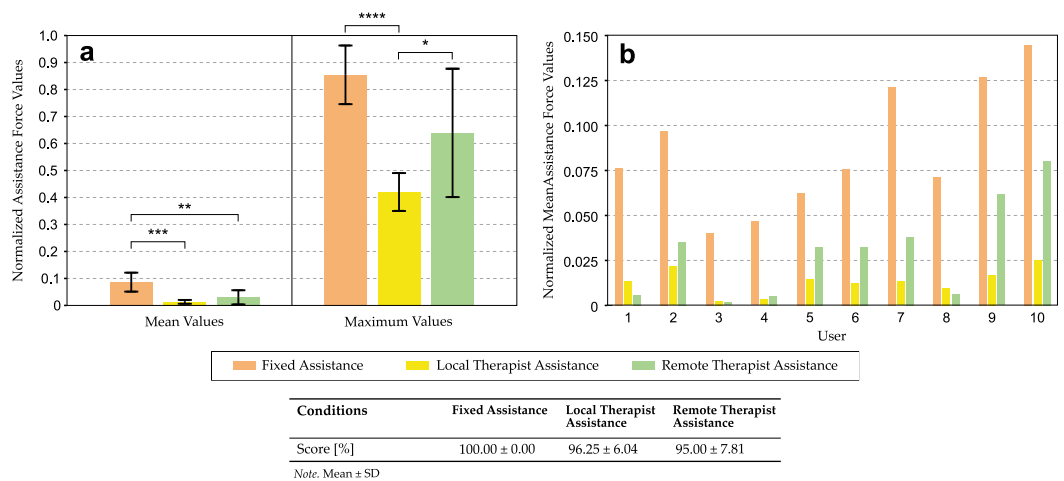


Figure 10. Normalized assistance force values. (a) Mean and maximum assistance forces values in every condition for all patients. Bars indicate mean values, and error bars indicate standard deviations. (b) Mean assistance force value in every condition for each patient. In all cases, each patient’s assistance force was normalized by the maximum value measured for the patient throughout the three conditions. The table collects the mean percentage and the standard deviation of the score in every condition for all patients. Statistical differences are represented by * ($p < 0.05$), ** ($p < 0.01$), *** ($p < 0.001$) and **** ($p < 0.0001$).

3.2. Intrinsic Motivation Inventory

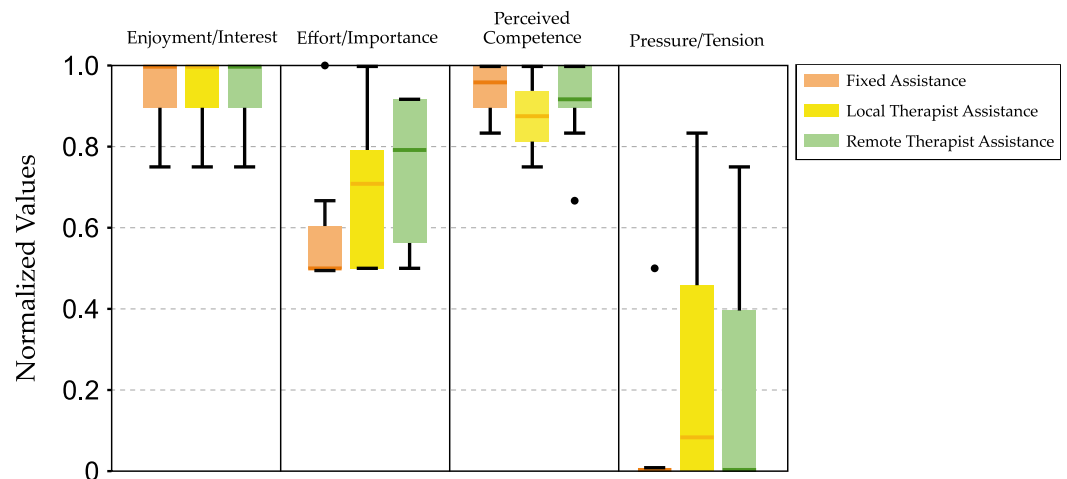
In Figure 11, results from the IMI for all three conditions of the study are shown. We do not obtain significant differences in any of the parameters. However, we consider that there are trends in the results that must be discussed.

Regarding the Interest/Enjoy parameter, we did not observe any difference between the three modes. They are very similar. However, in the case of the Effort/Importance parameter, differences between modes are observed. According to the patients’ subjective assessment, the least effort mode is the fixed assistance mode, followed by local and the remote therapist assistance modes.

In the case of the Perceived Competence parameter, it is very high in all cases, being a little lower in the local therapist assistance mode.

Finally, in the Pressure/Tension parameter, patients indicate that the pressure is higher in the assistance modes in which the therapist is involved. In the case of fixed assistance mode, the value is practically zero.

Results suggest that patients' perceived exertion is greater when the assistance is provided by the therapist. However, patients enjoy all three modes equally, and they are satisfied with their performance. Therefore, results do not suggest that the effort is too high.



Conditions	Fixed Assistance	Local Therapist Assistance	Remote Therapist Assistance
Enjoyment/Interest	1.00(0.90, 1.00)	1.00(0.90, 1.00)	1.00(0.90, 1.00)
Effort/Importance	0.50(0.50, 0.60)	0.71(0.50, 0.79)	0.79(0.56, 0.92)
Perceived Competence	0.96(0.90, 1.00)	0.88(0.81, 0.94)	0.92(0.90, 1.00)
Pressure/Tension	0.00(0.00, 0.00)	0.08(0.00, 0.46)	0.00(0.00, 0.40)

Note. Median (Q₁, Q₃)

Figure 11. Results from the Intrinsic Motivation Inventory for all three conditions of the study. The table collects the median value and the first and third quartiles of each parameter from the Intrinsic Motivation Inventory.

3.3. Usability Assessment of the Assistance Modes

Figure 12 shows the results of system usability assessment by the patients and the clinical staff. In the case of patient evaluation, all modes obtain a very high SUS score. They were rated as Best Imaginable (SUS score > 85.0). We also get very high SUS scores in the assessment of the clinical staff. However, the remote therapist assistance mode achieves a lower SUS score (SUS score = 76.88, Excellent).

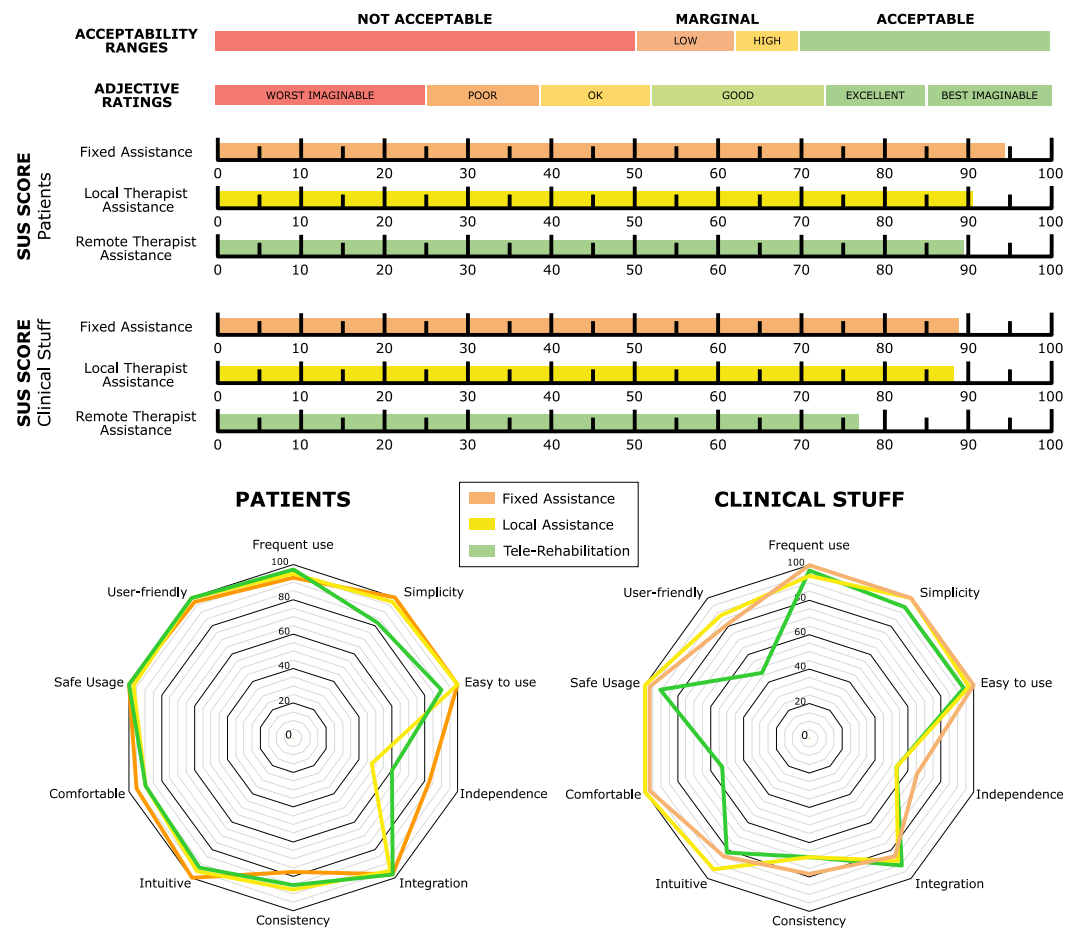


Figure 12. Mean scores of the System Usability Scale (SUS) given by the patients and the clinician staff.

4. Discussion

4.1. Differences between Assistance Modes

As previously mentioned, the assistance level is estimated through the force assistance value. Results suggest that the fixed assistance mode has a significantly higher assistance level than the others (Figure 10).

The score is a parameter commonly used to estimate the exercise performance [25,26]. It allows us to evaluate whether or not patients can perform the exercise correctly. In this study, a high level of performance is obtained in all modes. These results indicate that the assistance provided to the patients was adequate to perform the exercise correctly.

In fixed assistance mode, the robot assists equally towards all targets. However, this is not the case of the assistance modes where the therapist is involved. The therapist can decide the right way and time to assist the patient to reach each target. This means that he can decide not to provide assistance and let the patient put more effort into those in which he can reach by himself. In this way, the assistance profile is not the same in all targets as it happens in the fixed assistance mode, which is why the assist forces are better adapted to the patients.

Regarding the result of the IMI (Figure 11), patients' perceived exertion is greater when assistance is provided by the therapist. However, patients indicate that they enjoy all three modes equally. Furthermore, they are satisfied with their performance in all modes. Therefore, there is no evidence to suggest that the patients' perceived exertion can demotivate them in any of the modes.

Based on these results, we can conclude that in the fixed assistance mode, assistance level was greater than necessary, or in other words, the assistance forces provided by the therapist are better adapted to the needs of the patient.

On the other hand, the assistance level provided by the therapist remotely is generally greater than locally. The only difference between the three conditions in this study is the way the patient is assisted. Therefore, the only difference between the therapist assisting the patient locally or remotely is the interaction with the user. According to the feedback we have obtained from the clinical staff, remotely, communication with the patient is more difficult, especially with certain pathologies. That is why it is more difficult to assess when to assist the patient. The way of working with patients differs from what clinical staff is used to. The therapists' decisions, and therefore the results, would improve with training and knowledge of the system.

Even so, the results are better than those obtained with the fixed assistance mode; therefore, although communication with the patient is more complicated, the assistance proves to be better adjusted to the patients.

4.2. Usability of the Assistance Modes

The evaluation of the three assistance modes of this study was carried out from two points of view: the patients who have used the system and the clinical staff.

The results obtained in the evaluation of the patients show that all modes obtained a very high SUS score, but we observed a lower score in the case of the assistance modes in which the therapist is involved. Analyzing the answers to the questions, the main difference of these modes concerning the fixed assistance mode lies in the independence level reported by the patients. They perceive a lower level of independence in these modes because they need the assistance of the therapist. On the other hand, we do not observe significant differences between these two modes.

In the evaluation carried out by the clinical staff, four therapists and four physiotherapists participated. In this case, we also obtain a very high SUS score in all cases, but in the remote therapist assistance mode, the score is lower than in the others. The answers to the questionnaire suggest that the remote therapist assistance mode is more difficult to use than the others. As we discussed earlier, in the Remote Therapist Assistance mode, the way of working with patients differs from what clinical staff is used to.

5. Conclusions

In this study, we have evaluated the advantages of a master–slave strategy, where patient assistance is provided by a therapist. We have also explored if this type of strategy is applicable in a tele-rehabilitation environment, where the social interaction with the patient is more limited compared to being with the patient at the clinic. To do this, we have carried out a study involving 10 patients that have performed typical point-to-point exercises under three assistance modalities: fixed assistance (no therapist interaction), local therapist assistance and remote therapist assistance (teleoperated).

Our results indicate that the assistance provided by a therapist is better adapted to the needs of the patient. The assistance profile is not the same in all targets as it happens in the fixed assistance mode. The therapist can decide the right way and time to assist the patient to reach each target. Therefore, this mode maximizes the effort of the patient, which is an important aspect to improve the outcomes of rehabilitation therapies. We have also seen that in a tele-rehabilitation environment, it is more difficult to assess when the patient requires assistance than in the local therapist mode. Remotely, communication with the patient is more difficult, especially with patients who suffered certain pathology. That is why it is more difficult to assess when to assist the patient. However, although communication with the patient is more complicated, the assistance provided by the therapist remotely proves to be better adjusted to the patients than the assistance provided by the fixed assistance mode.

Author Contributions: J.M.C., J.V.G.-P, and A.B. conceived of and designed the experiments. J.M.C., J.V.G.-P. worked on the construction of the experimental setup. A.G. and T.C. carried out the recruitment of patients and the schedule to participate in the experimentation. J.M.C., J.V.G.-P. and S.E. performed the experiments and the data measurement. J.M.C. and A.B.-M. analyzed the data.

J.M.C., A.B. and S.E. drafted the paper. I.D. and N.G.-A. contributed to the design of the study and deeply revised the manuscript. All authors have read and agreed to the published version of the manuscript.

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Abbreviations

The following abbreviations are used in this manuscript:

ACM	Artery Cerebral Middle
ANOVA	Analysis of Variance
IM	Index Motor
IMI	Intrinsic Motivation Inventory
N/A	Not available value
ROM	Range Of Movement
STREAM	Stroke Rehabilitation Assessment of Movement
SUS	System Usability Scale

Symbols

The following symbols are used in this manuscript:

α	Angle formed by vectors F and $V_{trajectory}$
d	Distance of the player cursor to the target
ϵ	Parameter of the Greenhouse–Geisser correction method
F	Current force applied by the robot
F_{assist}	Assistance force vector
$V_{trajectory}$	Vector defined by trajectory towards the target
r	Minimum distance to reach the target successfully

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