A feasibility study to assess the effectiveness of Muvity: A telerehabilitation system for chronic post-stroke subjects

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Objectives: To assess the feasibility of a telerehabilitation system for chronic post-stroke subjects compared to a conventional treatment. *Methods:* A feasibility cross-over analysis was conducted in ten chronic post-stroke subjects. Two randomized groups followed two eight-weeks treatments, one with the telerehabilitation system Muvity and the other following conventional therapy (in random order). Before and after each treatment, physical evaluations were performed assessing functional independence, the perceived level of pain, balance control and self-reported health status. After the study, the participants answered a short questionnaire to measure the usability of the system. *Results:* Four out of six subjects demonstrated better performance in ADLs (equal or higher FIM scores) and five out of six reported lower pain (VAS score) after the treatment with Muvity when compared to the treatment without. There were no clear trends in terms of balance control (Berg scale) or self-reported health status (PCS score within SF-36). *Conclusions:* The results suggest that the proposed telerehabilitation system aids users to overall maintain or improve their ability to perform ADLs without increasing pain, when compared to conventional therapy. Most subjects found the use of Muvity more motivating than the conventional rehabilitation treatment. This provides initial evidence that Muvity might be an appropriate complement for the telerehabilitation of patients with physical disabilities. However, the differences observed between both treatments were not statistically significant. A clinical study with a larger sample size will be necessary to obtain more robust results.

Keywords: Stroke rehabilitation—Movement analysis—Physical therapy—Telerehabilitation—Feasibility trial

Introduction

The first three months after a cerebrovascular accident are crucial for the recovery process of survivors. In this period, the natural physiological response of the tissue to injury facilitates increased neuroplasticity and, consequently, improved functional gains.[1] Public health systems typically offer rehabilitative care during this phase as part of the treatment for stroke. However, this is not where the subject's journey ends. Despite diminishing returns in recovery during the later chronic phase, keeping up training is still important to prevent function deterioration.[2] Nevertheless, public healthcare cannot cover

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patients indefinitely, so they must turn to other options to continue pursuing their rehabilitation. One such alternative lies in private centres. However, many people are not able to afford the cost of these or are otherwise limited in their access to these venues by geographical proximity or waiting lists.[3] Training on their own is another option, but the nature of rehabilitation programs makes them monotonous and demanding. After all, stimulating cortical reorganization for functional recovery requires intensive and repetitive training based on specific activities of daily living (ADLs).[4,5] Because of this, motivation to follow an exercise plan decreases sharply over time.

There is evidence that Virtual Reality (VR) enhances adherence rates and cortical reorganization by providing immersive, engaging and task relevant environments for users to train in the literature.[6–9] A potential way to address the problem so far presented is to use non-immersive VR applications to support the rehabilitation of subjects at home, a telerehabilitation scheme. This approach can be made more effective when combined with gamification strategies.[10–12] In addition, VR can provide further benefits in this context by, for instance, facilitating means to track the progress of the subject remotely.[13] Finally, the barriers to implementation of telerehabilitation systems encountered a decade ago[14] have likely been reduced as a result of widespread access to a rapid internet connection. Together, these points paint a positive picture for this kind of solution. However, validation of the use of these systems in physical functionality needs to be performed. Past studies have assessed the effect of systems of this kind on chronic post-stroke subjects using depth sensors,[5,15–20] or a combination of depth sensors and inertial measurement units (IMUs) for motion tracking.[21–24] In most of these works, tests were performed in a clinical setting,[15,16,18–22] whereas the number of in-home studies is limited.[5,17,23,24] Additionally, only some of these works put forward exergames specifically designed for the post-stroke population,[5,15,17,20,23,24] taking into account the potential physical and visual limitations of those subjects.

The work presented herein fits into this underexplored niche of the literature. A novel non-immersive VR telerehabilitation system was developed in collaboration with the Osona Association for Functional Diversity (ADFO) to support the rehabilitation of chronic post-stroke subjects in their homes. An initial feasibility study was conducted to assess the adequacy of this platform in its intended use case. The effectiveness of rehabilitation treatments is usually measured with standard clinical tests.[25,26] In addition to such tests, the application also facilitates objective comparisons in range of motion (ROM) of multiple anatomical degrees of freedom. In this context, the effectiveness of the telerehabilitation system will be considered adequate if outcome measures (both those associated with clinical tests and those associated with ROMs) do not reflect a worse performance when compared to conventional treatment, i.e. subjects training on their own without the assistance of the platform. Adequate effectiveness and high reported user satisfaction are both necessary for a positive ruling on the overall adequacy of the platform.

Methods

Telerehabilitation system

The basic setup of the system used in this study consists of a depth camera connected to a household computer running our application called Muvity. The Intel® RealSenseTM D415 depth camera (Intel, Santa Clara, CA, USA) was chosen as a relatively low-cost option with good precision. The NuiTrack SDK (3DiVi, Walnut, CA, USA) was used to convert RGB-D data into real-time skeleton tracking without markers. Extraction of joint positions over time permits the user to control an avatar to exercise in a virtual environment. The kinematic information obtained by this means can also be used to compute metrics of the subject's performance (usually the ROM), as was done for the post-study data analysis. At present, the application offers six games and five exercises. Exercises put the user into a simple environment where they focus on practising a particular movement (single joint motion) by doing a set number of repetitions or as many repetitions as possible within a set timeframe. These movements include flexion and extension of the shoulder (glenohumeral joint), horizontal abduction and adduction of the shoulder, vertical abduction and adduction of the shoulder, flexion of the elbow and medio-lateral translation of the pelvis.

On the other hand, games contain a wide variety of environments designed to resemble ADLs (as this has been shown to be effective in enhancing motor recovery[4,27]), can incorporate multiple movements and are reinforced with further game mechanics to boost motivation and engagement. These also possess extra internal measures of performance not derived from kinematic data - see Table 1 for a summary of the different degrees of freedom and performance scores associated with each game.

The *Goalkeeper* game puts the player in a soccer game, where he/she must raise their arms to stop incoming balls. The *Clean-the-bathroom* game consists in cleaning a fogged mirror by pointing the arm at the screen. The arm must either follow a predefined trajectory to make a pattern on the mirror or be moved all around to clean the entirety of the surface. *Clean-the-horse* is similar to the previous one. The same arm motions control a hose to wash the dirt off a horse. In this case, the only modality is to follow a predefined trajectory to draw geometrical shapes. The *Kitchen* game consists of three different scenarios where the player must follow a sequence of movements emulating kitchen activities involved in preparing a pizza, such as chopping ingredients or mixing dough.

PickApples and *Imbalance* games both deal with the medio-lateral translation of the waist. The swinging

Table 1. *Summary of the human's body degrees of freedom treated at each game with the type of score collected.*

Games	Joint movements	Performance score
Goalkeeper	Shoulder flexion/extension	Number of shots blocked - max. of 4
Clean-the-bathroom	Shoulder flexion/extension and vertical and horizontal abduction/adduction	Percentage of accuracy following a trajectory or covering an area of the screen
Clean-the-horse	Shoulder flexion/extension and vertical and horizontal abduction/adduction	Percentage of accuracy following a trajectory
Kitchen	Shoulder flexion/extension and vertical and horizontal abduction/adduction Elbow flexion/extension	Time to complete 6 repetitions or number of repetitions (<6) completed before timeout
PickApples	Medio-lateral translation of the pelvis	Number of apples collected - max. of 9
Imbalance	Medio-lateral translation of the pelvis	Number of coins collected: Level 1 max. 63, level 2 max. 48, level 3 max. 56

motion of the body (shifting body weight) allows the player to control their avatar to gather collectibles. In the case of *PickApples*, the avatar is a basket that swerves to catch apples falling from a nearby tree. In the case of *Imbalance*, the avatar is invisible as the game adopts a first-person perspective. The player is taken through one of three levels, moving forward automatically but with the ability to move from side to side to collect coins and avoid obstacles.

Both in the case of exercises and games, the time-to-time positions of joints as reported by the skeleton extraction algorithm are exported to an external database for later processing and analysis. Other statistics of application usage, such as time played are also collected, as are the performance scores reported in Table 1 in the case of games. A physiotherapist can access this data server-side to track the progress of their patients asynchronously.

Feasibility study

Recruitment was conducted primarily through ADFO's network. Only subjects who fulfilled all of the following inclusion criteria were eligible for involvement in the trial:

- The subject has suffered a stroke.
- The subject must have at least one-third of the upper-limbs ROM needed to perform ADLs[28,29]:
    - ○ The subject must be able to resist counter-gravity elbow flexion of at least 45°.
    - ○ The subject must be able to resist counter-gravity shoulder flexion, and shoulder abduction/adduction of at least 45°.
    - ○ The subject must be able to resist counter-gravity shoulder rotation of at least 30°.
- The subject must pass a standard visual acuity test with corrective lenses of 20/50 or better. Subjects were excluded if they had visual field deficits that may impair the ability to see the computer screen and/or if they exhibited hemispatial neglect that would impair their ability to process and perceive visual stimuli.
- The subject must display a minimal amount of functional independence as reflected by a score of 3 or below on the Modified Rankin Scale.[30]
- The subject must display a minimal ability to understand and follow verbal cues. Subjects were excluded if they presented a high degree of dementia, defined as a score below 24 on the Mini-Mental State Examination (MMSE).[31]

Physiotherapists within the association contacted their post-stroke subjects (a total of 16) about the possibility of trying out Muvity application. Of these, ten met all inclusion criteria and were selected for the study (mean and standard deviation of age = 49.7 ± 12.3 years, 5.5 ± 3.8 years from the stroke, seven women and three men). Participants were then randomly split into two groups by a physiotherapist who did not take part in subsequent evaluations. A cross-over study design was adopted. Both groups followed two eight-week periods of in-home rehabilitation. One of the groups partook in telerehabilitation by means of the provided application, whereas the other conducted conventional rehabilitation. At the end of the first eight-week period, the roles of the groups were exchanged.

The conventional rehabilitation treatment consisted of 30-minute sessions of upper-limb and weight-shifting movements that the subjects were asked to do on their own three days per week. Prior to beginning treatment, subjects had a face-to-face session (~15 minutes) with a physical therapist who instructed them on how to do the exercises and handed them a sheet of paper with a training routine. This setup mirrors the maintenance rehabilitation treatment that most post-stroke subjects who do not regularly frequent private rehabilitation centers get in their chronic stage. Similarly, subjects were also instructed to train for 30 minutes, three times per week for the telerehabilitation treatment. In this case, the training consisted of doing exercises and playing games with the application. Prior to the beginning of the treatment, a physiotherapist from ADFO visited the subject's home to set up the telerehabilitation system, either on the subject's personal computer or on one loaned to them by the association. During these visits, the physiotherapist also instructed them on how to use the application and how to play each of the games (sessions of ~15 minutes). Subjects in both groups were given the freedom to train more if they so desired. This permits a soft measurement of the impact of the application on the user's motivation to continue with their rehabilitation.

The subjects rested for a two-week washing-out period in-between the two in-home rehabilitation phases (prior to the exchanging of roles of the groups). Clinical evaluations of the subjects were conducted before and after each of the rehabilitation phases (for a total of four evaluations). These evaluations were performed by physiotherapists at ADFO's facilities and consisted of: measuring the degree of disability via the Functional Independence Measure (FIM),[32] determining the ability to self-balance via the Berg Balance scale,[33] measuring the perceived intensity of pain that the subject was under with a simple Visual Analog Scale (VAS),[34] and assessing the self-reported health status of the subject via the SF-36 questionnaire,[35] In addition, during these evaluation sessions, the ROM of the anatomical degrees of freedom mentioned in the previous section was captured using the telerehabilitation system to allow comparisons of these metrics across treatment plans. In total, when accounting for this washing-out period, the study lasted for 18 weeks. Six subjects finished the full 18-week plan - see Fig. 1 for a rundown of participant retention throughout the different stages of the study. Those that finished were asked to fill out a satisfaction questionnaire, adapted from Parmanto et al.'s Telehealth Usability Questionnaire (TUQ).[36] This questionnaire was designed to evaluate a telehealth implementation and service by covering all the usability factors (i.e., usefulness, ease of use, effectiveness, reliability, and satisfaction). See supplementary material - Satisfaction questionnaire - for a list of the questions included in the version used in this study. Six months after the end of the study, those subjects who finished the entire program were also called back to ADFO for a follow-up evaluation. These follow-ups were conducted in exactly the same manner as the four evaluations done during the study. The Ethics Committee of the Universitat Politècnica de Catalunya reviewed and issued local institutional approval for this study prior to the beginning of the interventions. The participants provided written informed consent.

Data analysis

Data acquired from the subjects during the in-home treatment were processed and analyzed with MATLAB (Mathworks, Natick, MA, USA) in order to obtain consistent results of the rehabilitation sessions' performance. All joint angles and positions were calculated from the joint data recorded by the depth camera. Noise due to bad or incorrect point detections was removed with a median filter. We also calculated the ROM for the right and left sides of the body in the exercises and games, and the performance of the games in terms of scores (e.g. percentage of collected coins, percentage of mirror cleaning or the time that has elapsed until the game goal has been reached, among others). In addition, the time spent on each exercise and game were also extracted from the application.

All these above-mentioned data were calculated for each rehabilitation session and averaged per day and week. The average per week was used to compare ROM, games' performance and the total time using the application for each subject, whereas the average per day was used to study correlation among all the variables. Correlations among the calculated ROMs per each week were also calculated. Each subject underwent five evaluations in total. We measured the difference between the evaluations after and before the time period with and without application in order to observe if there was an improvement or a difference between the two periods.

Correlations and differences of ROM (parametric variables) within treatment and between treatments were assessed with t-Student tests. Significant differences of FIM, Berg, VAS and PCS scales (non-parametric) within and between treatments were assessed with the Wilcoxon-Mann-Whitney test. In both tests, a significant difference was considered when *p-value* < 0.05. Effect sizes were calculated using *Hedge's g*.[37]

Results

Evaluations

The averages of maximum values for all assessed ROMs and across all participants were superior with the telerehabilitation system treatment compared to the conventional treatment, except for shoulder flexion (Table 2). However, those differences were not statistically significant ($p > 0.05$). The effect sizes were considered low for the elbow flexion (*Hedge's* $g = 0.07$), and medium for shoulder horizontal abduction ($g = 0.25$), shoulder vertical abduction ($g = 0.61$), shoulder flexion ($g = 0.63$), and waist translation ($g = 0.48$).

The VAS score (measurement of pain feeling) was the physical outcome, out of the four physical scales assessed, which reported the highest effect size when comparing both treatments. Most subjects reported less pain intensity after using Muvity than with the traditional rehabilitation (Fig. 2), though no statistical significant differences were observed within VAS scores (with $g = 0.65$). Muvity decreased the pain level in Subjects 2, 3 and 4 up to a difference of 6 points. Subjects 1 and 5 did not have a difference in pain level in any of the two treatments. However, Subject 6 showed higher VAS score differences with Muvity than following traditional rehabilitation. Six months

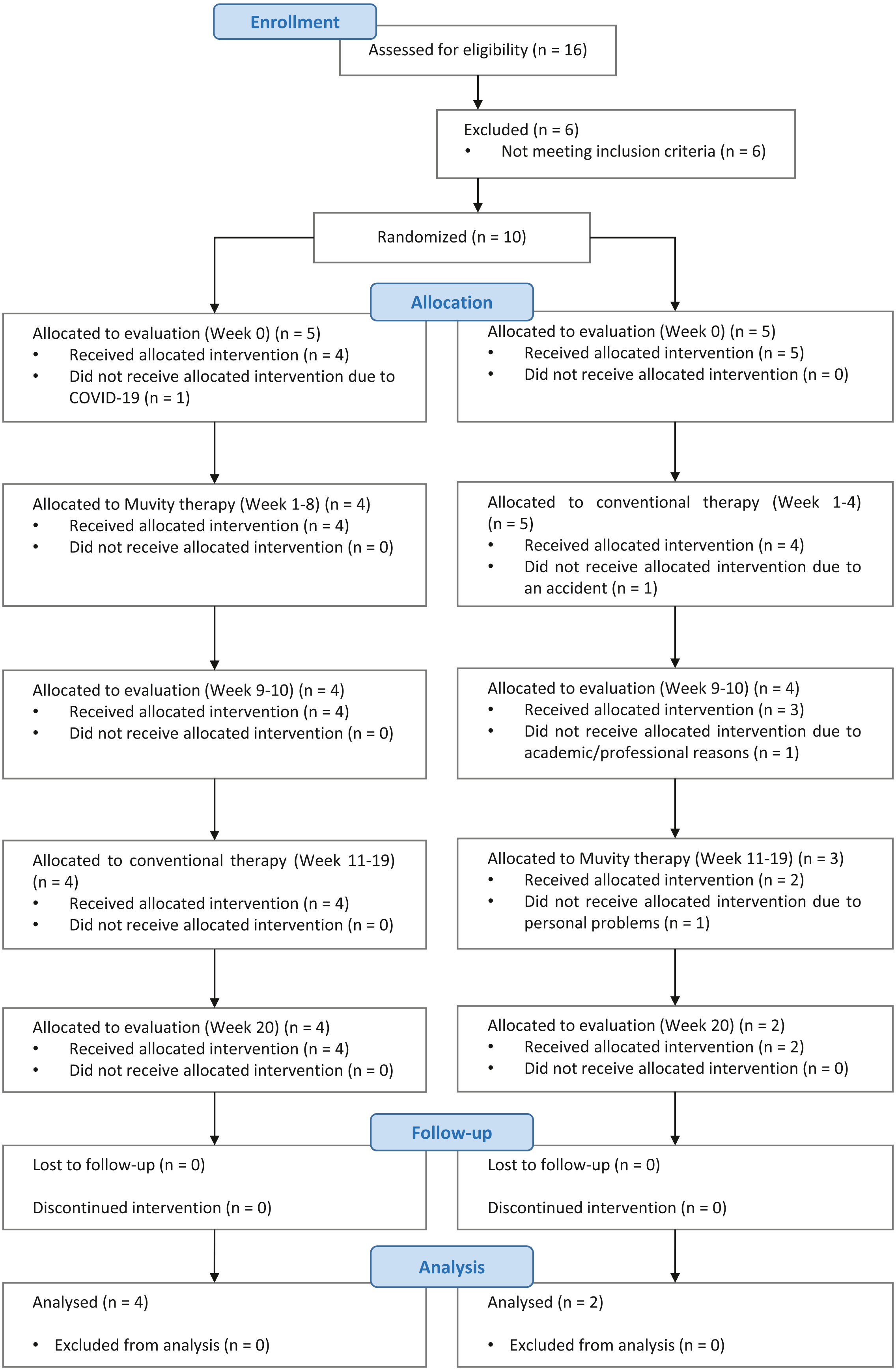

Fig. 1. *Consort diagram of the feasibility study.*

Table 2. *Differences in ranges of movement between pairs of evaluations, before and after the treatment with the application, without the application; and the differences between the follow-up evaluation after six months and just after the treatments.*

Degree of freedom	Δ treatment using app	Δ treatment without using app	Δ six-month after treatment
Shoulder flex/ext (°)	-22.9 ± 37.2	-3.2 ± 20.5	25.7 ± 44.6
Shoulder vertical abd/add (°)	17.0 ± 42.9	-3.2 ± 14.1	14.4 ± 32.1
Shoulder horizontal abd/add (°)	1.1 ± 19.5	-3.8 ± 18.0	0.8 ± 26.4
Elbow flexion (°)	4.1 ± 13.1	3.2 ± 11.4	-9.2 ± 21.2
Waist translation (mm)	18.4 ± 43.8	-0.6 ± 30.9	9.9 ± 40.5

after the treatment, the level of pain decreased for three subjects and increased for the others. Four of the six subjects maintained or improved their functional independence (FIM score) with the application (Fig. 2). However, the effect size was low (g = 0.13). The exceptions were Subject 4 (with a difference of 1) and Subject 6, the latter being the same subject that reported the highest pain intensity using the application. Six months after the treatment, the FIM score decreased for four subjects and kept constant for the other two.

After any treatment (in both, with and without application), an increase of the Berg balance outcome was observed on most subjects (Fig. 2). Only Subject 3 showed a decrease without the application, and Subject 4 a decrease using the application. However, the differences in Berg score were superior in five subjects without using the application compared to the treatment using the application (with an effect size of g = 0.25, no statistical difference). After six months, the Berg scores increased for three subjects and decreased for the other three. PCS score decreased in five and three subjects using the application and without using it, respectively (Fig. 2). In two subjects the difference was superior using the application (with g = 0.32, no statistical significant difference). After six months, PCS score increased for five subjects.

Monitored data

The total time that the subjects spent using Muvity during the treatment is shown in Table 3. This is the time within the exercises and games, without counting the time spent on the menus or intermediate resting periods. During the eight weeks period without the application, the subjects were required to write down the time spent following the exercises and all six subjects mentioned that they followed three 30-min sessions per week.

Significant positive correlations among all five analyzed ROM variables during the eight weeks monitored with

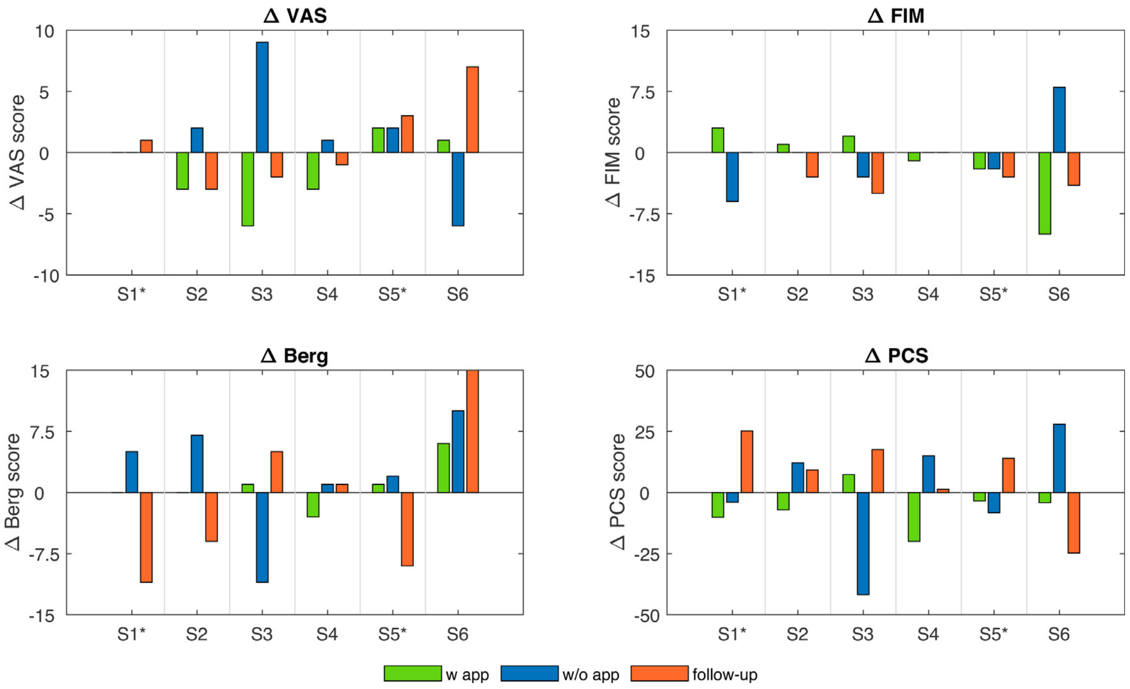

Fig. 2. *Differences in FIM, Berg, PCS and VAS scales in three periods: before and after the treatment with application, the treatment without the application and between the finalization of the last treatment and the follow-up measurement after six months. Subjects with asterisk * started with the treatment without the application.*

Table 3. *Mean and standard deviation of weekly time spent on using application.*

Subject	Time played per week (hours)
1	1.16 ± 0.41
2	0.76 ± 0.49
3	0.45 ± 0.31
4	0.68 ± 0.39
5	0.47 ± 0.27
6	1.71 ± 0.61

the application (Figs. S1 to S6, Supplementary Material) were observed ($p < 0.01$), except for the pair of vertical shoulder abduction and waist translation. Three pairs had $r > 0.8$ (shoulder flexion / vertical shoulder abduction, shoulder flexion / elbow flexion, vertical shoulder abduction / elbow flexion). The other pairs had $r > 0.25$.

The results also show that we could identify progressions, abnormalities or status of the subjects remotely. For instance, Subject 5 had the left side impaired; therefore, the maximum shoulder flexion angle that we observed in this case was very low (overall < 10°). The same subject tended to support the weight more in the right side (non-paretic leg) than on the left, as illustrated in Fig. S5 showing the medio-lateral translations of the waist (split between right and left) during the Swing exercise (consisting of repetitions of waist's medio-lateral translations without moving the feet). For this subject, almost no difference can be observed between the physical evaluations before and after the period without application.

The increase of the ROM is also reflected in the performance of the games. For instance, the *Goalkeeper* game deals with shoulder flexion at different levels, according to the height of the ball. The application records the ROM, but also the score, as shown in the example of Fig. 3 for Subject 6, who improved the performance in this game over the weeks. However, we could not analyze all data of the games for all weeks since the participants did not consistently play all games.

Satisfaction

All main items evaluated within the satisfaction questionnaire were higher or equal than 3.9 points over 5.0 and a standard deviation inferior to 1.5 points (Table 4). All detailed results of the TUQ are shown in Table S1. Some questions should be highlighted as being of great value for the objectives of the study. These questions relate directly to the benefit of the application during the rehabilitation program (questions 6, 12, 13 and 16 from Table S1, Supplementary Material). All these questions ranged above 3.6 over 5.0 (72%) of satisfaction, highlighting that the system is a good tool for the physiotherapy sessions and the application increased the subjects' motivation during the rehabilitation.

Moreover, the satisfaction questionnaire included some questions related to the interface satisfaction. The exercises and all the game environments were scored above 3.29, resulting in 3.92 ± 1.24 points (78.4%). The two games with the highest score were *PickApples* and *Imbalance*, whose main aim was to promote the weight-shifting exercise. *PickApples* was the game that subjects liked the most with a score of 4.43 ± 0.79 over 5.00. *Clean-the-horse* was the game less attractive for the subjects, although its score was around 3.29 ± 1.5.

Discussion

Some people have difficulties attending outpatient rehabilitation, especially those with physical limitations or those who live far from the rehabilitation centers.[38] Muvity breaks down these barriers by providing patients

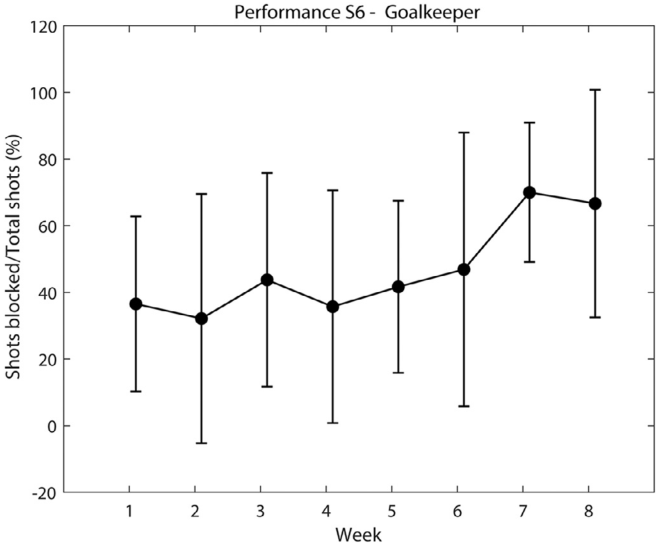

Fig. 3. *Example of performance (measured as shots blocked / total shots) in the game* Goalkeeper *for Subject 6.*

Table 4. *Mean of the subjects' usability factors outcomes rated from 1 to 5.*

Usefulness	4.1 ± 1.21
Ease of use and learnability	4.1 ± 1.21
Interface quality	4.2 ± 0.70
Interaction quality	4.5 ± 0.58
Reliability	3.9 ± 1.46
Satisfaction and future use	4.0 ± 1.12
Overall satisfaction	4.1 ± 1.14

in-home rehabilitation sessions and providing physiotherapists a remote analysis of the patients' progression. Virtual reality environments allow more entertaining rehabilitation sessions avoiding falling into monotonous therapies.[39] Muvity application increases the subject's motivation to continue with the rehabilitation sessions without giving them up. The aim of this feasibility study is to analyze the data collected from a small group of subjects captured remotely during the telerehabilitation, and compare the functional independence measure (FIM score), the balance control (Berg's scale), the pain feeling (VAS score) and the self-reported health status (SF-36 questionnaire) obtained before and after the eight-week in-home treatments (with and without Muvity).

Four out of six subjects reported equal or higher scores in performing ADLs (FIM scores) after the treatment with Muvity than without (with differences lower than what is considered as minimal clinically important difference[40,41]). Five out of six subjects also reported equal or lower levels of pain using Muvity (VAS score). The questionnaire results showed that overall the participants felt much more motivated to continue rehabilitation with Muvity than without (4.14 ± 1.46 out of 5.0), and that this in-home telerehabilitation system is a good tool for the physiotherapy sessions (Table S1, Question 2). The time spent using Muvity is similar to other studies using telerehabilitation systems.[42] The Muvity system covers all the usability factors that have been analyzed in the study: usefulness, ease of use, interface and interaction quality, reliability and satisfaction. Thus, the results suggest that Muvity might be an appropriate complement for telerehabilitation therapies for patients with physical disabilities.

Data analysis showed that the difference in ROM for most subjects after the treatment with the application was higher compared to the conventional treatment (except for shoulder flexion angle). These results suggest that the use of the telerehabilitation system increases their motivation to perform ADLs (in line with the higher FIM scores). Differences in Berg scores were not higher overall using Muvity, as they were in the study of Cikajlo et al.,[43] but our system was not specifically designed to treat balance (in agreement with[44]). However, Muvity could be used to detect the progression of the tendency to balance the body weight to one side compared to the other. For instance, Subject 5 tended to have a higher range of movement to the right (non-paretic leg) (Fig. S5, Supplementary Material), which is in agreement with other studies focused on weight-shifting in chronic post-stroke subjects.[45]

We need to take into account that we would not expect a significant improvement of the ROM since they are chronic post-stroke subjects.[46] The advantages are related to the provision of rehabilitation accessibility for a large number of subjects with mobility impairments, subjects living in remote areas or during events such as COVID-19 pandemic.[47] However, the project seeks to find whether there are differences with the conventional motor rehabilitation treatment and avoid the deterioration of the physical condition of chronic post-stroke subjects. Previous studies support the idea that telerehabilitation therapies are not superior to conventional therapies in terms of improving the abilities of ADLs and motor function for chronic stroke survivors.[26,48–49] However, since the motor assessment scores measured (FIM, VAS, Berg and PCS) showed differences that are not worse than with conventional methods, it is an indication that Muvity provides at least the same healthcare service as conventional rehabilitation therapies. The telerehabilitation system would allow extending the period between clinical face-to-face visits (due to the remote monitoring) and therefore increase the number of subjects treated for the same number of physiotherapists.

There is interest to know the minimum number of subjects needed in a larger clinical study to detect differences between treatments. We are interested in detecting differences at the level of standard tests (like FIM, VAS, Berg and PCS). According to the literature,[50–52] since the VAS score has an effect size of $g = 0.65$, we would need 37 subjects to observe significant differences. In order to observe significant differences in PCS and Berg scales we would need 153 and 251 subjects respectively. The most limiting effect size was in the FIM scale ($g = 0.13$). However, caution needs to be taken due to the small sample size, since in case we would only exclude Subject 6, the effect size would increase more than four times for this score.

The present study has several limitations which led us to define future work. First, some subjects dropped throughout the study, one due to COVID-19. Although Muvity is an in-home rehabilitation system, we did not have access to provide and install the camera system to the patient with COVID-19. Once the subject came out of quarantine and started to recover, there was already a delay with the subjects who were under study, so we decided to leave him/her out. Second, a decrease in the performance and state of mind of Subject 6 was noticeable by the physiotherapists but, studying the results, it was not enough relevant to discard the subject of the study. Nevertheless, this effect is associated with the decrease in the FIM, VAS and PCS scales, which is worth considering in future studies. Third, another limitation was that some subjects were not able to reach the maximum ROM values set in the games, leading to lower performance results in the games. Consequently, a calibration at the beginning of the rehabilitation session to collect the minimum and maximum ROM values for each subject has been considered. For this, games will be adapted to subjects' needs to fit the rehabilitation therapies to their abilities. Fourth, there was no chance to measure the performance during the control weeks without application. Having this data would have made it easier to compare the adherence between conventional and home-based rehabilitation. Fifth, the evolution after six months of the treatments was quite variable among participants. In future analysis, the rehabilitation treatments followed after the study should also be monitored to extract robust follow-up conclusions. Another future work related to the usability of the application has been scoped. The idea is to give physiotherapists the opportunity to determine the rehabilitation therapy of each patient by choosing the exercises or games that the patient has to perform each day. Once the patient starts the daily session, the application will run the games by itself without the need for the patient to navigate through the application. As the potential users are usually older, this work will open doors for users with no experience in technologies.

In conclusion, these initial results suggest a good outcome for both the effectiveness and satisfaction of Muvity. In the case of the former, trends showed either better or comparable changes in outcomes with the application relative to without. This supports the claim that rehabilitation with Muvity is at least as effective as conventional therapy. In the case of the latter, satisfaction questionnaires show a strongly positive response to the application. In tandem, these two factors indicate that the telerehabilitation system under scrutiny fulfils the requirements for adequacy set forth in the beginning of this work. However, this point should be taken with caution. Because this is a pilot study, the sample size restricts the force of the conclusions. In particular, the matter about effectiveness cannot be stated with statistical robustness and a larger study is needed to further substantiate these results. On the other hand, the feasibility trial has provided an opportunity to estimate the sample size required to conduct this assessment properly in such a future study. Finally, rather simple forms of analysis of our data allowed for the detection of features about subjects' impairment and progress. This is indicative that the system may be of value to physiotherapists for tracking and adjusting the treatment of their patients remotely.

Author contributions

Conceptualization: G.S., J.T., F.A., A.P. and C.M. Data curation: A.G., C.M., J.M. and G.S. Formal analysis: A.G., B.M. and G.S. Funding acquisition, project administration, resources: G.S. and A.P. Investigation and Methodology: C.M., J.T, F.A. and G.S. Software: A.G., C.M., B.M. Supervision: A.P. and G.S. Validation: J.M., C.M. and A.P. Visualization: C.M., A.G. and B.M. Writing and review & editing: A.G., B.M. and G.S.

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Declaration of Competing Interest

The authors report no conflict of interest.

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Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.jstrokecerebrovasdis.2022.106791.

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