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Engaging in a home-based exercise program: a mixed-methods approach to identify motivators and barriers for individuals with stroke

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ABSTRACT

Community-dwelling individuals with chronic stroke used a novel, portable rehabilitation system, mRehab, that uses a smartphone app coupled with 3D printed objects resembling daily use items. The objectives of this study include evaluating participant's approach and nature of engagement with mRehab and identifying factors that influenced the users' engagement with mRehab. An explanatory mixed-method approach was used. In the first phase, 16 participants used mRehab at home for six weeks; six participants were recruited from the first phase for in-depth interviews. Participants were categorized into High, Moderate, and Low Frequency groups based on their frequency of mRehab use. High frequency of use was not related to improved performance on clinical assessments; instead, High Frequency users more commonly initiated performance of new activities after the mRehab program compared to participants with lower frequency of use. Useful activities that are challenging and meaningful to the participants, and availability of objective feedback for self-monitoring were some of the motivators for mRehab use. Difficulty with time management, lack of caregiver availability, and difficulties with the design of the system posed as barriers to mRehab use. Tailoring home programs to the recipients' needs including perceived meaningfulness of the activities is key for long-term rehabilitation.

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Information technology and telecommunications; mhealth; rehabilitation; self-management; stroke; usability

Introduction

Among the 6.6 million stroke survivors in the United States, over 70% experience a form of disability ranging from mild to major functional impairments that cause them to require varying levels of assistance from family members to complete activities of daily living and instrumental activities of daily living (Lutz et al., 2017). Furthermore, motor functional impairments are among the most common deficits reported following a stroke (Miller et al., 2017). Over 80% of stroke survivors continue to report impaired upper limb function (Doman et al., 2016; McLaren et al., 2020). Rehabilitation at home through completion of home exercise programs is increasingly recommended (Miller et al., 2017). However, adherence to home exercise programs remains unsatisfactory (Jurkiewicz et al., 2011; Miller et al., 2017). Although there is no clearly documented level at which adherence is considered poor (Argent et al., 2018), there is robust evidence that home exercise programs are not consistently performed as prescribed (Babbar et al., 2021). Studies have identified barriers to exercise which include lack of motivation, missing instructions, lack of personalization of technology, low self-efficiency or mood, and lack of availability of caregivers (Donoso Brown et al., 2020; Novak, 2011; Scorrano et al., 2018).

Both adherence as well as recommendation for dosage of rehabilitation should be appreciated when considering home exercise programs. While some research suggests higher doses of rehabilitation therapy are more beneficial (Cauraugh et al., 2011; Lohse et al., 2014; Veerbeek et al., 2014; Ward et al., 2019) other research suggests lower doses of rehabilitation (Page, 2003; Smania et al., 2012) are also beneficial in improving mobility. In line with the clinical adage, the most effective home program is the one the patient does, it is necessary to consider how the individual carries out a home program. This includes appreciating what are motivators and barriers to initiating an exercise session and the dosage of exercise completed.

Community-dwelling stroke survivors live with varied levels of disability and often rely on informal caregivers for some level of assistance (Lutz et al., 2017; Woodford et al., 2018). Commonly, the individual with stroke and their caregiver engage in the home exercise program as a team. Use of technologies by individuals with stroke and their caregivers has been identified as an approach to exercise programs (Cramer et al., 2019) that has the potential to capture the individuals' performance and provide objective feedback (Chen et al., 2019). Using technology-aided home programs can engage the participant and keep the user-dyad apprised of user's performance. Previous studies have reported on the usability and user acceptance of technology (Niknejad et al., 2021). However, few studies have reported on the factors that influence the users' level of engagement with technology-aided home

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programs (Holthe et al., 2018). This critical piece of information can inform the design of home programs.

To promote self-management of upper extremity rehabilitation for community-dwelling individuals with chronic stroke, mRehab, a novel, portable rehabilitation system was developed (Bhattacharjya et al., 2019). This mRehab system included an android-based smartphone and 3D-printed technology to engage users in simulated daily living tasks in their homes. The smartphone and all 3D printed items were provided to the participants. The users interacted with the mRehab smartphone app and 3D printed mug, bowl, key, and doorknob housed in a box that also included a printed instruction manual (Figure 1). The 3D printed items and related activities were selected based on initial focus group discussions conducted with individuals with stroke and rehabilitation therapists (Cavuoto et al., 2018). The mRehab activities were selected to include a variety of hand and arm movements typically used in day-to-day life (Langan et al., 2020). The daily objects were 3D printed so that the smartphone could snuggly fit within each object and measure the user's movements when they manipulated the object. The 3D printed mug, bowl, and doorknob resembled real-life designs of these objects. A screw-top was added to the mug to prevent the smartphone from accidently sliding out during the activities. The key was bigger in size compared to daily use keys (Figure 1). Participants were trained on using the smartphone and the app (Langan et al., 2020). The mRehab app allowed the user to select an activity, provided instructions about the activity, counted repetitions while the user performed the activity, measured duration of activity performance and provided visual and auditory feedback on the users' performance. Use of mRehab resulted in improved mobility of the involved upper extremity post stroke (Langan et al., 2020). Usability of the mRehab system was examined and participants' qualitative feedback was largely positive with favorable comments on the design of the 3D printed items, structure of the activities, as well as performance-based auditory and visual feedback (Bhattacharjya et al., 2021). Participant-reported self-efficacy for exercise did not interact with their performance (Bhattacharjya et al., 2021). Interestingly, the level of adherence with the mRehab home program varied across participants. In an effort to better understand how and why participants engaged with the mRehab home exercise program, participant centric information is provided to give a fuller picture of the participants, and the dual purpose of this study was to (1) evaluate the participants' approach and nature of engagement with the mRehab system and corresponding changes in outcome measures, and (2) identify the self-reported factors that positively or negatively influenced the use of the mRehab system at home by community-dwelling individuals with chronic stroke.

Methods

Design

A sequential explanatory mixed-method study design was used that included quantitative data from an intervention study in Phase I, followed by qualitative data from an in-depth interview with some participants in Phase II. A sequential explanatory mixed-method design used to first recruit, collect, and analyze quantitative data, followed by collecting and analyzing qualitative data to help explain or further elaborate on the quantitative findings (Creswell & Plano Clark, 2017; Ivankova et al., 2016). The decision to design this sequential explanatory phase was a during study decision based on visual analysis of frequency of mRehab use by participants recruited in staggered stages. Data were triangulated across multiple data collection methods (i.e. mRehab quantitative data, data from questionnaire, and data from qualitative interviews). The trial is registered at the ClinicalTrials registry (NCT04363944, https://clinicaltrials.gov/ct2/show/NCT04363944). The study was approved by the University at Buffalo IRB and all participants provided written informed consent. In Phase I, a single-subject design with multiple-baseline was used where participants completed one to three weeks of baseline, six weeks of intervention using the mRehab system and one week of follow-up. Due to the limited number of mRehab systems, participants were recruited in three stages over an 18-month period.

Figure 1. mRehab system including 3D printed mug, bowl, key, doorknob and box.

Participants made three lab visits, first at the start of the baseline, second at start of intervention and third at end of intervention. Selected participants were invited for Phase II for conducting the qualitative interviews. Phase II was conducted at the end of 18-months. Participants who had most recently completed the quantitative phase were invited for the qualitative interviews to limit recall bias. Phase II interviews were conducted one week since completion of Phase I for the invited participants.

Phase I: quantitative data

Participants

Using convenience sampling from the local community, 18 participants were recruited over 18 months for the quantitative section. Inclusion criteria were 18+ years of age, six or more months post stroke, and minimum score of 124 on the Mattis Dementia Rating Scale (MDRS) (Marson et al., 1997). Exclusion criteria were presence of acute or chronic pain that would interfere with participation, severely limited range of motion of the upper limb, absent or severely impaired proprioception of the upper limb, musculoskeletal or circulatory conditions affecting the upper limb, spasticity graded as 3 or greater for upper extremity movement on the Modified Ashworth Scale (MAS), or botulinum toxin injections for spasticity management within three months of starting the study.

Procedure and instruments

The methods for data collection and quantitative analysis have been described in detail in previous publications (Bhattacharjya et al., 2021; Langan et al., 2020). Methods essential to the data reported herein are described. Quantitative data were collected from both in-lab and in-home measurements (Langan et al., 2020). Over a 10-week period, participants made three lab visits, which included two baseline lab visits over a variable baseline (1–3 weeks) period, followed by a six-week intervention at home, and one follow-up lab visit. Participants completed a demographic survey, the MDRS, and the following clinical assessments: 1) Fugl Meyer, 2) Wolf Motor Function Test (WMFT), and 3) 9-hole peg test. The Fugl Meyer was only collected in the initial visit to characterize impairment of the paretic upper extremity (Duncan et al., 1983). The WMFT and 9-hole peg test were used as outcome measures and repeated at each lab visit (Grice et al., 2003; Whitall et al., 2006). During the 6-week intervention, participants used the mRehab system in their home. The smartphone app collected data on day and time exercise was performed, repetitions of activities performed, and duration for each activity. It was recommended to participants to complete 10 repetitions of each activity per day for five days per week, or 30 days total. Exercise days were defined as days that a participant engaged with mRehab even if they did not complete every activity. Participants that engaged in 25 or more exercise days were considered High Frequency users. Participants that engaged in 10–24 days were considered Moderate Frequency users and those engaging in exercise less than 10 days were Low Frequency users. The cutoff for the levels of engagement were set based on the natural breaks identified through a visual analysis of the number of days of mRehab use by participants. Participants were provided with a notebook to record any unexpected event that interfered with their use of the system. The number of days that each participant used the mRehab system has been included in Table 1.

Statistical analysis of quantitative data

Descriptive statistics was used to summarize the demographic characteristics of the participants. The baseline scores for the WMFT and 9-hole peg tests were calculated by averaging the test scores from lab visits 1 and 2 (scores were not significantly different) to account for variability in the performance of individuals with stroke. Percentage change for the WMFT and 9-hole peg tests were calculated by subtracting score from the third lab visit from the average baseline scores (score lab visit one + score lab visit two 2) and dividing by the average baseline score. Positive percent change indicated a decrease in time taken to complete task. The average number of repetitions per week was calculated by averaging the weekly number of repetitions for each activity within the three user categories.

Phase II: qualitative subset

Participants

To understand the factors that influenced the participants' use of the mRehab system at home, participants (n = 6) from the intervention study who were representative of the three user categories (two per category of high, moderate, and low frequency) were interviewed during the third lab visit. Since participants were recruited in staggered stages for the quantitative phase, participants who most recently completed the mRehab system were invited first to limit any recall bias. All six participants who were recruited in the last quantitative stage agreed to participate in the interviews, therefore additional invitations were not extended to previously recruited participants. If the participant's caregiver accompanied them during the lab visits, they were also recruited for this interview to gather further details about their extent of involvement.

Procedures and instruments

Each participant with stroke completed a brief 7-item questionnaire that used a 5-point Likert scale to identify factors that influenced how often or how long a participant used the mRehab system, and the potential motivators or barriers for using the system more often or longer. Then they, and caregivers when applicable, engaged in a 60 min in-depth, audio-recorded interview with an occupational therapist. Using a semi-structured interview guide, the interviewer engaged in an iterative form of questioning while paraphrasing participants' responses to verify interpretation of statements. The brief questionnaire and interview guide is available in the Supplementary Material. The semi-structured interview guide was developed based on interviews with study participants from the 1st and 2nd rounds of recruitment and information that participants volunteered outside of the set interview protocol were used to guide the development of the interview questions. Similar interview guides tailored to the study intervention have been previously used (Ashford et al., 2018). The

Table 1. Participant demographics, baseline performance, and percentage change in their performance in clinical assessments.

User Category	User ID	Exercise days	Age	Gender	Caregiver supported mRehab use	Years Since Stroke	Cognitive Score (MDRS)	FM Total	WMFT Baseline Avg (sec)	9-Hole Peg test Baseline Avg (sec)	% Change in WMFT	% Change in Peg test	Initiated New Activity
High Frequency (At Least 21 Days of Exercise)	s03	29	68	M	N	4	142	20.5	13.8	161.1	8.7	13.1	In general, use the hand more
	s04	29	61	F	N	12	140	26	10.1	59.5	55.9	9.2	
	s07	36	73	M	N	1	139	21.5	39.4	300.0	25.7	0	Use both hands – to wear socks, use hand exerciser
	s11	41	76	M	N	6	133	25	2.3	36.5	17.5	−23.4	Use hand to stabilize items such as when drying dishes or vacuuming
	s13	26	76	M	Y	4	144	26	2.1	32.6	25.4	10.9	Started house repainting
	s18	28	37	M	Y	1	141	24	5.0	95.0	24.6	14.7	Use the hand more for holding and carrying items
Moderate Frequency (10 to 20 Days of Exercise)	s02	13	54	F	N	7	144	24.5	4.8	262.5	−9.9	28.0	Tie shoelace, stabilize objects
	s05	15	78	F	N	1	140	20	4.7	55.6	31.4	−1.0	
	s06	20	66	M	Y	14	140	26	44.8	300.0	3.4	0.0	
	s09	22	62	F	Y	2	124	19.5	24.0	143.5	43.3	19.1	
	s14	20	39	F	N	4	143	25	2.4	46.5	36.9	28.8	Try to hold plate, coffee mug – not successfully
	s17	16	72	M	Y	11	142	8	81.1	300.0	0.3	0	Try Saebo, looking to start something new
Low Frequency (Less than 10 Days of Exercise)	s08	7	61	M	N	0.5	142	26	1.8	50.0	21.5	33.9	
	s10	9	67	M	N	1	130	26	8.6	240.0	52.4	30.8	
	s12	9	43	M	N	5	143	26	3.0	56.5	48.2	30.8	Install fixtures in the bathroom
	s15	9	78	M	Y	3	134	16.5	34.0	300.0	−5.0	0	

de-identified audio-recorded interviews were professionally transcribed.

Thematic analysis of qualitative data

An inductive thematic analysis of the qualitative data was conducted using NVivo 12. Thirumalai et al. (2018) used this analysis approach to assess usability of a tele-exercise program. Each interview was professionally transcribed. One coder (SB) checked the transcriptions with the audio recordings for accuracy. Next, two coders (SB & IL) independently analyzed each transcript. Data analysis (Elo & Kyngäs, 2008) included (1) re-reading all interview-transcripts several times to get an overall impression of the content, (2) breaking the content down to smaller segment, (3) coding each segment into clusters of themes, and (4) refining them into major themes and sub-themes based on homogeneity (Patton, 1990), (5) discussing any discrepancy in coding by the coders and a last author (LC) until consensus was reached.

Results

Participant characteristics

A total of 18 participants were recruited; two of whom did not complete the study. One participant did not complete the 6-week intervention period because she preferred assistance from her caregiver for the tasks and it was difficult to find mutually convenient times. Another participant discontinued the program after their first lab visit, explaining that he did not think his schedule would allow him to commit to the program. Sixteen participants completed the study, with mean age = 63.19 years (SD = 13.57, range = 37–78 years), 5 participants (31%) were females, and one participant (6%) was African American. The right side was reported as the paretic side by 50% of the participants (Table 1). Participant IDs indicate if they were in the *High*, *Moderate*, and *Low Frequency* (HF, MF, and LF, respectively) groups. Mean age of participants in HF, MF, and LF groups were 65.17 (SD = 14.93), 61.83 (SD = 13.89), and 62.25 (SD = 14.64) respectively. Running statistical comparison of baseline characteristics was not appropriate for the small sample size within each group; however, the range of scores on MDRS, and WMFT are similar across groups (Table 1). Among the participants who completed the interviews in Phase II, four caregivers were also recruited since they provided assistance during mRehab use.

Phase I: quantitative data results (n = 16)

Participant's frequency of mRehab use

Sixteen participants who completed the 6-week study were grouped by their number of exercise days into *High Frequency* group, *Moderate Frequency* group, and *Low Frequency* group (Table 1). Their demographic characteristics, baseline scores from MDRS, Fugl Meyer, Wolf Motor Function Test, and 9-hole Pegboard, percentage change in their performance on the WMFT and the 9-hole Pegboard and report of starting new activities post mRehab training are provided in Table 1. Participant's cognitive scores on the MDRS ranged from 124 to 144.

Changes in motor performance during mRehab program

For the High, Moderate, and Low Frequency groups, the average percentage change in average WMFT scores were 26.3, 17.57, and 29.28 s, respectively; and the average percentage change in average 9-hole pegboard scores were 4.08, 12.48, and 23.88 s, respectively (Table 1).

New activities initiated by participants outside of mRehab

As presented in Table 1, 5 out of 6 participants in the *High Frequency* group report initiating new activities following their participation in the mRehab home program. Comparatively, only 3 out of 6 participants from the *Moderate Frequency* group, and 1 out 4 participants from the *Low Frequency* group initiated new activities. Caregivers of participant s17-MF and s18-HF corroborated participants were initiating new activities. For example, one caregiver said, "*He carried something from the kitchen to the bedroom with his left hand with something also in his right. That's one of the first time I've seen him do that. There wasn't as much focus on the left hand. He was able to do both and watch where he was going.*"

Average weekly repetitions for each mRehab activity

Figure 2a–d depict the average number of repetitions the participants performed for each activity. The charts demonstrate that, for all three groups, the participants completed on average more than eight repetitions each week for all transport activities and doorknob and key activities. While the *High Frequency* group continued to average at least eight repetitions a week for the Slow Pour, Sip, Phone Number, Quick Tap and Walk with Mug, the other groups completed fewer repetitions.

Phase II: qualitative subset results (participants, n = 6; caregivers, n = 4)

Weekly compliance of the representative group

The exercise routine of the participants interviewed is represented in a calendar pattern in Figure 3. Days shaded within the six-week calendar indicate days when any exercise was performed, regardless of whether all activities were completed that day. Visual inspection leads to the conclusion that participants in each category exercised for at least one day each week throughout the six-week program.

During the interviews with participants s12 – s18, they discussed factors that influenced their engagement with their exercise sessions. Participants s14-MF, s15-LF, and s18-HF either agreed or strongly agreed that they felt obligated to complete the exercise session since they had made a commitment; whereas participants s12-LF, s13-HF, s17-MF disagreed or strongly disagreed with this statement. Participant s13-HF said that he thought his performance was being recorded and monitored by the researchers and this acted as a motivation for him. Additionally, participants discussed factors that influenced their engagement with the mRehab system. These discussion themes have been summarized as barriers and motivators.

Motivators to mRehab use

Participants and their caregivers discussed factors that motivated them to continue using the mRehab system. All participants agreed that external rewards that are either part of the system (such as a congratulatory tone) or encouragement from caregivers or supervising therapists are important for motivation. Some common themes of discussion are presented here.

Activities were considered useful. Participants continued to engage in their exercise sessions because they perceived that the mRehab activities were useful. Three different subthemes emerged regarding how participants described usefulness: activities that they found challenging in real life; activities that they found challenging in the mRehab system; activities with which they experienced improvement.

Activities that were challenging in real life. Participants explained that in daily life, they struggled with certain activities and therefore, these activities were their personal goals. For example, being able to use a key or doorknob were goals for participants s14-MF and s15-LF. Participant s13-HF explained "*For me, walking and holding a cup was really very important. Maybe for other people it wouldn't be, but for me that's where I really needed to work.*" Participant s12-LF said " . . . *real-life scenarios, the drinking, the pouring was helpful, because those are the ones with which I struggle . . . .*"

mRehab activities that were challenging. Participants (s12-LF, s13-HF, s14-MF) reported that they found the Walking with Mug and the Slow Pour activities challenging. The participants explained that these challenging activities made them want to exercise, because they felt they were getting more benefit out of these activities.

Perceived improvement. All participants agreed that working with mRehab activities improved their arm/hand movement (average = 4.33/5). Participant s18-HF said "*I think my reward is seeing the progress within myself. When I was doing this – I would say it was three or four days into the activity – I noticed that I was getting better. I was hooked from that point on.*" Similarly, participant s17-MF said that he could tell that he was improving by "*the way it felt.*"

Reviewing self-performance. Most participants (s12-LF, s13-HF, s15-LF, s18-HF) agreed or strongly agreed that they enjoyed receiving their performance scores (average = 3.33/5). They reported that they regularly reviewed their scores and would like to continue to do so over time. All participants except s14-MF also reported that they missed the performance feedback screen when it was absent during assessments following the conclusion of the mRehab home program. Participant s12-LF stated "[it] *was less encouraging while I was doing them.*" All participants agreed or strongly agreed that they felt competitive and wanted to see if they could beat their previous scores (average = 4.33/5). Three participants (s12-LF, s14-MF, s15-LF) explained that, occasionally, if they did not get a green light on their performance, they repeated the activity to get a better score. One participant (s17-MF) explained that the feedback would "*make you try to beat your record*" and "*make it more fun.*"

Support from others. Four participants (s12-LF, s13-HF, s14-MF, s18-HF) said that although another person (their fiancé, spouse, or mother) was aware of the participant's engagement

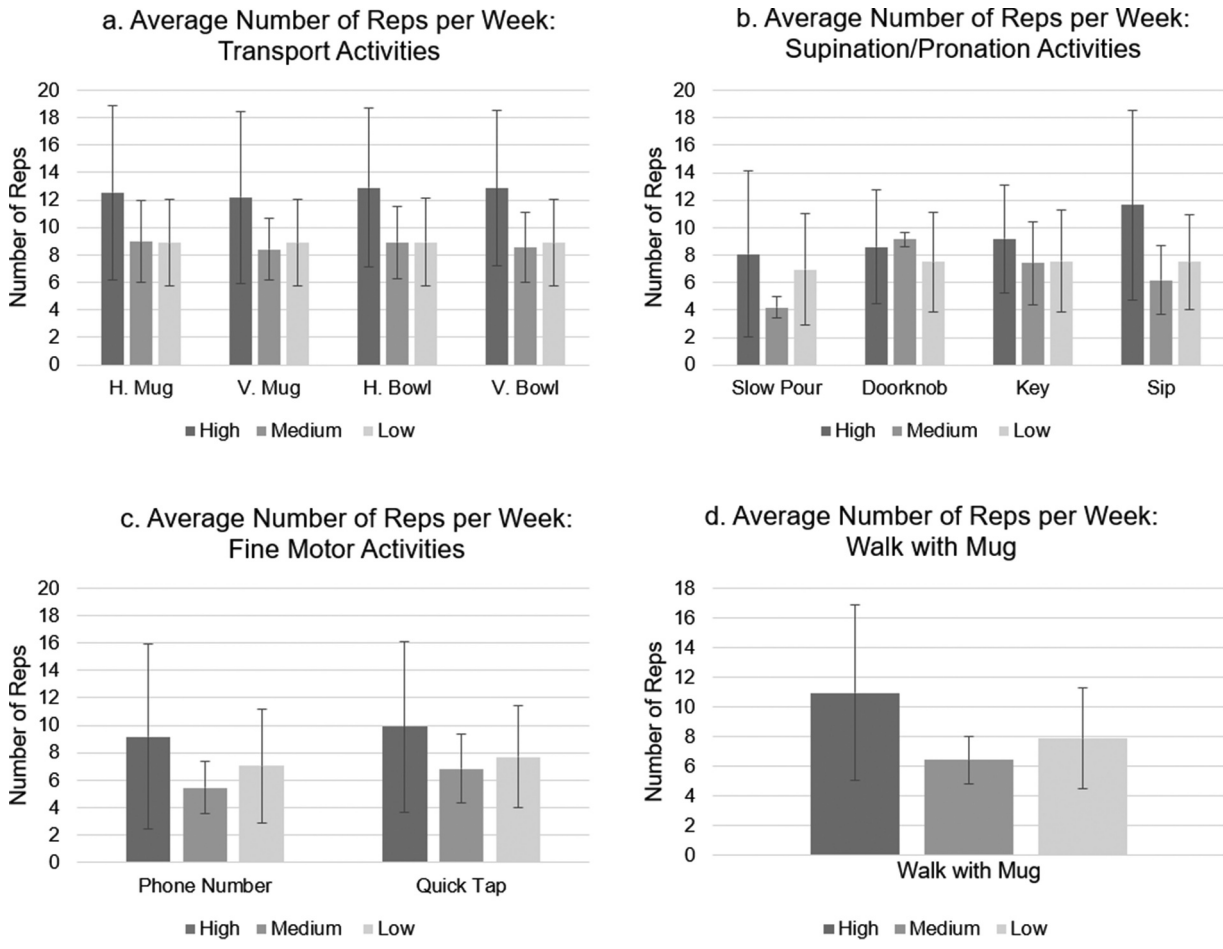

Figure 2. Average number of repetitions completed per week in each compliance category. Note 1: Error bars are based on ± 1 SD of the average number of repetitions per week in each category. Note 2: In Figure 2a, H refers to Horizontal movement of the item; V refers to Vertical movement of the item.

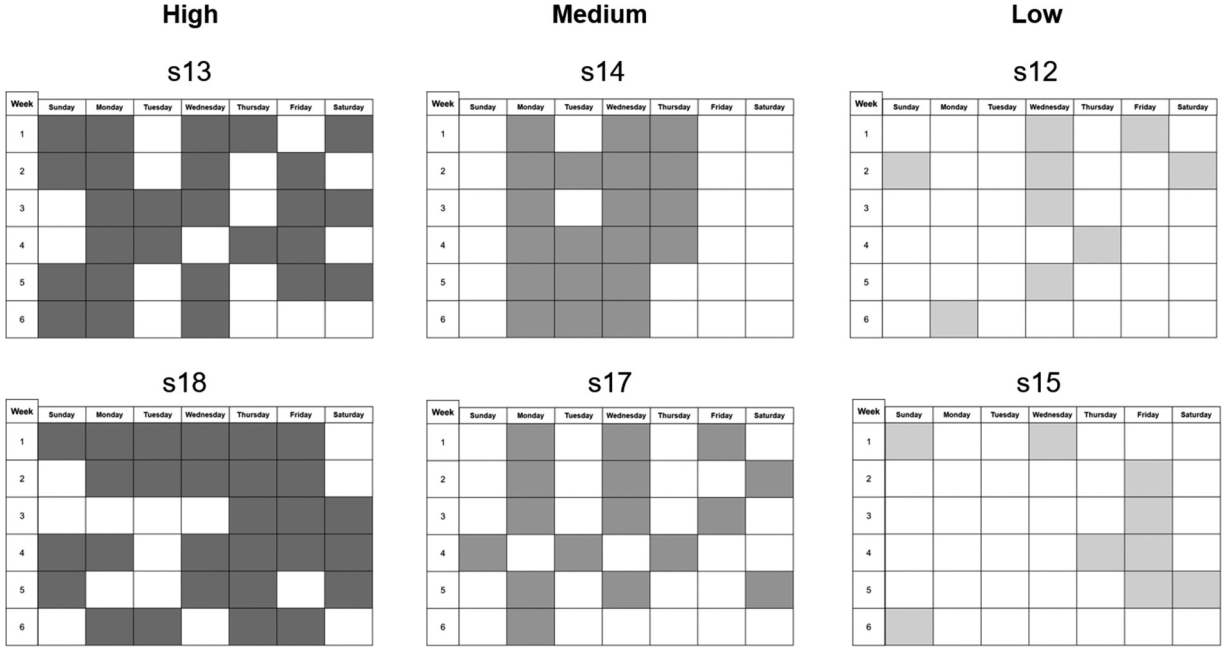

Figure 3. Calendar of exercise patterns for two participants per compliance category, where shaded boxes represent a day that exercise was completed.

with the mRehab system, the participant completed the session on their own. Occasionally, a family member may have casually asked if the participant completed their session or not. Although five participants strongly disagreed to the statement "mRehab was too awkward to set up to use it more often or longer" (average = 1.33/5), participants s15-LF and s17-MF

said that their caregiver was present throughout the session to set up the system and the activities and motivate them during the activities. Participant s15-LF's caregiver also pointed out if he was " *cheating*" and read out the feedback to the participant.

Barriers to mRehab use

Time management. Although four participants (s13-HF, s14-MF, s17-MF, s18-HF) strongly agreed that they had time to use the mRehab system more often or for longer duration (average = 3.83/5), two participants (s15-LF, s17-MF) pointed out that their exercise session was dependent on the availability of their caregiver. Participant s12-LF explained that he could not manage his time well between his life, work, and his exercise. Although he set aside time for the sessions, on occasions when " *life got in the way*" he felt bad for not completing his sessions.

mRehab system design. Participants discussed experiencing some difficulties with the design of the mRehab system which, as they reported, did not interfere with their use of the system. Some of these difficulties were related to (a) technical challenge such as delay in count reading by the app during transfer activities (s13-HF, s14-MF, s17-MF); (b) 3-D design of the mug (s15-LF), bowl (s17-MF), and the box (s13-HF, s15-LF); (c) design of the Slow Pour activity because it required slow movement and they needed to start over every time they moved quickly (s12-LF, s14-MF); and (d) app design such as difficulty with interpreting repetition count for the key and doorknob activities (s12-LF, s17-MF, s18-HF) and participants' incorrect recall of the activity (s14-MF, s15-LF, s17-MF) which were followed by suggestions for pairing activity instructions with short video clips.

Exercise routine of the representative group

The range of times that participants completed exercise throughout the six-week program is visualized on a timeline (Figure 4). In the box and whisker plot, the distributions of exercise times present the times that each of the six participants completed an activity. The box and whisker plots were constructed by determining the earliest and latest exercise times, the median time, and first and third quartiles. This visual is useful in comparing exercise practices among participants, as it demonstrates that the majority of participants, 5 out of 6, concentrated their exercise in the afternoon to evening hours.

During the interviews, the participants discussed their strategy of time management. Three participants (s12-LF, s15-LF, s18-HF) said that they set aside time for doing their activities, and selected the repetitions based on the time that the activity took and the time that they set aside. Participant s18-HF said that he did 30 repetitions of each activity (maximum allowed by the app). Although he wanted to do more repetitions, he wanted to wrap up in one session and, therefore, did not engage in multiple sessions. Participant s14-MF noticed that she performed better in the middle of the day after testing out exercise sessions at different points throughout the day. She noted that her hands were very shaky in the morning and at night when they became tired. Participant s15-LF noted that he performed best in the morning as his vision was more affected at night and that prevented him from completing the tasks as effectively. Participant s12-LF explained that he completed his sessions in between television shows at night after work, when there was no one around, because he "*didn't want the kids or the dogs influencing it*."

When planning the activities performed within their sessions, participants took different approaches. For example, participant s18-HF said that he saved the activities that took longer time, or were difficult to perform, for the latter part of his exercise session. Slow pour and walking with the mug "*were the longest and most challenging all along*." The participant explained that he got tired after these activities and therefore, did not want to influence his scores on the other activities. Participant s14-MF said that he planned to build up the repetitions for each activity to 10 eventually over multiple sessions. Two participants (s12-LF, s14-MF) said that they performed 10 repetitions of each activity as suggested by the researchers. Participant s14-MF said that she preferred being told how many repetitions she needs to do. Participant s12-LF said that initially he was hesitant that the exercise session might be long, but after one session, he found out that he completed 10 repetitions in 20 to 30 minutes and continued with the sessions. He also explained that "*the things like the pouring of the jug I only did three. It was more frustrating because I would take longer, and I had to start again few times*."

Insight from representative group for technology in home programs

Functional versus gamified activities. All participants said that, in general, they enjoy playing videogames either by themselves (s12-LF, s14-MF, s18-HF), or with their children (s14-MF), or their grandchildren (s13-HF, s15-LF). However, two participants (s12-LF and s14-MF) further explained that motor impairments following their stroke have made the experience challenging and frustrating. Regarding gamification of exercise, two participants explained that gamified activities would be interesting to the user and " *something that they would actually use more because it's fun*" (s12-LF, s18-HF). However, others did not think that gamification of activities was necessary (s13-HF, s14-MF, s15-LF), while explaining that performing higher number of repetitions was enough to improve performance (s13-HF), and that they would perform the activities "*if it helped me no matter what it is*" (s17-MF). Three participants also added that a story-driven scenario would strike their interest (s12-LF, s15-LF, s17-MF). Scenarios could involve actions such as making breakfast, passing a bowl, or preparing coffee for a friend. Moreover, a buildup of activities can reinforce functional movement as one participant (s15-LF) noted "*if you've accomplished [the basic part], the next thing is, Gee. Now, I can cook. I can make coffee*." Participants (s12-LF, s13-HF, s15-LF) also pointed out that they would appreciate feedback that are more functional in context such as "you provided eight glasses of water for people" or "you poured four cups of tea." Participant s14-MF on the other hand did not want to review her performance scores and suggested that participants can be given the choice to opt-in to receive feedback.

Incorporating a social network. When specifically asked about their thoughts on social scoreboards shared among a close

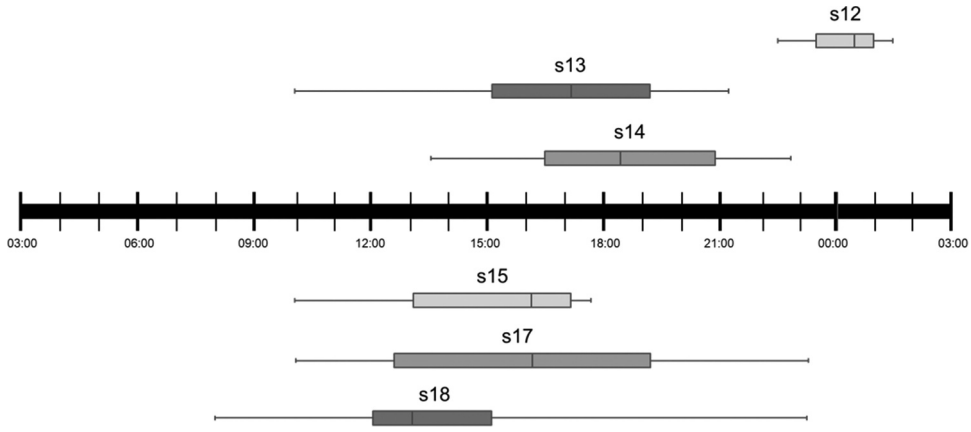

Figure 4. Exercise timeframes (in military time), from the earliest to latest times that each participant completed an activity.

network of other individuals with stroke, participants were more hesitant. Two participants (s12-LF, s14-MF) expressed concerns that sharing scores on social scoreboards could be discouraging for some participants. Participant s12-LF explained that having a social network of other individuals with stroke might be helpful to have more collaborative conversations rather than being competitive. He explained that in such networks, participants might discuss activities that they liked or how they problem-solved their way through an activity. Whereas participant s18-HF said it should be an option if the individual selected it. He explained that he would have preferred contact with other individuals with stroke and have a little healthy competition to motivate and help each other.

Incorporating interaction with clinicians. Participant s15-LF said that he would prefer direct contact with a healthcare professional in addition to the smartphone feedback. He explained that occasional feedback on video conference from a healthcare professional maybe once in ten days or so would be motivating – " *A little reminder and a little encouragement, that would be good.*" Participants s12-LF and s17-MF explained that they liked how things were and did not think that they needed to interact with a healthcare professional. Participant s18-HF explained that he would like to have occasional interaction with a healthcare professional "*I think it would have been helpful to have an OT after week two or week three come in and say – This is where you're doing well and this is where you still need to improve, maybe do these activities more. Customize it to my challenges.*"

Discussion

This paper discusses the approach and nature of participants' engagement with the mRehab system and factors that influenced their use. All of the 16 participants that completed the 6-week training maintained some level of adherence, at least one session per week. In their interview, the subset discussed about their weekly compliance with the mRehab system, factors that motivated them to use the system (i.e. activities that are useful, being able to review self-performance, and support from others), factors that interfered with their use (i.e. time management, and system design). They discussed their exercise routine when using the mRehab system. They also discussed their preferences in design of home programs with technology, with discussion themed as functional versus gamified activities, incorporating a social network, and incorporating interaction with clinicians.

All 16 participants continuing to use the system rather than discontinuing it suggests motivation to use the system, but barriers to use it for the recommended dosage of 10 repetitions per activity, five times a week. Even in the High Frequency group, few met the recommended dosage. This finding is similar to previous research demonstrating lower than recommended adherence to a home program prescribed (Babbar et al., 2021). This raises the question of whether it is reasonable to anticipate that high dosage rehabilitation approaches can be maintained for an extended period of time in a home program. Additionally, the findings indicated that although participants used the mRehab system a certain number of days placing them in the high, moderate, or lower frequency groups, they may have actually used the system for compatible number of repetitions.

Qualitative analyses on the subset of six participants revealed motivators and barriers to use of mRehab. Representatives from the High, Medium and Low Frequency use groups reported similar motivators and barriers. Useful activities that are challenging and meaningful to the participants, and availability of objective feedback for self-monitoring were some of the motivators for mRehab use. Participants stated that their schedules posed a challenge to using mRehab. However, participants in the High Frequency group explained that they were able to manage their time to fit in mRehab within their daily routine, while participants in the Low Frequency group explained that they needed to balance work and life. Representatives from both Moderate and Low Frequency group also reported being dependent on their caregiver's schedule. Caregiver availability has been previously identified as a barrier to exercise adherence following stroke (Scorrano et al., 2018). This underscores the need for tailored programs that are customized for the recipient-caregiver dyad rather than the recipient alone. Developing a protocol to facilitate self-management of home exercise programs by users should include discussion of routines to facilitate better time management and inclusion of the programs within daily routines.

Consequent outcomes following technology use, such as occupational performance or quality of life (Holthe et al.,

2018), are not commonly reported. Five of six participants in the High Frequency group initiated new activities following the use of mRehab as compared to three of six in the Moderate and one of four in the Low Frequency group. Extended practice may have a cumulative impact on motor performance (Lang et al., 2015) and self-confidence thereby promoting the trial of new activities outside of mRehab. On a similar note, a theme in motivators for use-frequency was meaningfulness of the activity. The repeated practice in the High Frequency group may have allowed them to see how the practice can be extrapolated to other activities. Increasing arm use in daily activities is a desired outcome in rehabilitation (Kelly et al., 2018).

On prompting, participants reported mixed views about utilizing social networks to either engage in mild competitions or to facilitate discussions on problem solving when participating in a rehabilitation program. Magnusson and colleagues reported that during exergame use, instead of sharing results on social media, participants with stroke used social media for interacting and playing the same games (Magnusson et al., 2020). While social interaction may be considered a motivator, little research has been done to better understand how it could be implemented in home stroke rehabilitation (Tamayo-Serrano et al., 2018).

Limitations and future directions: Although the participants included in the second phase of this mixed methods study were representative of the larger quantitative phase, the limited number of participants make it difficult to draw specific conclusive recommendations for long-term home programs. Caregivers were interviewed to get a better understand the type of assistance or support that they provided or the amount of support that was needed by the participant with stroke. Taking into consideration that caregiver availability is a determining factor in rate of adherence, future studies should target intentional interviews with caregivers to understand dyadic interaction and roles for the care-recipient and caregiver as a team.

Conclusion

This study underscores the significance of individually tailoring home programs based on the recipient's need and requirements. Understanding the motivators and barriers that influence the user's level of engagement with rehabilitative programs is significant when designing and implementing exercise programs that are individually tailored.

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References

Argent, R., Daly, A., & Caulfield, B. (2018). Patient involvement with home-based exercise programs: Can connected health interventions influence adherence? *JMIR Mhealth Uhealth*, *6*(3), e47. https://doi.org/10.2196/mhealth.8518

Ashford, M. T., Olander, E. K., Rowe, H., Fisher, J. R., & Ayers, S. (2018). Feasibility and acceptability of a web-based treatment with telephone support for postpartum women with anxiety: Randomized controlled trial. *JMIR Ment Health*, *5*(2), e19. https://doi.org/10.2196/mental.9106

Babbar, P., Vijaya Kumar, K., Joshua, A., Chakrapani, M., & Misri, Z. K. (2021). Adherence to home-based neuro-rehabilitation exercise program in stroke survivors. *Bangladesh Journal of Medical Science*, *20*(1), 145–153. https://doi.org/10.3329/bjms.v20i1.50361

Bhattacharjya, S., Cavuoto, L. A., Reilly, B., Xu, W., Subryan, H., & Langan, J. (2021). Usability, usefulness, and acceptance of a novel, portable rehabilitation system (mRehab) using smartphone and 3D printing technology: Mixed methods study. *JMIR Hum Factors*, *8*(1), e21312. https://doi.org/10.2196/21312

Bhattacharjya, S., Stafford, M. C., Cavuoto, L. A., Yang, Z., Song, C., Subryan, H., Xu, W., & Langan, J. (2019). Harnessing smartphone technology and three dimensional printing to create a mobile rehabilitation system, mRehab: Assessment of usability and consistency in measurement. *Journal of Neuroengineering and Rehabilitation*, *16*(1), 127. https://doi.org/10.1186/s12984-019-0592-y

Cauraugh, J. H., Naik, S. K., Lodha, N., Coombes, S. A., & Summers, J. J. (2011). Long-term rehabilitation for chronic stroke arm movements: A randomized controlled trial. *Clinical rehabilitation*, *25*(12), 1086–1096. https://doi.org/10.1177/0269215511410580

Cavuoto, L., Subryan, H., Stafford, M., Yang, Z., Bhattacharjya, S., Xu, W., & Langan, J. (2018). Understanding user requirements for the design of a home-based stroke rehabilitation system. In Proceedings of the Human Factors and Ergonomics Society Annual Meeting. Philadelphia, PA.

Chen, Y., Abel, K. T., Janecek, J. T., Chen, Y., Zheng, K., & Cramer, S. C. (2019). Home-based technologies for stroke rehabilitation: A systematic review. *International Journal of Medical Informatics*, *123*, 11–22. https://doi.org/10.1016/j.ijmedinf.2018.12.001

Cramer, S. C., Dodakian, L., Le, V., See, J., Augsburger, R., McKenzie, A., Zhou, R. J., Chiu, N. L., Heckhausen, J., Cassidy, J. M., Scacchi, W., Smith, M. T., Barrett, A. M., Knutson, J., Edwards, D., Putrino, D., Agrawal, K., Ngo, K., Roth, E. J., . . . Janis, S. (2019). Efficacy of home-based telerehabilitation vs in-clinic therapy for adults after stroke: A randomized clinical trial. *JAMA neurology*, *76*(9), 1079–1087. https://doi.org/10.1001/jamaneurol.2019.1604

Creswell, J. D., & Plano Clark, V. L. (2017). Core mixed methods design. In Creswell, J. W., & Plano Clark, V. L. (Eds.), *Designing and conducting mixed methods research* (3rd ed.). SAGE Publications, Inc.

Doman, C. A., Waddell, K. J., Bailey, R. R., Moore, J. L., & Lang, C. E. (2016). Changes in upper-extremity functional capacity and daily performance during outpatient occupational therapy for people with stroke. *The American Journal of Occupational Therapy*, *70*(3), 1–11. https://doi.org/10.5014/ajot.2016.020891

Donoso Brown, E. V., Nolfi, D., Wallace, S. E., Eskander, J., & Hoffman, J. M. (2020). Home program practices for supporting and measuring adherence in post-stroke rehabilitation: A scoping review. *Topics in Stroke Rehabilitation*, *27*(5), 377–400. https://doi.org/10.1080/10749357.2019.1707950

Duncan, P. W., Propst, M., & Nelson, S. G. (1983). Reliability of the fugl-meyer assessment of sensorimotor recovery following cerebrovascular accident. *Physical Therapy*, *63*(10), 1606–1610. https://doi.org/10.1093/ptj/63.10.1606

Elo, S., & Kyngäs, H. (2008). The qualitative content analysis process. *Journal of Advanced Nursing*, *62*(1), 107–115. https://doi.org/10.1111/j.1365-2648.2007.04569.x

Grice, K. O., Vogel, K. A., Le, V., Mitchell, A., Muniz, S., & Vollmer, M. A. (2003). Adult norms for a commercially available nine hole peg test for

finger dexterity. *The American Journal of Occupational Therapy*, *57*(5), 570–573. https://doi.org/10.5014/ajot.57.5.570

Holthe, T., Halvorsrud, L., Karterud, D., Hoel, K. -A., & Lund, A. (2018). Usability and acceptability of technology for community-dwelling older adults with mild cognitive impairment and dementia: A systematic literature review. *Clinical Interventions in Aging*, *13*, 863–886. https://doi.org/10.2147/CIA.S154717

Ivankova, N. V., Creswell, J. W., & Stick, S. L. (2016). Using mixed-methods sequential explanatory design: From theory to practice. *Field Methods*, *18*(1), 3–20. https://doi.org/10.1177/1525822x05282260

Jurkiewicz, M. T., Marzolini, S., & Oh, P. (2011). Adherence to a home-based exercise program for individuals after stroke. *Topics in Stroke Rehabilitation*, *18*(3), 277–284. https://doi.org/10.1310/tsr1803-277

Kelly, K. M., Borstad, A. L., Kline, D., & Gauthier, L. V. (2018). Improved quality of life following constraint-induced movement therapy is associated with gains in arm use, but not motor improvement. *Topics in Stroke Rehabilitation*, *25*(7), 467–474. https://doi.org/10.1080/10749357.2018.1481605

Langan, J., Bhattacharjya, S., Subryan, H., Xu, W., Chen, B., Li, Z., & Cavuoto, L. (2020). In-home rehabilitation using a smartphone app coupled with 3D printed functional objects: Single-subject design study. *JMIR mHealth and uHealth*, *8*(7), e19582–e19582. https://doi.org/10.2196/19582

Lang, C. E., Lohse, K. R., & Birkenmeier, R. L. (2015). Dose and timing in neurorehabilitation: Prescribing motor therapy after stroke. *Current Opinion in Neurology*, *28*(6), 549–555. https://doi.org/10.1097/wco.0000000000000256

Lohse, K. R., Lang, C. E., & Boyd, L. A. (2014). Is more better? Using metadata to explore dose-response relationships in stroke rehabilitation. *Stroke*, *45*(7), 2053–2058. https://doi.org/10.1161/STROKEAHA.114.004695

Lutz, B. J., Young, M. E., Creasy, K. R., Martz, C., Eisenbrandt, L., Brunny, J. N., & Cook, C. (2017). Improving stroke caregiver readiness for transition from inpatient rehabilitation to home. *The Gerontologist*, *57*(5), 880–889. https://doi.org/10.1093/geront/gnw135

Magnusson, C., Rassmus-Gröhn, K., & Rydeman, B. (2020). Developing a mobile activity game for stroke survivors—lessons learned. *Journal on Multimodal User Interfaces*, *14*(3), 303–312. https://doi.org/10.1007/s12193-020-00342-y

Marson, D. C., Dymek, M. P., Duke, L. W., & Harrell, L. E. (1997). Subscale validity of the mattis dementia rating scale. *Archives of Clinical Neuropsychology : The Official Journal of the National Academy of Neuropsychologists*, *12*(3), 269–275. PMID: 14588419.

McLaren, R., Signal, N., Lord, S., Taylor, S., Henderson, J., & Taylor, D. (2020). The volume and timing of upper limb movement in acute stroke rehabilitation: Still room for improvement. *Disability and rehabilitation*, *42*(22), 3237–3242. https://doi.org/10.1080/09638288.2019.1590471

Miller, K. K., Porter, R. E., DeBaun-Sprague, E., Van Puymbroeck, M., & Schmid, A. A. (2017). Exercise after stroke: Patient adherence and beliefs after discharge from rehabilitation. *Topics in Stroke Rehabilitation*, *24*(2), 142–148. https://doi.org/10.1080/10749357.2016.1200292

Niknejad, N., Ismail, W., Bahari, M., & Nazari, B. (2021). Understanding telerehabilitation technology to evaluate stakeholders' adoption of telerehabilitation services: A systematic literature review and directions for further research. *Archives of Physical Medicine and Rehabilitation*, *102*(7), 1390–1403. https://doi.org/10.1016/j.apmr.2020.12.014

Novak, I. (2011). Effective home programme intervention for adults: A systematic review. *Clinical rehabilitation*, *25*(12), 1066–1085. https://doi.org/10.1177/0269215511410727

Page, S. J. (2003). Intensity versus task-specificity after stroke: How important is intensity? *American Journal of Physical Medicine & Rehabilitation / Association of Academic Physiatrists*, *82*(9), 730–732. https://doi.org/10.1097/01.Phm.0000078226.36000.A5

Patton, M. (1990). *Qualitative evaluation and research methods* (2nd ed.). SAGE Publications, Inc.

Scorrano, M., Ntsiea, V., & Maleka, D. (2018). Enablers and barriers of adherence to home exercise programmes after stroke: Caregiver perceptions. *International Journal of Therapy and Rehabilitation*, *25*(7), 353–364. https://doi.org/10.12968/ijtr.2018.25.7.353

Smania, N., Gandolfi, M., Paolucci, S., Iosa, M., Ianes, P., Recchia, S., Giovanzana, C., Molteni, F., Avesani, R., DiPaolo, P., Zaccala, M., Agostini, M., Tassorelli, C., Fiaschi, A., Primon, D., Ceravolo, M. G., & Farina, S. (2012). Reduced-intensity modified constraint-induced movement therapy versus conventional therapy for upper extremity rehabilitation after stroke: A multicenter trial. *Journal of Neurologic Rehabilitation*, *26*(9), 1035–1045. https://doi.org/10.1177/1545968312446003

Tamayo-Serrano, P., Garbaya, S., & Blazevic, P. (2018). Gamified in-home rehabilitation for stroke survivors: Analytical review. *International Journal of Serious Games*, *5*(1). https://doi.org/10.17083/ijsg.v5i1.224

Thirumalai, M., Rimmer, J. H., Johnson, G., Wilroy, J., Young, H., Mehta, T., & Lai, B. (2018). TEAMS (Tele-exercise and multiple sclerosis), a tailored telerehabilitation mHealth app: Participant-centered development and usability study. *JMIR Mhealth Uhealth*, *6*(5), e10181. https://doi.org/10.2196/10181

Veerbeek, J. M., van Wegen, E., van Peppen, R., van der Wees, P. J., Hendriks, E., Rietberg, M., & Kwakkel, G. (2014). What is the evidence for physical therapy poststroke? A systematic review and meta-analysis. *Plos One*, *9*(2), e87987. https://doi.org/10.1371/journal.pone.0087987

Ward, N. S., Brander, F., & Kelly, K. (2019). Intensive upper limb neurorehabilitation in chronic stroke: Outcomes from the queen square programme. *Journal of Neurology, Neurosurgery & Psychiatry*, *90*(5), 498–506. https://doi.org/10.1136/jnnp-2018-319954

Whitall, J., Savin, D. N., Harris-Love, M., & Waller, S. M. (2006). Psychometric properties of a modified wolf motor function test for people with mild and moderate upper-extremity hemiparesis. *Archives of Physical Medicine and Rehabilitation*, *87*(5), 656–660. https://doi.org/10.1016/j.apmr.2006.02.004

Woodford, J., Farrand, P., Watkins, E. R., & Llewellyn, D. J. (2018). "I don't believe in leading a life of my own, i lead his life": A qualitative investigation of difficulties experienced by informal caregivers of stroke survivors experiencing depressive and anxious symptoms. *Clinical gerontologist*, *41*(4), 293–307. https://doi.org/10.1080/07317115.2017.1363104