HHS Public Access

Author manuscript

OTJR (Thorofare N J). Author manuscript; available in PMC 2024 August 07.

Published in final edited form as:

OTJR (Thorofare N J). 2023 July ; 43(3): 549–557. doi:10.1177/15394492231153998.

Acceptability of a Telerehabilitation Biofeedback System Among Stroke Survivors: A Qualitative Analysis

Miranda R. Donnelly[1], **Coralie S. Phanord**[1], **Octavio Marin-Pardo**[1], **Jessica Jeong**[1], **Barrisford Bladon**[1], **Kira Wong**[1], **Aisha Abdullah**[1], **Sook-Lei Liew**[1]

[1]University of Southern California, Los Angeles, USA

Abstract

Electromyography (EMG) biofeedback delivered via telerehabilitation can increase access to occupational therapy services for stroke survivors with severe impairment, but there is limited research on its acceptability. This study identified factors influencing the acceptability of a complex, muscle biofeedback system (Tele-REINVENT) for upper extremity sensorimotor stroke telerehabilitation among stroke survivors. We conducted interviews with stroke survivors ($n = 4$) who used Tele-REINVENT at home for 6 weeks and analyzed the data with reflexive thematic analysis. Biofeedback, customization, gamification, and predictability affected the acceptability of Tele-REINVENT among stroke survivors. Across themes, features and experiences that gave participants agency and control were more acceptable. Our findings contribute to the design and development of at-home EMG biofeedback interventions, which can improve access to advanced occupational therapy treatment options for those who need it most.

Keywords

rehabilitation; stroke; intervention; qualitative research

Outpatient stroke rehabilitation services are underutilized in the United States (Ayala et al., 2018), in part because of barriers to accessing in-person care (e.g., rural location, limited transportation, lack of social support, low income; Edgar et al., 2017). These contribute to service gaps and unrealized rehabilitation potential, especially among historically underserved groups and those with severe disabilities (Ellis et al., 2014). Given these gaps, there is a need for accessible post-stroke outpatient rehabilitation alternatives.

Telerehabilitation can reduce access barriers by providing outpatient treatment at home (Caughlin et al., 2020). Telerehabilitation includes a range of approaches, but this article

Corresponding Author: Sook-Lei Liew, Neural Plasticity and Neurorehabilitation Laboratory, Chan Division of Occupational Science and Occupational Therapy, University of Southern California, 2025 Zonal Ave., Los Angeles, CA 90033, USA. sliew@usc.edu.

Ethical Approval

This work was approved by the University of Southern California Institutional Review Board (Reference No.: HS-17–00916).

Supplemental Material

Supplemental material for this article is available online.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

focuses on remotely delivered occupational therapy (OT) for post-stroke sensorimotor recovery of the arm. Many telerehabilitation paradigms that use common technologies (i.e., phones, computers) for virtual therapy visits (Dahl-Popolizio et al., 2020) or mobile health interventions are often designed for stroke survivors with mild to moderate arm impairment and typically require a minimum threshold of movement or hands-on assistance from a caregiver (Rintala et al., 2022). Thus, survivors with severe hemiparesis who have no functional movement in their affected arm often cannot use these interventions independently. By contrast, paradigms that use complex technologies, such as electromyography (EMG) biofeedback (Kim, 2017) and brain–computer interfaces (BCI; Cervera et al., 2018), provide high doses of attempted movement with amplified feedback, opening doors for clients with severe hemiparesis to participate in telerehabilitation.

Specifically, EMG biofeedback has been used with stroke survivors to enhance motor outcomes (Donoso Brown et al., 2014; Kim, 2017). Muscle signals from the affected arm (measured with surface EMG sensors) are transformed into adapted sensory experiences (e.g., visual or tactile) to provide extrinsic feedback about performance during movement attempts (Nelson, 2007). EMG biofeedback can provide awareness and control of residual muscle activity for people with severe hemiparesis, for whom movement attempts in daily life do not yield functional feedback. In addition, EMG biofeedback may retrain functional brain-to-muscle connectivity where stroke lesions have disrupted motor pathways (Marin-Pardo et al., 2020).

Despite the promise of EMG biofeedback and other complex interventions for motor recovery, most studies have been conducted in a laboratory environment, so there is limited evidence on how to implement them at home in a telerehabilitation paradigm (Donoso Brown et al., 2014). One important outcome for evaluating the implementation of novel telerehabilitation technologies is *acceptability* among stakeholders, including the attitudes and satisfaction with content, complexity, comfort, and delivery (Proctor et al., 2011). For example, in a qualitative study of a stroke telerehabilitation system, Chen et al. (2020) identified that engaging experiences, progress indicators, and logistical flexibility positively influenced acceptability. Studying the acceptability of EMG biofeedback as a telerehabilitation intervention is a vital step in translating this innovation from the laboratory to stroke survivors' homes.

Tele-REINVENT

Tele-REINVENT is a low-cost, EMG biofeedback telerehabilitation system that trains sensorimotor recovery of the hemiparetic arm in stroke survivors with moderate to severe impairment through adaptive computer games. It is a home-based adaptation of REINVENT, a brain and muscle biofeedback system with virtual reality, which has shown to be effective for improving quality of life, motor control of the hemiparetic arm, and corticomuscular coherence of the affected side (Marin-Pardo et al., 2020; Vourvopoulos et al., 2019). Although REINVENT was designed for laboratory or clinic use, Tele-REINVENT is portable and can be used by stroke survivors at home without a therapist. It consists of a laptop computer, low-cost EMG sensors, a custom interface, and three adaptive games (Figure 1). A daily EMG calibration process tailors game thresholds for stroke survivors'

muscle activity. The purpose of the calibration is to improve the "fit" between a user's muscle activation that day and the EMG thresholds required to play the games. During game play, EMG sensors detect muscle activity during wrist movement attempts. The signals are processed in real time and transformed, enabling stroke survivors to use their hemiparetic arm as the controller. This paradigm reinforces movement attempts, even in the absence of full or functional movements. Tele-REINVENT is a complex technology because it integrates various technological components into a specialized, novel product.

The purpose of this study was to gain insight from stroke survivors' experiences using an EMG biofeedback telerehabilitation system (Marin-Pardo et al., 2021), specifically to identify factors that influence its acceptability. Findings from this study will advance the implementation of EMG biofeedback in the home.

Method

The data reported here were collected in-person between November 2021 and March 2022 as part of a pilot and feasibility trial of Tele-REINVENT. Here, we briefly describe the trial procedures to contextualize the qualitative data. See Marin-Pardo et al. (2022) for the full protocol and quantitative findings. All study procedures were conducted observing the ethical standards of the University of Southern California Institutional Review Board and the revised (2013) Helsinki Declaration.

Participants

We recruited chronic stroke survivors (>6 months since onset) through a stroke research registry, word of mouth, and flyers. Through a phone screening and in-person pre-study visit, we identified participants with moderate to severe hemiparesis, which we defined as being less than 20° of active wrist extension at baseline, detectable muscle activity using surface EMG, access to wireless internet, normal or corrected vision, and English proficiency. A history of more than one stroke, aphasia, cognitive impairment (Montreal Cognitive Assessment [MoCA] score <20 points), and wrist contracture were exclusion criteria. We did not exclude participants with neglect, apraxia, or other conditions associated with stroke as long as they could complete the study tasks. We intended to analyze data from four participants who completed the 6-week protocol. Following Braun and Clarke's (2021) guidance for determining sample sizes in reflexive thematic analysis (RTA), we hypothesized that a sample of four participants with extensive experience using Tele-REINVENT (approximately 30 hr) would (a) be sufficient to gather experiential data about the acceptability of Tele-REINVENT, (b) be pragmatic within the constraints of the pilot study, and (c) yield results that could be used to optimize Tele-REINVENT. In addition, Creswell and Poth (2018) recommend three to ten participants for phenomenology, a philosophical approach guiding this study, and was therefore used to determine sample size. Participation was voluntary, and participants were informed of the study procedures, risks, and benefits during the informed consent process. All data were securely stored to maintain confidentiality and privacy.

Procedure and Data Collection

Participants completed thirty 1-hr remote Tele-REINVENT sessions over 6 weeks. Half of the sessions were facilitated by a therapist or technician to offer feedback, provide technical support, and monitor EMG signal quality. In each session, participants donned EMG sensors, completed an EMG calibration, and chose which game(s) they wanted to play (Marin-Pardo et al., 2022). Additional intervention details are reported in the findings for context.

Three researchers (M.R.D., C.S.P., O.M-P.) conducted semi-structured interviews with participants who had used Tele-REINVENT for 6 weeks to learn about factors that influenced its acceptability (see Supplemental Methods for the interview guide). All interviews were audio recorded and manually transcribed verbatim (Poland, 1995) to promote data familiarization and accurately capture (non)verbal features that automated programs may not (e.g., intonation, accents, pauses). A second reviewer evaluated transcript accuracy. Participant quotes in this article were only edited with brackets for clarity (e.g., replacing “it” with [Tele-REINVENT]), with ellipses for brevity, or to remove identifiable data for privacy. The “accents” of non-native English speakers (i.e., English as a second language) have not been edited.

Theoretical Positioning

This analysis is informed by the assumption that occupations are lived *experiences* (not just acts of *doing*) linked to the development of meaning in everyday life (Hasselkus, 2011). In our study of stroke survivors’ use of a novel technology, we sought to learn about meaning tied to experiences with the system rather than only processes of *doing* (e.g., interactions with the interface). Phenomenology is a fitting philosophical approach to learn about multiple layers of stroke survivors’ experiences with Tele-REINVENT. Therefore, phenomenology informed the development of an interview guide to capture the phenomenon of using Tele-REINVENT, including practicalities of using the technology, perceived outcomes, and meaning tied to its use (Cilesiz, 2011). To identify patterns in the data, we used RTA, a theoretically flexible method that involves researchers’ active involvement in co-producing knowledge (Braun et al., 2019). Interpretation is conducted at the intersection of data, theoretical assumptions of the analysis, and analytic skills of the researcher (Byrne, 2022).

Data Analysis

Data analysis was completed by two members of the research team (M. R. D., C. S. P.) to address our research question, “What factors influence the acceptability of Tele-REINVENT?” This was addressed within a constructivist paradigm and was *experientially oriented*, so participant-ascribed meaning was central in the interpretation of codes and themes. The research question lends to inductive analysis, so we used open coding. In the first phase of analysis, we independently familiarized ourselves with the data through repeated listening and reading of transcripts and identified initial trends. Second, we conducted iterations of initial code generation, including independent coding followed by investigator triangulation (Archibald, 2016). We developed preliminary descriptive codes using quotes, descriptive, and interpretive labels for all data about participants’ attitudes,

behaviors, preferences, and perceptions related to Tele-REINVENT. Third, we collaborated to generate themes by iteratively reducing and synthesizing codes according to shared meanings and developed theme candidates (Byrne, 2022; Cilesiz, 2011). Finally, in the fourth and fifth phases, we recursively reviewed potential themes, including reviewing supporting evidence for the development of each theme and defining them (Byrne, 2022). While consensus is not a focus of RTA, having multiple coders with diverse experiences led to richer interpretations (Braun et al., 2019).

In RTA, researchers' subjective and reflexive engagement is an analytic resource (Braun et al., 2019). M. R. D. is an occupational scientist and occupational therapist with research and clinical experience with stroke survivors. C. S. P. is trained in human-centered design, engineering, and computer science and has psychology research experience. Both contributed to Tele-REINVENT's development, and M. R. D. participated in delivering the intervention. Given our proximity to the phenomenon, we initially used semantic coding to extract participants' explicit meanings without infusing context from our experiences. In the final iteration of Phase 2 (and later phases), we used latent coding, infusing our knowledge of the system and field notes to interpret and contextualize participants' experiences. This subjectivity was particularly important for our inquiry because participants discussed their experiences *with* the technology, but not *how* the technology is intended to work. Both perspectives are needed to understand factors that affect acceptability. These co-produced findings have practical application in the development of EMG biofeedback interventions.

Findings

We enrolled four stroke survivors (mean age = 63 years, $SD = 7.8$) in the chronic phase of recovery (mean time post-stroke = 7.4 years, $SD = 6.2$). Despite our purposeful recruitment efforts, we did not enroll any females, a challenge that is also noted in the literature (Carcel & Reeves, 2021). See Table 1 for additional demographic data. We identified four themes about factors that influenced acceptability: biofeedback, customization, gamification, and predictability (Figure 2).

Biofeedback: "The Little Movement That's Coming Back, Let's Put it to Work"

—The EMG biofeedback enabled visualization of attempted arm movements and positively affected the acceptability of Tele-REINVENT. Immediate visual biofeedback reinforced attempted movements, whereas in daily life participants experienced repeated failed attempts to use their arm:

> I've started using my hand to pull doorknobs, you know, because uh a lot of times you just, you kind of just are already too comfortable just using the right hand because that's all . . . you've been doing. But you got to try to, you know with the little movement that's coming back, let's put it to work.

Participants were motivated and satisfied by the feedback and conveyed that it was meaningful to actively use their affected arm to control the games, such as one participant who said, "You have motivation that you, you work with that [arm]" and another who said, "[I feel] more at ease. I'm more proud, happy, content, satisfied, because you're doing something about it, you know you're not just sitting around hopeless and waiting for some

movement to come back." Multiple participants contrasted Tele-REINVENT to their prior experiences with electrical stimulation, preferring biofeedback to gain awareness of their residual muscle activity, such as one participant who stated, "[Tele-REINVENT] makes the person do something more than—[electrical stimulation] charges on electrical movements, right? To stimulate the muscles—but this makes you use it yourself."

All four participants perceived that the EMG biofeedback increased their awareness of residual movement and motivated task practice with the affected arm, both within the game and in daily activities, such as holding a shopping bag, doing laundry, and opening doors. Participants reported other self-assessed functional benefits of the biofeedback, including experiences of improved arm motor control, spasticity, flexibility, and sleep. The biofeedback provided through Tele-REINVENT enhanced perceived outcomes, which positively influenced acceptability.

Customization: "I Change Position Every Three Times I Play"—Customizable features of Tele-REINVENT that were evident in the data include the daily EMG calibration, game settings, structure of the sessions, and interactions with technical support. These positively influenced acceptability, with some caveats. A successful EMG calibration depended in large part on the correct placement of the EMG sensors on the forearm; however, all four participants described experiences of having issues with sensor placement, particularly in earlier sessions: "That can be the boring part, setting up, cause it's time consuming and you might not always match the sensors." However, over the course of the sessions, they learned how to place the sensors correctly and troubleshoot problems, with some assistance. Specifically, multiple participants found it helpful that we discretely marked the target placement on their arms with a skin-safe marker during the in-person pre-study visit and gave them the pen to use at home if they wished. We also provided basic education on motor control and anatomy to support identification of the target muscles during Zoom sessions, which yielded an unanticipated benefit of self-reported increased knowledge about their stroke recovery: "I learned a lot about when you were explaining to me about the various muscles in my arm and what they control . . . I never knew that before." Three of the participants placed the sensors independently at home and one reported working with his wife to place the sensors. Despite issues with sensor placement and calibration, participants were highly satisfied with the system and found it "easy to use" and "self-explanatory." Although the calibration used to customize the system created technical issues (mainly due to the variability of sensor placement), it did not deter participants from enjoying and accepting the system: "It was very impressive . . . you have to calibrate and then the everything respond the calib[ration], you know the arm movement, your muscle movement and it's . . . a great experience."

A second customizable feature that influenced acceptability is the game settings (e.g., number of trials in a game, system sensitivity) which could be adjusted during therapist-supervised sessions. One participant shared about a session that he perceived to be too easy, so the therapist changed the sensitivity, making the games more challenging and acceptable to him. Third, participants customized the structure of every session and the timing of independent sessions. All participants described how Tele-REINVENT fit into their routine, with three designating a specific time in their schedule to use it, such as one who said,

> When I play the game, brain is a little bit relaxed, you know, and focused only on the—you know that my responsibility to play . . . one hour a day. So when I walk outside . . . I tell to my wife, “oh, it’s already 10:00! Let’s go! Come on, hurry up, I need to go practice!” (*laughing*).

A different participant preferred to use Tele-REINVENT in the evening because he perceived sleep benefits: “I used it every day that I was supposed to use it. And so I always remember this before bedtime. I would always do it . . . because I do a lot of strength and it tired me out.” Participants also shared other ways they customized their participation with Tele-REINVENT. For example, during his interview, one participant demonstrated how he stood up to play the games (vs. sitting) and used props to support his arms, “I change position every three times I play,” sharing that it prevented pain and boredom and improved his performance. Participants also customized the content and sequencing of the sessions. Some said they favored playing one game for an entire session and others established specific patterns of play. Participants reported they were satisfied with the variety of games, but also wanted more choices and games that train different movements. Overall, the choice of games and session structure promoted agency among the participants.

Finally, participants customized how they received technical assistance (e.g., texting, calling, emailing, or videoconferencing the researchers, using the printed user manual). Participants engaged with the research team differently and found it to be accessible, helpful, and customizable based on their communication preferences, the nature of the issue, and their familiarity with the technology: “In the beginning when I couldn’t calibrate, the person on the Zoom helped me a lot and uh I picked up easy and I think it was a very helpful like uh contribution.” While some factors of the system customization, such as sensor placement, created barriers to using Tele-REINVENT, other factors facilitated acceptability, such as customizing game settings, controlling the structure of the sessions, and choosing their preferred methods of receiving support.

Gamification: “I Was a Soccer Player When You Hear the Crowd”—Tele-REINVENT infuses games and game components into repetitive task practice. Gamification of rehabilitation positively influenced acceptability and was perceived as meaningful and motivating. For example, one participant stated, “Not only was I able to participate in gaming, but what made it interesting is . . . I was challenging myself, my disability, so that . . . pushed me even more to want to do it.” Another participant described himself as a “little kid in a candy store” because he was excited to play games with his affected arm.

> Multiple participants were motivated by scoring:
>
> When it’s a challenging day, sometimes . . . you’re so into it, that maybe the hour might be up but you’re still playing with it, because you want to top that –you want to um either match that score, or do better . . . It just gets you more involved and participating because you want to beat the higher score.

Another participant said, “. . . it gives you something to shoot for each time you try it.” Similarly, progressing through the levels in Plant Jump led to a sense of accomplishment for some participants, such as one who proudly said, “When I try to play [Planet Jump] before, it’s hard to go up like this (*motions wrist extension*). Now, I . . . pass the Level 1, so

I go to Level 2." As opposed to Skeeball and Planet Jump, in which performance directly influenced scores, Blinko scores were probability-based. Some participants wanted more control, including one participant who said, "Blinko was very interesting, but the thing is, once the ball gets released you can't control the ball . . . but if I can control it, I can try and get a higher score." All participants voiced a desire to control the games, indicating that the game mechanisms influenced acceptability.

Tele-REINVENT is a single player system; however, social gamification factors, such as community and peer approval, were noted. One participant described,

> When you guys are on Zoom with me, it make[s] me go further because . . . it's like . . . I was a soccer player when you hear the crowd. You cheer me . . . it helped me like a motivate me going further . . . because I'm by myself doing it . . . so people like they encourage me.

Other participants wanted more therapist-guided sessions, highlighting benefits such as adjusting game settings and teaching techniques; however, they did not explicitly describe social benefits. Overall, participants enjoyed playing games as part of their rehabilitation, especially when they felt greater control over the outcomes, and Tele-REINVENT was described as a fun therapy alternative.

Predictability: "As Long as the Games Were Cooperating, There Was No Problem"—The predictability of Tele-REINVENT affected acceptability; when a user's prediction of how the system would respond was correct, the experience was more acceptable, and vice versa. One participant said, "As long as the games were . . . cooperating, there was no problem, but I noticed that some of the games only work certain days." The EMG sensors were a source of unpredictability. Their location varied slightly between sessions, so the system responded differently. Another source of unpredictability was system failures. However, participants could not always distinguish between malfunctions and user errors, causing frustration and doubt in their ability to use Tele-REINVENT:

> I might notice that, one day, you can have a problem, but maybe the next day. . .there's no problems again so maybe it was the way the sensors were connected that day, you know . . . because maybe if I essentially connect it wrong, the games are going to be faulty . . . and then you might be discouraged because of that, you know what, [if] all this stuff doesn't work for me, why should I participate?

When the system worked predictably and participants did not encounter issues, they were motivated to keep using it: "When they do [work] I play one hour and ten minutes." Even participants who had frequent technical issues noted that when Tele-REINVENT worked well, it was fun and enjoyable. While predictability seems to be associated with greater acceptability, the unpredictable elements seemed to be moderated by technical support.

Discussion

The purpose of this study was to identify factors influencing the acceptability of Tele-REINVENT among stroke survivors who used it at home for 6 weeks. We conducted interviews with four users about their experience and identified four factors that influenced acceptability: biofeedback, customization, gamification, and predictability. These findings will support the implementation of EMG biofeedback at home.

Participants were highly satisfied to actively use their affected arm in the biofeedback paradigm, compared with passive interventions they had previously used. Prior research shows that biofeedback gives people with limited motor control the awareness and motivation to control their own biological processes (Nelson, 2007). One of the most compelling factors leading to the acceptance of Tele-REINVENT was perceived functional improvements, which has also been seen in other telerehabilitation studies (Chen et al., 2020; Neibling et al., 2021). Participants were motivated to try using their affected arm during everyday occupations after sessions, suggesting that biofeedback may counter nonuse and retrain functional movements. This study did not evaluate other interventions, so interview data comparing Tele-REINVENT with past experiences may be influenced by a recall bias.

Tele-REINVENT conducts a daily EMG calibration to achieve quality biofeedback and adjust the games to be an appropriate challenge for each participant. Despite the benefits of the calibration, sensor placement challenges detracted from the acceptability of the system. However, timely technical support ameliorated those issues. In fact, both planned and spontaneous interactions with researchers were highlights of participants' experiences. Previous telerehabilitation literature also shows that interactions with clinicians improves adherence and motivation (Caughlin et al., 2020; Chen et al., 2020; Neibling et al., 2021). Sessions monitored by a therapist also enabled customization. Customizing interventions to reflect individuals' goals, skills, and interests is a vital ingredient in telerehabilitation to increase motivation, engagement, and adherence (Caughlin et al., 2020; Neibling et al., 2021) and a key pillar of OT practice (American Occupational Therapy Association [AOTA], 2020).

Participants also valued predictability; when the technology responded predictably, they were motivated to use it longer, but when it did not, the experience was disappointing. Technical issues including poor internet connection, audiovisual disruptions, equipment failure, and effort-requiring systems are widely recognized in the literature (Caughlin et al., 2020; Chen et al., 2020; Neibling et al., 2021). However, this and other studies have found that stroke survivors tend to accept novel systems despite these issues (Caughlin et al., 2020). In fact, all participants in our study said they would continue using it if given the opportunity.

Engaging games led to system use beyond the scheduled sessions. Playfulness and gamification have been shown to promote engagement in stroke rehabilitation compared with conventional repetitive exercises (Chen et al., 2020) through features such as high

scores, levels, badges, and leader-boards that measure progress (Miller et al., 2016). Tele-REINVENT participants particularly liked scoring points and mastering levels.

Our findings suggest that stroke survivors with moderate to severe hemiparesis were able and willing to use at-home EMG biofeedback because it enabled active use of their affected arm, even in the absence of functional movement. The acceptability of Tele-REINVENT was supported by remote-guided and independent sessions, which facilitated social interaction, technical assistance, and logistical flexibility. We also identified barriers to using EMG biofeedback at home. Technical issues were frustrating, especially when the system responded unpredictably. It was also challenging to precisely place the sensors, which may have implications for other sensor-based systems (e.g., BCI, room-scale virtual reality). Despite these barriers, participants valued the novelty of EMG biofeedback and accepted technical challenges (and support) as realities of using new technologies.

Desire for Agency and Control

Across all themes and participants, there was a desire for agency and control over both their rehabilitation and affected arm. This aligns with previous work showing that agency in recovery is meaningful and affects participation in stroke rehabilitation (Hawkins et al., 2017). In this study, participants were satisfied with the features of the system that enabled control, such as using their affected arm to play games, which contrasted with the lack of arm motor control they experienced in daily life. They also valued the choice of games and structure. Conversely, they were less accepting of features that reduced their control, such as technical challenges and perceived error between their movements and the biofeedback. Neibling et al. (2021) also found that engagement declines when feedback inaccurately represents performance. Finally, participants suggested improvements that would give them more agency (e.g., games that challenge different muscles). EMG biofeedback and other complex interventions may facilitate agency for individuals with severe impairment in ways that standard interventions cannot through custom feedback and movement repetition without hands-on support.

Limitations and Future Directions

First, this study analyzed a small sample of Tele-REINVENT users comprising males with left hemiparesis. Future research will analyze a more diverse data set and conduct member-checking to add greater depth to these findings. Second, participants had multiple ways to contact the researchers (e.g., text, call, email); however, this level of support may not be feasible in clinical telerehabilitation. Future work should identify and test implementation supports for clinical use of EMG biofeedback. Finally, as we only evaluated acceptability after 6 weeks of using the system, we do not know whether it would change after prolonged use; however, declining adherence to telerehabilitation over time (Neibling et al., 2021) suggests that implementation outcomes may change. A longer longitudinal study of Tele-REINVENT would help us (a) understand changes in participants' experience over time, (b) determine effects on behavior change, and (c) examine which factors are important for predicting sustained use. Future research should also examine other complex stroke telerehabilitation technologies (e.g., transcranial stimulation, BCI) to identify shared

and unique factors that influence acceptability. Such findings will enhance the design and accessibility of telerehabilitation technologies.

Implications

Telerehabilitation is a growing practice area in OT, but there is a paucity of home-based interventions for stroke survivors with severe hemiparesis. There are unique facilitators and barriers that affect the use of complex technology in the home environment. Occupational science is well positioned to identify these and contribute to interdisciplinary efforts to create home-based technologies that are acceptable and accessible. Bringing complex technologies such as EMG biofeedback into the home is important for improving therapy access and extending the current capabilities of telerehabilitation, but they should be customizable and informed by empirical evidence about environmental factors that enable or inhibit participation at home (AOTA, 2020). Our findings, interpreted with other telerehabilitation research, can inform the design of technologies that provide high-quality rehabilitation for stroke survivors at home.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This research was partially supported by American Heart Association (16IRG26960017), U.S. Army Research Office (W911NNF-14-D-0005), National Institutes of Health (K01HD091283), and USC Stevens Technology Advancement Grant.

References

American Occupational Therapy Association. (2020). Occupational therapy practice framework: Domain and process. American Journal of Occupational Therapy, 74(Suppl.2), 7412410010. 10.5014/ajot.2020.74S2001

Archibald MM (2016). Investigator triangulation: A collaborative strategy with potential for mixed methods research. Journal of Mixed Methods Research, 10(3), 228–250. 10.1177/1558689815570092

Ayala C, Fang J, Luncheon C, Coleman King S, Chang T, Ritchey M, & Loustalot F. (2018). Use of outpatient rehabilitation among adult stroke survivors - 20 states and the District of Columbia, 2013, and four states, 2015. Morbidity and Mortality Weekly Report, 67(20), 575–578. https://www.cdc.gov/dhdsp/programs/ [PubMed: 29795076]

Braun V, & Clarke V. (2021). To saturate or not to saturate? Questioning data saturation as a useful concept for thematic analysis and sample-size rationales. Qualitative Research in Sport, Exercise and Health, 13(2), 201–216. 10.1080/2159676X.2019.1704846

Braun V, Clarke V, Hayfield N, & Terry G. (2019). Thematic analysis. In Liamputtong P. (Ed.), Handbook of research methods in health social sciences (pp. 843–860). Springer Nature. 10.1007/978-981-10-5251-4_103

Byrne D. (2022). A worked example of Braun and Clarke's approach to reflexive thematic analysis. Quality & Quantity, 56(3), 1391–1412. 10.1007/s11135-021-01182-y

Carcel C, & Reeves M. (2021). Under-enrollment of women in stroke clinical trials: What are the causes and what should be done about it? Stroke, 52, 452–457. 10.1161/STROKEAHA.120.033227 [PubMed: 33493049]

Caughlin S, Mehta S, Corriveau H, Eng JJ, Eskes G, Kairy D, Meltzer J, Sakakibara BM, & Teasell R. (2020). Implementing telerehabilitation after stroke: Lessons learned from Canadian trials. Telemedicine and E-Health, 26(6), 710–719. 10.1089/tmj.2019.0097 [PubMed: 31633454]

Cervera MA, Soekadar SR, Ushiba J, Millán J, del R, Liu M, Birbaumer N, & Garipelli G. (2018). Brain-computer interfaces for post-stroke motor rehabilitation: A meta-analysis. Annals of Clinical and Translational Neurology, 5(5), 651–663. 10.1002/acn3.544 [PubMed: 29761128]

Chen Y, Chen Y, Zheng K, Dodakian L, See J, Zhou R, Chiu N, Augsburger R, McKenzie A, & Cramer SC (2020). A qualitative study on user acceptance of a home-based stroke telerehabilitation system. Topics in Stroke Rehabilitation, 27(2), 81–92. 10.1080/10749357.2019.1683792 [PubMed: 31682789]

Cilesiz S. (2011). A phenomenological approach to experiences with technology: Current state, promise, and future directions for research. Education Technology Research Development, 59, 487–510. 10.1007/s11423-010-9173-2

Creswell JW, & Poth CN (2018). Qualitative inquiry and research design: Choosing among five approaches (4th ed.). SAGE.

Dahl-Popolizio S, Carpenter H, Coronado M, Popolizio NJ, & Swanson C. (2020). Telehealth for the provision of occupational therapy: Reflections on experiences during the COVID-19 pandemic. International Journal of Telerehabilitation, 2, 77–92. 10.5195/ijt.2020.6328

Donoso Brown EV, McCoy SW, Fechko AS, Price R, Gilbertson T, & Moritz CT (2014). Preliminary investigation of an electromyography-controlled video game as a home program for persons in the chronic phase of stroke recovery. Archives of Physical Medicine and Rehabilitation, 95(8), 1461–1469. 10.1016/J.APMR.2014.02.025 [PubMed: 24657112]

Edgar MC, Monsees S, Rhebergen J, Waring J, Van Der Star T, Eng JJ, & Sakakibara BM (2017). Telerehabilitation in stroke recovery: A survey on access and willingness to use low-cost consumer technologies. Telemedicine and E-Health, 23(5), 421–429. 10.1089/tmj.2016.0129 [PubMed: 27705095]

Ellis C, Hyacinth HI, Beckett J, Feng W, Chimowitz M, Ovbiagele B, Lackland D, & Adams R. (2014). Racial/ethnic differences in poststroke rehabilitation outcomes. Stroke Research and Treatment, 2014, Article 950746. 10.1155/2014/950746

Hasselkus BR (2011). The meaning of everyday occupation (2nd ed.). SLACK.

Hawkins RJ, Jowett A, Godfrey M, Mellish K, Young J, Farrin A, Holloway I, Hewison J, & Forster A. (2017). Poststroke trajectories: The process of recovery over the longer term following stroke. Global Qualitative Nursing Research, 4, 1–13. 10.1177/2333393617730209

Kim J-H (2017). The effects of training using EMG biofeedback on stroke patients upper extremity functions. Journal of Physical Therapy Science, 29, 1085–1088. [PubMed: 28626331]

Marin-Pardo O, Laine CM, Rennie M, Ito KL, Finley J, & Liew S-L (2020). A virtual reality muscle-computer interface for neurorehabilitation in chronic stroke: A pilot study. Sensors, 20, Article 3754. 10.3390/s20133754 [PubMed: 32635550]

Marin-Pardo O, Donnelly MR, Phanord CS, Wong K, Pan J, & Liew S-L (2022). Functional and neuromuscular changes induced via a low-cost, muscle-computer interface for telerehabilitation: A feasibility study in chronic stroke. Frontiers in Neuroergonomics, 3, Article 1046695. 10.3389/fnrgo.2022.1046695

Marin-Pardo O, Phanord C, Donnelly MR, Laine CM, & Liew SL (2021). Development of a low-cost, modular muscle–computer interface for at-home telerehabilitation for chronic stroke. Sensors, 21(5), 1–15. 10.3390/s21051806

Miller AS, Cafazzo JA, Seto E, & Elliott RF (2016). A game plan: Gamification design principles in mHealth applications for chronic disease management. Health Informatics Journal, 22(2), 184–193. 10.1177/1460458214537511 [PubMed: 24986104]

Neibling BA, Jackson SM, Hayward KS, & Barker RN (2021). Perseverance with technology-facilitated home-based upper limb practice after stroke: A systematic mixed studies review. Journal of Neuro Engineering and Rehabilitation, 18, Article 43. 10.1186/s12984-021-00819-1

Nelson LA (2007). The role of biofeedback in stroke rehabilitation: Past and future directions. Topics in Stroke Rehabilitation, 14(4), 59–66. 10.1310/tsr1404-59

Poland BD (1995). Transcription quality as an aspect of rigor in qualitative research. Qualitative Inquiry, 1(3), 290–310. 10.1177/107780049500100302

Proctor E, Silmere H, Raghavan R, Hovmand P, Aarons G, Bunger A, Griffey R, & Hensley M. (2011). Outcomes for implementation research: Conceptual distinctions, measurement challenges, and research agenda. Adm Policy Ment Health, 38(2), 65–76. 10.1007/s10488-010-0319-7 [PubMed: 20957426]

Rintala A, Kossi O, Bonnechère B, Evers L, Printemps E, & Feys P. (2022). Mobile health applications for improving physical function, physical activity, and quality of life in stroke survivors: A systematic review. Disability and Rehabilitation, 44, 1–15. 10.1080/09638288.2022.2140844 [PubMed: 32393074]

Vourvopoulos A, Pardo OM, Lefebvre S, Neureither M, Saldana D, Jahng E, & Liew S-L (2019). Effects of a brain-computer interface with virtual reality (VR) neuro-feedback: A pilot study in chronic stroke patients. Frontiers in Human Neuroscience, 13, 1–17. 10.3389/fnhum.2019.00210 [PubMed: 30774588]

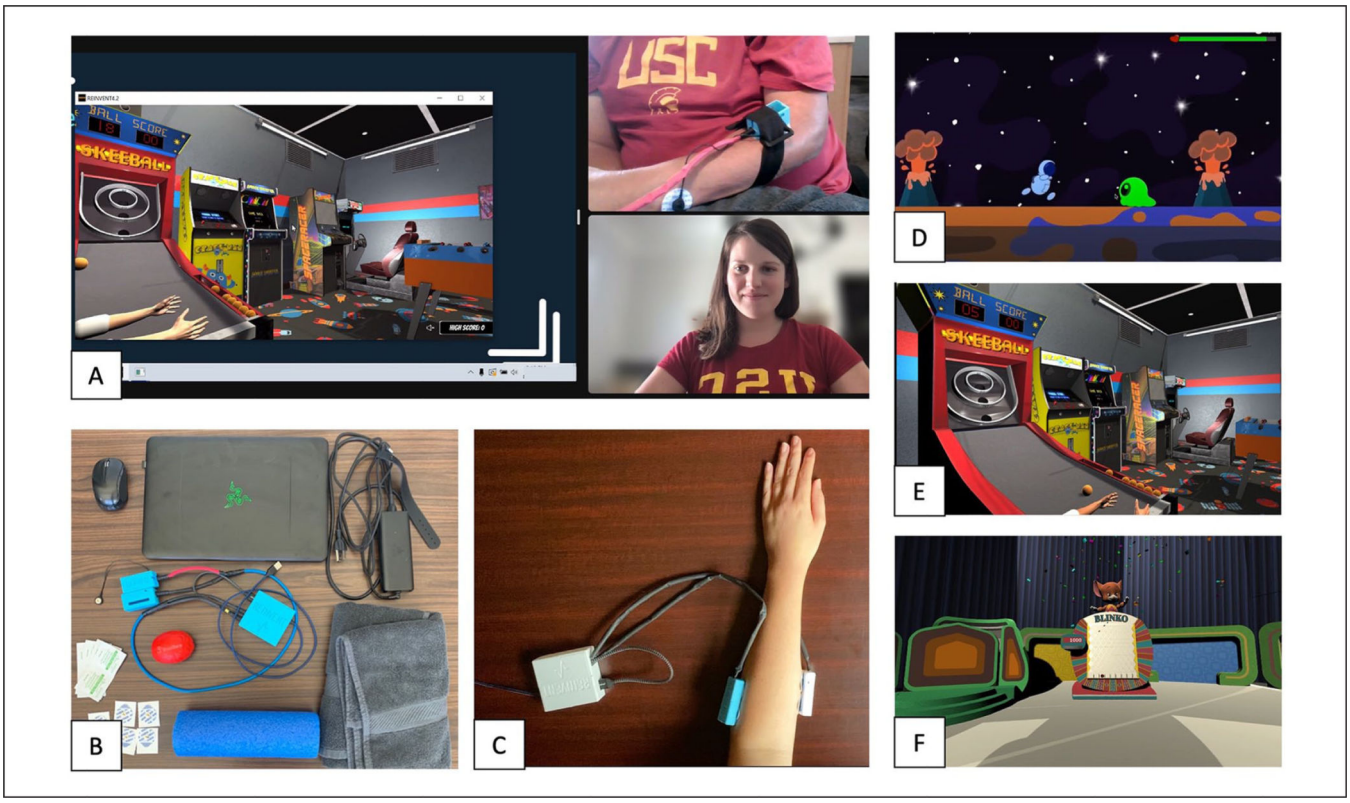

Figure 1. Tele-REINVENT System.

Note. (A) A participant and therapist interact via Zoom during a remote session. The participant is playing Skeeball. The therapist is collaborating with the participant to optimize rehabilitation performance (e.g., providing feedback on posture and positioning, adjusting game settings). (B) The Tele-REINVENT kit includes a laptop computer with charger, a wireless mouse, EMG sensors, disposable electrodes, alcohol wipes, and a pool noodle and towel for comfort/positioning as needed. (C) Participants place the EMG sensors over their wrist flexor and wrist extensor muscles using sticky electrode pads.

The sensors connect to the laptop via USB. (D) Planet Jump is a three-level side scroller game in which participants use wrist extension to jump the astronaut avatar over obstacles and flexion to stop the avatar from colliding with erupting volcanoes. (E) Skeeball is an arcade game in which participants use wrist extension to roll a ball up an inclined lane into one of three bullseye rings with different point values. (F) Blinko is a game show parody game in which participants use wrist flexion and extension to move a disc across the top of a vertical game board. When the timer runs out, the disc is released, and it cascades down the board until it lands on a point value. EMG = electromyography.

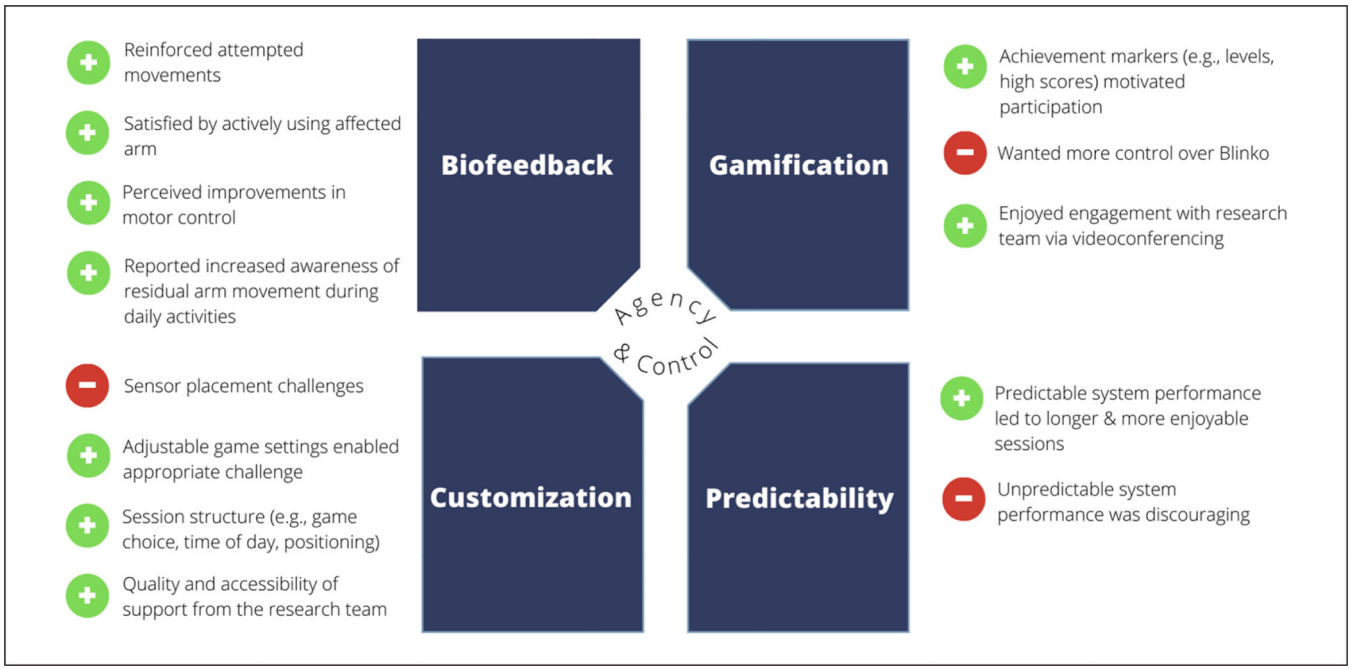

Figure 2.

Thematic Schema. *Note.* Schematic of the four themes: biofeedback, customization, gamification, and predictability. Next to each theme is an abbreviated list of factors that positively and negatively affected acceptability related to that theme, marked with green (+) and red (−) signs, respectively. Agency and Control is noted at the center of the four themes to indicate that across themes and participants, participants conveyed greater acceptance over features and experiences that gave them agency and control over their own movement and rehabilitation. On the contrary, features and experiences that participants perceived to limit their agency and control were less acceptable to them.

Table 1.

Participant Demographic Data.

Participant	Age	Time since stroke	Stroke type	Affected side	Pre-stroke hand dominance	MoCA	mRS	FMA	Sex	Race and/or ethnicity
1	61	156	Hemorrhagic	Left	Right	22	2	20	M	Hispanic
2	73	130	Ischemic	Left	Left	22	2	19	M	Asian
3	58	14	Ischemic	Left	Right	20	2	23	M	African American
4	57	25	Ischemic	Left	Right	21	1	40	M	Asian

Note. Age is participants' age at the time of study in years. Time since stroke is in months. Stroke type, pre-stroke hand dominance, sex, and race and/or ethnicity are self-reported. Clinical assessment scores (MoCA, mRS, FMA) were assessed at the pre-study visit to quantify disability. MoCA = Montreal Cognitive Assessment; mRS = Modified Rankin Scale; FMA = Fugl-Meyer Assessment of the upper extremity.